Revised
Edition

SOYBEAN
IN TROPICAL AND SUBTROPICAL CROPPING SYSTEMS

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PROCEEDINGS OF A SYMPOSIUM
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Foreword

These proceedings cover the cropping systems section of the International Symposium on Soybean held in Tsukuba, Japan, September 26 - October 1, 1983. The proceedings of the first section, which were recently published by the Tropical Agricultural Research Center of Japan (TARC), cover country reports and special research projects.

The papers presented in this publication provide a review of soybean cropping systems research from a variety of viewpoints, including those of international, national, and regional programs. There are also a number of papers from the private sector.

The proceedings likewise cover many of the scientific disciplines that relate to cropping systems research in the tropics. In the first chapter the authors review many of the most important tropical soybean cropping systems. This is followed by sections on breeding soybean for specific cropping systems and the development of complementary management practices. Subsequent sections cover topics such as the nutritional, photoperiodic, and thermal requirements of soybean, as well as the economic potential of the crop.

In reviewing the papers, a number of points come to mind. First, there seems to be general recognition of the need to accelerate cropping systems research in the tropics. This was not always the case. In the recent past, research was aimed almost exclusively at raising soybean yields rather than developing systems that provide the stability needed to grow soybean under high-risk conditions.

There also seems to be a greater sense of urgency to integrate cropping systems research with disciplines such as plant breeding, crop management, pest control, and plant nutrition. Each has a role to play if we are to succeed in raising the productivity of soybean in developing countries. This is a hopeful sign and a credit to the many scientists involved.

These proceedings also indicate a number of areas which require increased emphasis. There is, for example, repeated reference to the fact that success will ultimately depend upon economic and trading policies that support soybean production.

There is also a strong indication, both directly and obliquely, of the need to ensure that scientists from a variety of disciplines and backgrounds work together so that their research efforts are well coordinated.

In that sense, the symposium has helped to create a context in which scientists can cooperate in developing soybean cropping systems and related technologies. There are clear indications that researchers from different programs are willing to pool their resources and work together towards a common goal. While we have a long way to go, this symposium has provided a starting point from which to proceed.

For that reason, my thanks both to the authors and to the symposium's organizers. In particular, I would like to acknowledge Drs. Yoshiaki Ishizuka and Norio Kondo who served as our liaison with the Japanese Government and TARC and to Drs. S. Nakagawa and K. Hayashi of TARC for providing us with excellent facilities and superb logistical support. Considerable efforts were also made by the members of the Symposium's Advisory Committee: Dr. Al-Jibouri, Dr. E. H. Hartmans, Dr. S. Nakagawa, Drs. Ishizuka and Kondo, Dr. K. C. Hsieh, Dr. Harold Kauffman, Dr. Paul Sun, and Dr. Satoru Motomura. My thanks also to Ms. Marilyn Campbell of IDRC, who served as our editorial consultant, and to Ms. Pura Lastimosa of the Philippine Council for Agriculture and Resources Research and Development who proofed the manuscripts.

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G. W. Selleck
Director General, AVRDC

Section I

Cropping Systems

Increasing Tropical Soybean Production With Improved Cropping Systems and Management

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Introduction

Soybean (Glycine max) can be grown in the tropics and subtropics throughout the year, but a number of factors limit production, i.e. the physical and chemical characteristics of the soil and water environment and the overlapping effects of climate. The classifications for agricultural land in Indonesia are shown in Table 1. Table 2 shows the importance of soybean in the Indonesian diet.

Table 1. Agricultural land classifications in Indonesia.

Lowland rice-producing areas		
Full irrigation	-	10 months
Partial irrigation	-	7-9 months
Partial irrigation	-	5-7 months
Rainfed	-	± 5 months water availability
Upland rainfed areas		
Humid	-	9 months > 200 mm and 3 months ≤ 100 mm
Drought	-	6 months > 200 mm and 3 months ≤ 100 mm
Dry	-	3-4 months > 200 mm and 3 months < 100 mm
Tidal swamp		
Systematically drained		
Partially drained		
Swamp areas (fresh water)		

Source: Annual Report, Cropping Systems Research in Indonesia

Soybean in Lowland Rice Areas

Approximately 5.5 million ha of rice are grown in Indonesia under lowland conditions. Lowland areas in the country are similar to those in other parts of South and Southeast Asia. A common feature of most lowland areas in Asia is the fact that legumes can be grown after the last rice harvest. This system is not extensively practiced, however.

Table 2. Balance sheet for major Indonesian food crops , 1978.

Food source	Consumption per capita				
	kg/year	gm/day	cal/day	gm protein/day	gm fat/day
Cereals			1586	31.97	8.55
Rice	123.35	337.94	(1237)[z]	(21.63)[z]	(2.70)[z]
Starchy feeds			246	1.79	0.32
Sugar			116	0.10	0.03
Pulses and oil seeds			268	8.08	21.42
Soybean	4.85.	13.29	(53)[y]	(4.66)[y]	(1.35)[y]
Fruits			23	0.30	0.14
Vegetables			11	0.63	0.11
Meat			19	1.09	1.58
Eggs			4	0.27	0.27
Milk			8	0.40	0.40
Fish			17	2.90	0.49
Vegetable oils			117		13.24
Animal fats			2		0.21
Vegetable			2367	42.87	43.81
Animal			50	4.66	2.95
Total			2417	47.53	46.76

[z]Values attributable to rice
[y]Values attributable to soybean
Source: Statistical Pocketbook of Indonesia, 1980/1981

Common Management Practices

There are several common management practices (either used or proposed) for soybean grown in lowland rice areas. These can be summarized according to different levels of management:

Management Level	Practice
Low	Broadcasting into standing, mature rice.
Intermediate	Dibbling into rice stubble after the development of surface drainage.
Standard	Intermediate + pest management.
High	Intermediate + pest management + fertilizer.

The cropping patterns and climatic conditions of the major rice-producing regions in Indonesia are shown in Figs. 1 and 2. Fig. 1 represents the period before cropping systems research was initiated in West Java and before early maturing rice cultivars were introduced. Fig. 2 shows how soybean can fit into a more intensive cropping patterns. The benefits to the farmer are shown in Table 3.

In general, soybean yields in trial plots and on farmers' fields are quite low. Contributing factors include:

a. Poor stands due to inadequate seed germination, excess water, and improper soil/seed contact;
b. Excess water early in the season and the lack of drainage;
c. Weed problems due to inadequate land preparation and slow soybean development;
d. Poor growth due to inadequate soil fertility, weeds, excess water, or drought; and
e. Empty pods due to insect damage and drought.

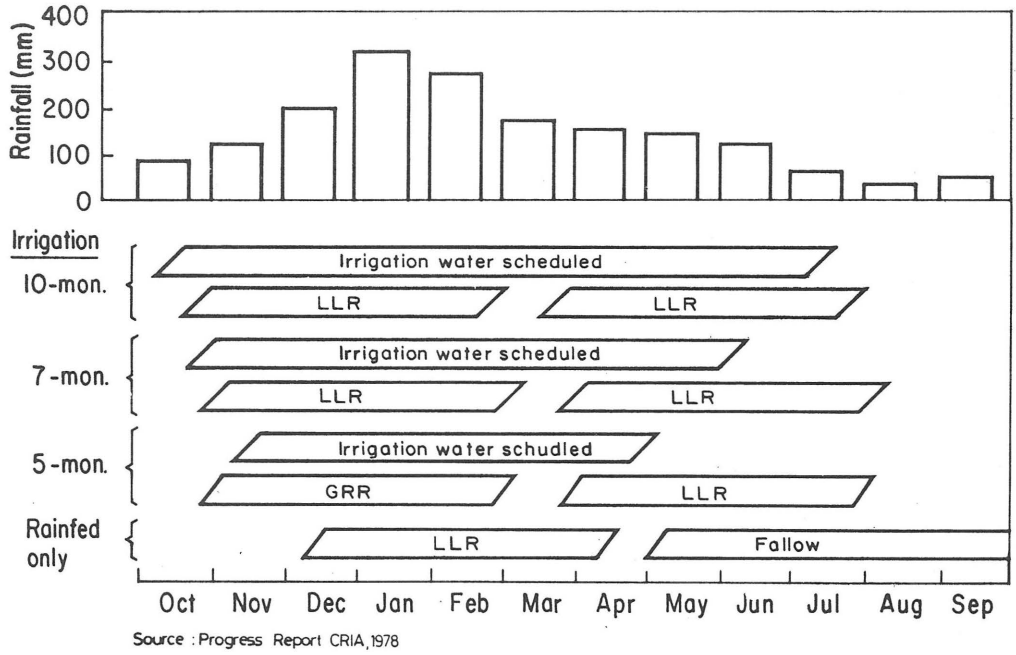


Fig. 1. Farm cropping pattern calendar, Indramayu, West Java, 1973 (LLR = lowland rice, WSR = Walik Jerami rice, CP = cowpea, SB = soybean, GRR = Gogo Rancah rice; also see Table 3).

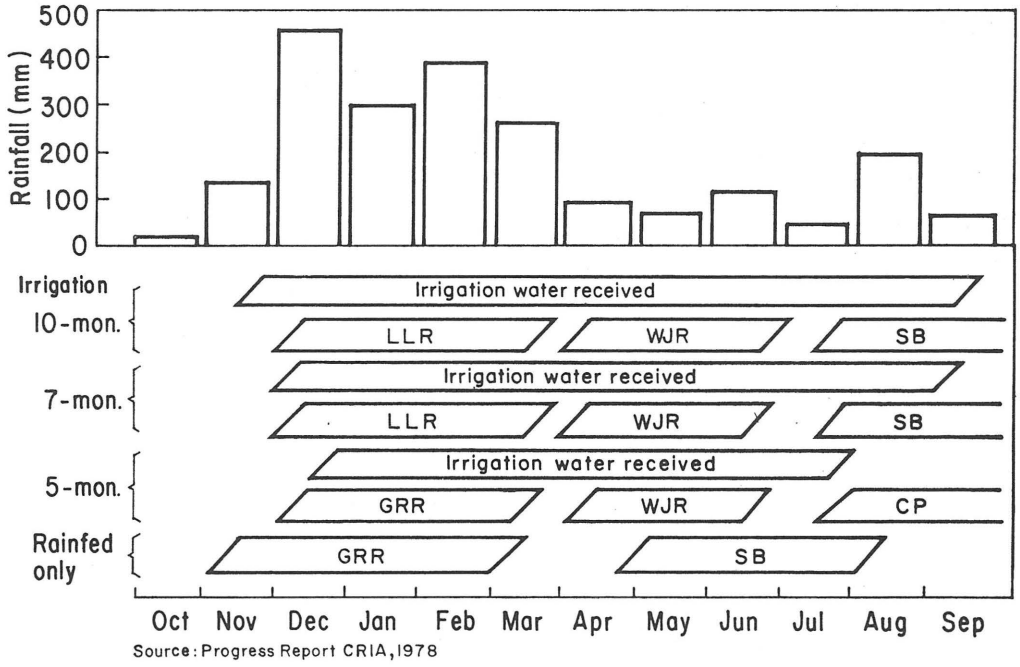


Fig. 2. Calendar of pre-production cropping patterns, Indramayu, West Java, 1977-78 (LLR = lowland rice, GRR = Gogo Rancah rice; also see Table 3) (CRIA 1978).

Table 3. Comparisons of yields and economic returns for introduced and traditional cropping patterns, Indramayu, West Java, 1975-78.

Cropping Pattern	Irrigation Category		
	10 months	7-9 months	5-8 months
	Average yield (t/ha[z])		
Farmer[y] (1975-77)			
Lowland rice	5.6	5.3	3.6 (GGR)
Lowland rice	5.8	2.8	2.2
Net returns (US$)	879	589	308
Introduced[x] (1975-77)			
Lowland rice	5.3	5.6	4.8 (GGR)
Walik Jerami rice -	5.0	4.6	4.6
Soybean	0.8	0.9	0.5
Net returns (US$)	893	993	524
Introduced[w] (1977-78)			
Lowland rice	6.9	7.2	3.5 (GGR)
Walik Jerami rice	4.9	4.5	2.9
Soybean	0.5	0.6	---
Cash surplus (rice)[v] (US$)	1,242	1,230	483

[z] Yields were measured by sampling from 1000 M^2 plots; 3 replications/treatment/year for 2 years, 1975-77

[y] Farmers' patterns as shown in Fig. 1

[x] Introduced patterns as shown in Fig. 2. Walik jerami rice is rice directly planted after the preceding rice crop w/o plowing; Gogo Rancah Rice (GRR) is rice directly seeded on aerobic soil at the beginning of the rainy season. It is flooded later.

[w] Yields were measured by sampling contiguous areas of approximately 3 ha for each irrigation category for pre-production test trials, 1977-78

[v] Cash surplus is gross returns minus cash costs for materials and labor; net returns is gross returns minus costs for all materials and labor, including farmers' labor

Source: Annual Reports, Cropping Systems Research in Indonesia

Soybean In Upland Rainfed Areas

Approximately 17 million ha in Indonesia are being used for agriculture, 11 million of which are located in upland, rainfed areas. An estimated 15 million additional ha with red-yellow podzolic soils could be used for crop production. These soils have low pH and base saturation, but respond dramatically to lime and fertilizer, and could be farmed with judicious soil management and the use of mixed cropping systems.

Common Management Practices

Soybean can be grown throughout the year provided that there is sufficient rainfall or irrigation. The crop is not generally irrigated in Indonesia, but irrigation might be a viable practice in the future. Most soybean is grown early

in the wet season, in the late wet season, or in the early dry season. Early wet-season crops escape many insect and disease problems but may be affected by excess rainfall at the pod filling stage or at harvest.

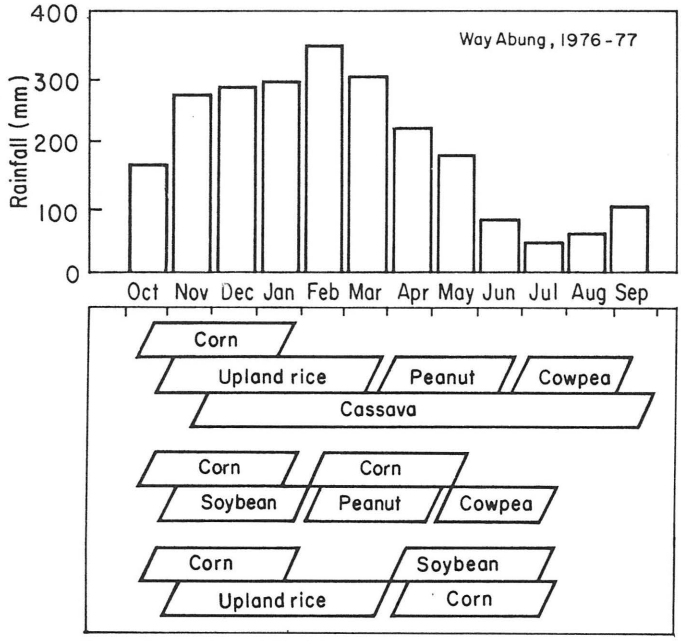
The main cropping period starts at the end of the rainy season. Because soybean follows other crops in Indonesian cropping patterns, minimum tillage can be used. Beanfly, Ophiomyia phaseoli, is extremely severe in most years, and seed treatment with carbofuran or a similar systemic insecticide is required.

Production Prospects

The most common upland soybean cropping patterns are shown in Fig. 3. Several of these patterns could be used in areas where soybean is not presently grown or where production is not intensive. However, major increases in production will depend on the availability of improved cultivars and seed and the development of a long-term, consistent management strategy.

Almost all upland soils respond to phosphorus and many low pH soils need lime. Raising soil pH to 6.0 or 6.5 is usually unnecessary. It would be helpful, however, to identify cultivars that are tolerant of Al and low pH.

Maintenance of soil organic matter and inoculation with adapted rhizobia are also important management practices, particularly in newly opened areas. Beanfly control is mandatory in almost all locations.



Source: Progress Report, CRIA, 1978

Fig. 3.

Rainfall pattern of rainfed, upland cropping areas in Indonesia and adapted cropping patterns.

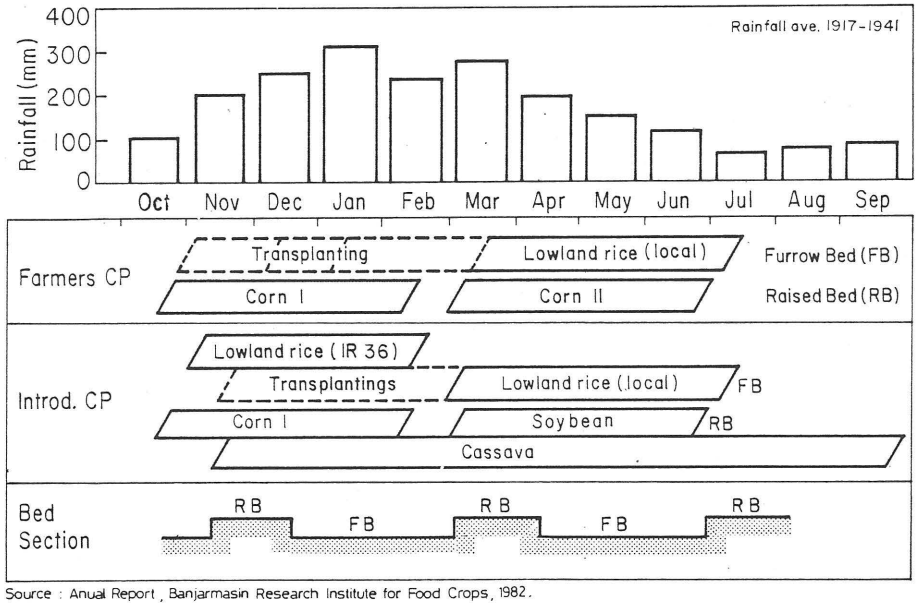
Soybean in Tidal Swamps

There are at least 6 million ha of tidal swamps in Indonesia that can be used for agriculture. Tidal swamps, however, present numerous problems, including poor drainage, high acid sulfate levels, deep layers of peat, as well as special plant nutrition requirements.

Management Practices

Swamp land in Indonesia falls into two categories. The first covers land that was gradually opened by settlers, usually sailors and traders who identified areas that were fertile and had potenial for simple drainage. A system of raised and lowered beds was usually placed between the drains. The lower beds were used for lowland rice, while the raised bed were used to grow upland crops such as rice, corn, cassava, and legumes. Perennial crops such as coconut, clove, and coffee were gradually interplanted on the ridges. Eventually, the raised beds were suitable only for perennial and shade-tolerant crops. The lowered bed were gradually shaded, but enough light penetrated the canopy to allow for the production of shade-tolerant rice cultivars. This system is presently in use and seems to be stable and productive.

The second development category deals with land that has been systematically drained, usually in transmigration areas selected for their lack of soil problems. The farming systems research program in Indonesia has conducted studies in these areas aimed at the development of farming systems patterned after traditional systems. Fig. 4 shows the rainfall distribution and the sequence of crops that can be grown on raised and lowered beds. Soybean is almost always a component in these types of systems, but the area planted is limited because of problems associated with transporting the crop to market. The demand for soybean in these locations is not as high as in other parts of Indonesia because of abundant fish supplies.



Source : Anual Report, Banjarmasin Research Institute for Food Crops, 1982.

Fig. 4. Rainfall distribution, cropping patterns (CP) tested, and bedding arrangements for cropping system research in drained tidal swamps, Barambai, South Kalimantan, 1979-81.

Production Prospects

Soil acidity resulting from the oxidation of sulfurous compounds is one of the major factors associated with poor soybean yields in tidal swamp areas. Soybean grows very well on peat soils that are not strongly affected by acid sulfate. While these soils have great potential for soybean, they will probably be used only for local consumption in the near future.

Swamp Areas

Indonesia's fresh water swamps lay between tidal areas and rainfed, upland zones, principally in Sumatra and Kalimantan. There are approximately 6 million ha of this type of land available for agriculture. The soils are high in organic matter and are quite fertile.

Management Practices

A single rice crop is grown each year as water levels recede. Seedling beds are planted on the high ground, and seedlings are transplanted in consecutively larger areas as the flood waters dissipate. Photoperiod sensitive cultivars are commonly planted. Other food crops, particularly green vegetables and citrus, are grown on higher ground to meet family food requirements.

Production Prospects

Some research has been carried out to increase crop productivity in swampy environments. It is possible to plant elongating, early maturing rice cultivars at the beginning of the rainy season. The rice crop is harvested before it is inundated by rising water levels. The second rice crop is planted as the flood waters recede. The excess rice produced would theoretically provide farmers with a greater incentive to grow alternative crops such as soybean during the dry season. This type of system will require considerable experimentation, especially to resolve pest problems,

Recent Soybean Research in Indonesia

Stand Establishment

In East Java most soybean is planted by broadcasting the seed after lowland rice without tillage. Other planting methods include drill-seeding with and without tillage. After the rice harvest, soil moisture is quite high, a condition which usually results in poor soybean germination.

Reports on the effects of soil tillage on soybean grown after lowland rice are conflicting, but most studies indicate that tillage does not increase yield. Nakayama et al. (1981) and Suhartatik et al. (1982) reported that soybean dibbled without tillage was more vigorous than soybean planted after soil tillage (Table 4). Seeding soybean in cut rice stubble appears to be a slightly better practice than seeding in standing stubble. Soil tillage is a laborious and time-consuming practice and is not likely to be used for intensive cropping unless farm income rises. The differences in soybean response to different soil tillage practices may be related to soil moisture and the physical and chemical characteristics of the soil. Tilling a heavy clay soil that is high in moisture may cause soil crusting and lead to poor germination. Draining excess water takes time, however, and late planting may induce drought stress and insect infestation. Nakayama et al. (1981) reported that soil tillage for soybean grown after lowland rice may actually cause weed problems.

Syarifuddin (1979) reported that soybean planted on beds immediately after rainfed, lowland rice grew poorly because of insufficient moisture in the first 5 mm of the soil. He also reported that if soybean is dibbled immediately after the rice harvest, emergence may be reduced by high soil moisture content. In contrast, stand establishment was improved 50% when soybean was planted as a relay-crop at the rate of 60 to 120 kg/ha.

Pasaribu (1980) reported that coating soybean seed with a commercial calcium peroxide product did not improve the germination of seed planted in saturated soil in a greenhouse.

Table 4. Effects of soil tillage and planting method on soybean yields at Muara substation, wet season (WS) 1977-78 and dry season (DS) 1980 and at Mojosari substation, dry season 1980.

Treatment	Seed Yield		
	Muara		Mojosari
	WS 1977/78[z]	DS 1980[y]	DS 1980[y]
	t/ha		
No tillage			
Broadcast	1.14	0.72	0.57
Dibbled	1.42	0.88	0.55
Rice stubble	1.39	--	--
Tillage			
Dibble	1.51	0.86	0.41
HSD	0.32	NS	NS
CV (%)	13.20	--	--

[z]Source: Suhartatik et al. (1982)
[y]Source: Nakayama et al. (1981)

Fertilizer Management

Research aimed at studying the effects of NPK fertilizer and crop residue management on soybean followed by corn and lowland or upland rice was conducted from 1973 to 1978 at the Muara Substation in Bogor. Trial results showed that the response of soybean to NPK fertilizer was considerably lower than that of rice or corn (Table 5). Soybean planted after lowland rice did not respond to NPK and crop residue application, but there was a consistent response to NPK for soybean planted after upland rice. Without NPK the yield of soybean planted after lowland rice was about equal to soybean planted with NPK after upland rice. Soybean responded better to crop residue application after upland rice than after lowland rice, particularly if the residues were incorporated in the soil or applied in the form of manure. These results indicate that the efficiency of phosphate fertilizer could be increased by incorporating crop residues. Soybean responded better to animal manure application after lowland rice, but responded even better to crop residues incorporated into the soil after upland rice.

Table 5. Cumulative yield of a five-year rice-soybean-corn cropping pattern, Bogor, 1974-1979.[z]

Treatment	Rice		Soybean		Corn	
	lowland	upland	after LLR[y]	after ULR[x]	LLR-soy	ULR-soy
	t/ha					
No NPK + no crop residue	6,38	4.37	5.78	4.70	7.71	5.46
No NPK + crop residue as mulch	7.80	5.07	5.39	4.69	8.45	5.87
No NPK + crop residue incorporated	9.12	5.23	5.71	5.25	8.84	6.79
No NPK + animal manure	7,39	5.06	5.97	5.20	8.41	6.38
NPK[z] + no crop residue	15.36	12.54	5.45	5.74	16.29	16.03
NPK + crop residue as mulch	18.46	13.10	5.91	5.92	15.98	17.12
NPK + crop residue incorporated	18.86	12.78	5.71	6.08	16.23	16.24
NPK + animal manure	15.99	13.31	5.94	5.82	16.16	17.13

[z]Application rates of NPK = 120-19.6-41.5; 20-19.6-41.5; and 120-19.6-41.5 for rice, soybean, and corn respectively.
[y]LLR:Lowland rice
[x]ULR:Upland rice
Source: Suhartatik et al. (1982) (summary of data from Annual Reports CRIA 1975-1980).

Reports from the Central Research Institute for Agriculture also showed a minor response to NPK. Soybean planted after lowland rice that received P fertilizer rarely responded to medium levels of NPK. Soybean planted after upland rice (or other upland crops) on soils with low available P generally responded to P fertilizer. Phosphate applied at the rate of 19.6 kg/ha was shown to increase soybean yields from 0.6 t/ha to as much as 1.7 t/ha (CRIA-IRRI 1979). Other research has demonstrated that Mo applied foliarly or mixed with soybean seed tended to increase yield in plots that did not receive P. The Mo effect on vegetative growth and color were striking even though there were no significant yield increases.

Rhizobium and Nitrogen Nutrition

In trials at two locations (Tasikmalaya and Yogyakarta) soybean grown after lowland rice did not respond to Rhizobium japonicum inoculation. Although the experimental sites had not been planted to legumes in more than five years, root nodulation in the uninoculated plots was quite good. In Yogyakarta, inoculation, in combination with 60 kg N/ha (20 kg N/ha planting and 40 kg 28 DAS), increased yields significantly (Table 6). It seems that the rate and timing of N application may be critical to soybean yield even in areas with established, indigenous rhizobia.

R. japonicum inoculation significantly increased yield in newly cleared upland areas. CRIA (CRIA-IRRI 1979) reported that adding soil from fields previously planted to soybean to the soil of newly cleared land increased soybean yield by 18%, while inoculation with a commercial inoculant (peat carrier) increased yield by 30% (peat inoculant also increased soybean seed size). A cultivar-inoculant-yield interaction was observed in another trial. Nitragin was found to be more compatible with cultivar Orba and Gm 1303 S, while Legin (a peat inoculant) was more compatible with cultivar No. 29 (Table 7). The response of cultivar Galunggung to Nitragin and Legin was roughly equal. All inoculants significantly increased soybean yield.

Table 6. Effect of inoculation and N fertilization on soybean nodule number and yield (Tasikmalaya, dry season 1981 and Yogyakarta, dry season 1982).

Treatment	Seed Yield		Nodule Number	
	Tasikmalaya	Yogyakarta	Tasikmalaya	Yogyakarta
	----------t/ha---------		-------no/plants-------	
Inoculant - N	1.42	1.96	21.2	30.4
Inoculant + N	1.49	-	20.7	-
Inoculant - N	1.48	1.98	20.1	30.8
Inoculant + N[z]	1.49	1.93	18.7	26.6
Inoculant + 20 N (0 DAS) + 60 N (28 DAS)	-	2.22	-	27.4
HSD 5%	NS	0.25	NS	NS
HSD 10%		0.37		
CV (%)		8.9		

[z]N application rates were 45 and 20 kg/ha for Tasikmalaya and Yogyakarta, respectively.

Intercropping

In general, yield is reduced when soybean is planted as an intercrop with taller plants. The effect of early, medium, and late-maturing maize cultivars on soybean yield was studied by Syarifuddin et al. (1974). They reported that

Table 7. Effect of cultivar and inoculant on soybean yield, Way Abung, Lampung, wet season 1981-82.

Inoculant	Seed Yield cultivar/line (sub plot(SP))				average
	Orba	Galunggung	No. 29	Gm 1303 Si	
	t/ha				
Main plot(MP):					
Control	0.62	0.49	0.63	0.26	0.50 b[z]
Soil	0.97	0.86	1.06	0.48	0.84 ab
Legin	1.14	1.00	1.25	0.75	1.04 a
Nitragin	1.47	1.03	0.85	1.43	1.19 a
Average	1.05	0.85	0.95	0.73	

SP/MP HSD 5% = 0.85 HSD 1% = 1.11 CV = 21.0%
MP/SP HSD 5% = 0.60 HSD 1% = 0.79 CV = 35.2%
[z]Values followed by the same letter are not significantly different as per Duncan's multiple range test at the 5% level
Source: CRIA-IRRI (1979)

soybean yields decreased by a percentage of 7.5, 11.2, 24.8, and 28.9 with corn populations planted at 20, 40, 60, and 80% of the crop's normal population density, respectively. Toha (1976) reported that with a normal soybean population (332,000 plants/ha), soybean yields decreased to 56 and 86% of the sole-crop population when intercropped with corn planted at 25,000 and 50,000 plants/ha, respectively. In a subsequent experiment, Toha (1981) also noted that soybean, peanut, and mungbean yields were linearly, but negatively correlated with corn populations. Soybean yields were 37.1, 60.1, and 74.2% of sole-crop soybean when grown with corn at populations of 62,500, 31,200, and 20,800 plants/ha, respectively. Intercropping soybean with cassava also reduced soybean yields (CRIA 1978). Soybean yields decreased from 33 to 63% as the cassava population increased from 3,333 to 10,000 plants/ha. Growing several food crops under 6-year-old coconut trees reduced the yields of cassava, mungbean, cowpea, and peanut by 25 to 60% of sole-crop plantings; soybean and upland rice yields were not affected (CRIA 1978).

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Soybean Response to Intercropping With Cassava

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Introduction

Cassava (Manihot esculenta Crantz.) is a major root crop in the tropics and subtropics. Its growth duration is usually 9 to 24 months; the canopy closes after about three months. Cassava is frequently intercropped with legumes, sugarcane (Saccharum officinarum), maize (Zea mays), yams (Colocasia sp.), and tree crops (Weber et al. 1979). Grain legumes are often grown in association with cassava on small family farms, thus providing a balanced diet of proteins and carbohydrates. The growth habits of these crops complement one another since the legume crop can be harvested before the rapid bulking of the cassava tubers. Legumes also help to minimize the decline of soil fertility, a serious problem when cassava is repeatedly sole-cropped (Sinthuprama 1979).

Intercropping usually produces higher combined yields because it can make better use of available resources (Willey 1979). The advantages of intercropping is maximized when the component crops complement one another in such a way that limited resources are thoroughly used by the intercrops. Under favorable growing conditions (no water stress) and optimal nutrient availability, light is often the limiting factor. A combination of appropriate crop varieties and management practices (planting date and population density) can then be selected to maximize the use of solar radiation.

This paper reports the results of an experiment where light interception and plant dry matter production were monitored throughout a cassava-soybean (Glycine max) intercropping season to examine the relationship between soybean yield and the availability of solar radiation.

Materials and Methods

General

The experiment was conducted at the Redland Bay Farm of the University of Queensland near Brisbane, Australia (altitude 5 m, latitude 27° 37'S, longitude 153° 19'E). The soil is a deep, fertile, well-drained red loam (Krasnozem). A cover crop of oats (Avena sativa) was plowed in two months before cassava planting; the experimental area was disked twice and harrowed to control weeds and to prepare the seedbed.

A basal fertilizer of 70 kg N/ha, 105 kg P/ha, and 57 kg K/ha was applied one day before cassava planting. Stem cuttings (10 to 15 cm) with one to two nodes of cassava cultivar M AUS 7 were planted on October 5, 1982 in 180 cm rows (east to west) with 45 cm between planting positions. The same spacing was used for both the sole cassava crop and the cassava intercropped with soybean. The area was irrigated immediately after planting; sprouting of the planting material was almost 100%. Irrigation was applied periodically to prevent water stress in the soybean crop.

Fiskeby (V) 53 days after planting and cassava M AUS 7 56 days after planting.

Fiskeby (V) 83 days after planting and cassava M AUS 7 118 days after planting.

Changes in photoperiod, weekly mean solar radiation, and weekly mean-maximum and -minimum temperatures during the experiment are shown in Fig. 1. Photoperiod increased from 13 h at cassava planting to 14.5 h, and then declined to 12.5 h in April. Solar radiation followed a similar pattern to that of photoperiod, but there were two weeks in January when radiation levels were very low. Air temperatures increased gradually from October to February, followed by a gradual decrease.

Red spider mites (Tetranychus sp.) attacked the soybean crop in March and April, and yield reductions were observed in cultivars that were under-going pod filling at the time.

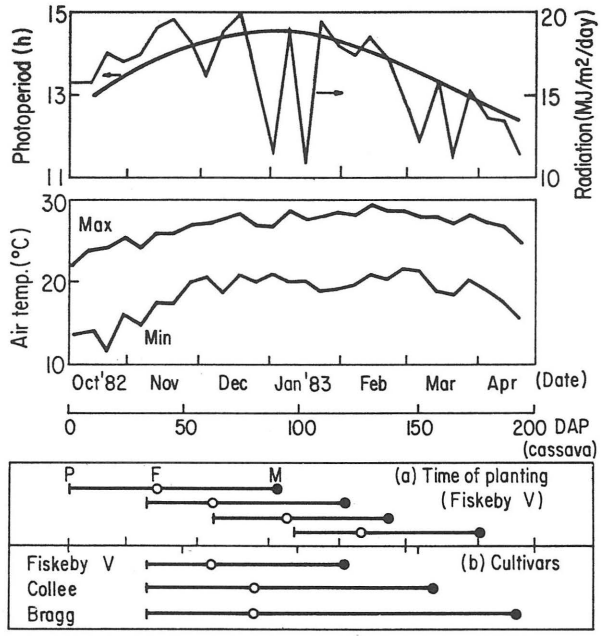

Fig. 1. Change in photoperiod, weekly mean daily solar radiation, and weekly mean-maximum and -minimum temperatures during the experiment at Redland Bay, S. E. Queensland, Australia. Times of planting (P), 50% flowering (F), and maturity (M) are shown for the soybean cultivar Fiskeby V sown at four different times (a) and for three cultivars, Fiskeby V, Collee, and Bragg sown five weeks after cassava planting (b).

Treatments

Thirteen treatments were randomized in four blocks. Plot size was 10.8 m x 7.5 m.

With No Soybean: 1 (treatment number) sole cassava.

Relative Sowing Time of Soybean: The early maturing soybean cultivar Fiskeby V (90 days maturity) was sown four times (1, 5, 9, and 14 weeks after cassava planting (WACP)). Soybean was also planted as a sole-crop.

	Treatment number	
	Sole crop	Intercrop
Fiskeby V (1)	2	3
Fiskeby V (5)	4	5
Fiskeby V (9)	6	7
Fiskeby V (14)	8	9

(Numbers in parenthesis denote WACP)

In treatment 9, intercropped soybean was sown 14 WACP in the area where the first soybean intercrop (treatment 3) had just been harvested. Therefore, the combined soybean yield from treatments 3 and 9 represents two sequential soybean crops intercropped with a single cassava crop.

Cultivars: In addition to Fiskeby V, medium maturing cultivar Collee (120 days) and late maturing Bragg (150 days) were also sown 5 WACP.

	Treatment number	
	Sole crop	Intercrop
Collee (5)	10	11
Bragg (5)	12	13

Soybean row width was 30 cm in both the sole-crop and the intercrop. In the intercrop two out of six rows were replaced by one row of cassava. Because cassava row width was 180 cm, there was a 45 cm gap between a cassava row and an adjacent soybean row. Because one-third of the soybean area was replaced by cassava in the intercropping treatments, "expected" soybean growth or yield in intercropped plots would be 67% of that in the corresponding sole-cropped soybean.

Soybean seeds were hand-planted, and the seedlings were thinned to produce the planned plant spacing of 10 cm (33.3 plants/m^2 in the sole-crop and 22.2 plants/m^2 in the intercrop) for Fiskeby V and plant spacing of 15 cm (22.2 plants/m^2 in the sole-crop and 14.8 plants/m^2 in the intercrop) for the later maturing cultivars. Actual plant numbers measured at maturity were close to the plan for Fiskeby V, but were higher than expected for others, particularly in the intercrops (26.0 and 18.9 for Collee and 23.1 and 19.7 for Bragg). All soybean tops were removed from the field at maturity.

Sampling Procedures

Five consecutive plants from each of two adjacent rows were harvested from each plot to estimate plant height, top dry matter, and leaf area at three-week intervals starting four weeks after sowing until maturity. A harvest area of

7.2 m^2 for each plot was taken for a final seed yield estimate. Pod number per plant, seed number per pod, and 100-seed weight were estimated from the ten-plant samples at harvest. Cassava height was estimated at 30-day intervals, starting 70 days after planting.

Light Transmission Measurement

Light transmission through the canopy was measured with four 50-cm tube solarimeters sensitive to all solar radiation wave lengths (Szeicz et al. 1964). The solarimeters were placed on the ground at right angles to the crop row, and were moved from one plot to another every three or four days. In the sole-crop cassava and in the intercrop, the solarimeter was placed at the mid-interrow between the 180 cm cassava rows. Thus, in the sole-crop, the transmission value should have been higher than the average of the plot. In the intercrop and sole-crop soybean, one solarimeter covered the two center rows of soybean. Because of physical limitations, light transmission was measured in only one block without replication.

Results

Plant Development

There were no significant differences in time to 50% flowering or to maturity between the sole-crop soybean and the corresponding intercrops. The occurrence of 50% flowering and maturity are shown in Fig. 1.

Fiskeby V (1) sown in October took about eight days longer to reach 50% flowering than when it was planted in November, December, or January. Time to maturity decreased from 88 days in the October planting to 75 days in the December planting (Fiskeby V (9)) and 79 days in the January planting (Fiskeby V (14)).

Although both Collee (5) and Bragg (5) reached 50% flowering at 44 days, Bragg matured much later than Collee. The three cultivars showed a large variation in time from 50% flowering to maturity.

Plant Height

Soybean plant height at all stages of development was not significantly affected by the cassava intercrop (Fig. 2). Plant heights of Fiskeby V was 34 cm for the October crop (Fiskeby V (1)) and increased to 56 cm in December (Fiskeby V (9)). Planting late in the season (Fiskeby V (14)) resulted in a reduced rate of height increment and a low maximum height of 38 cm.

The rate of plant height increment was much higher in the later maturing Collee (5) and Bragg (5) than in the early maturing Fiskeby V (5); the maximum height was 96 and 94 cm for Collee and Bragg, respectively. Slight decreases in the height of Collee were due to lodging.

The height of the cassava was affected by the intercrop, and the response to intercropping varied according to cultivar type. When Fiskeby V (1) was sown immediately after cassava planting, the soybean plants were taller than the cassava; the intercropped cassava was slightly taller than the sole-cropped cassava throughout the soybean growth period. However, after the soybean crop matured and was removed from the field, the height increment of the cassava intercrop was less than that of the sole-cropped cassava. This trend was not affected when a second soybean crop (Fiskeby V (14)) was planted with cassava.

When Fiskeby V was sown at 5 and 9 WACP, the soybean plants were shorter than the cassava and had little effect on the associated cassava. However, Collee (5) and Bragg (5) became taller than the cassava about 60 days after cassava planting, and this enhanced the height of the cassava. The cassava intercrop was 30 cm taller than the cassava sole-crop 80 days after cassava planting. The difference in height diminished after the soybean attained its maximum height and when the soybean completed its growth cycle.

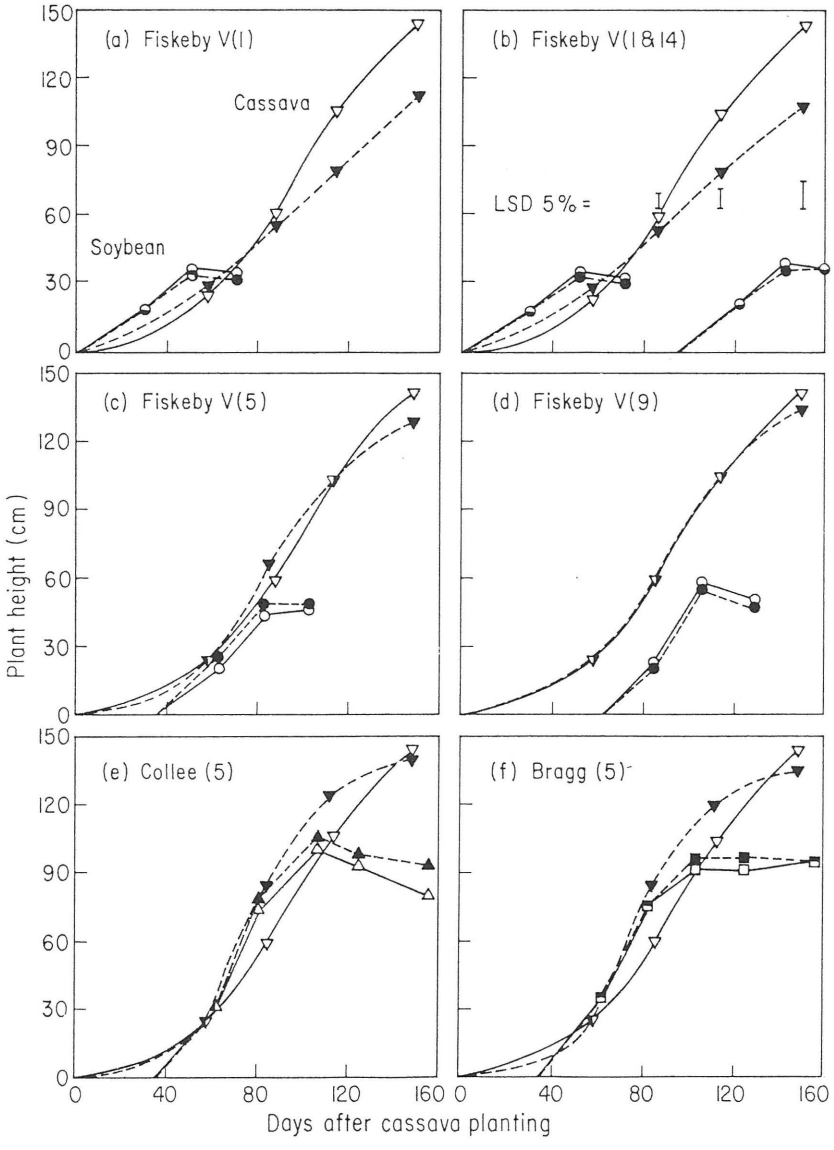

Fig. 2. Changes in cassava height (sole ▽——▽, intercrop ▼--▼) for Fiskeby V (sole ○—○, intercrop ●---●) sown one (a), one and fourteen (b), five (c) and nine (d) weeks after cassava planting for Collee (sole △—△, intercrop ▲---▲) and for Bragg (sole □—□, intercrop ■---■) sown five weeks after cassava planting. LSDs shown in (b) apply for all cassava heights.

Dry Matter Production

Dry matter accumulation of sole-cropped and intercropped Fiskeby V at different planting times are shown in Fig. 3a. Maximum dry matter production of Fiskeby V decreased from first planting to fourth planting in both the sole-cropped and intercropped treatments. Final weights were 5.77, 5.10, 4.20, and 2.53 t/ha for sole-cropped Fiskeby V sown 1, 5, 9, and 14 WACP, respectively. The decrease in final weight with delayed sowing was more pronounced in the intercropped soybean, and the ratios of total dry matter at maturity in the soybean intercrop to that of the corresponding sole-crop were 0.63, 0.63, 0.48, and 0.27 t/ha in the 1, 5, 9, and 14 WACP plantings, respectively. Because the intercropped soybean occupied only about 67% of the planting area, the figure of 0.63 indicates that the cassava had a minor effect on soybean growth. However, soybean growth was significantly reduced by the cassava intercrop when the soybean was sown 9 and 14 WACP.

Three soybean cultivars sown 5 WACP grew at similar rates when sole-cropped or intercropped. However, the longer growth duration of Bragg resulted in higher total dry matter than that of Fiskeby V; the final weight of Collee was similar to that of Fiskeby V. Intercropped Bragg was not affected by the cassava (similar to Fiskeby V, 5 WACP); total biomass of the intercropped soybean was close to 67% of the corresponding sole-cropped soybean. On the other hand, the data from the last two harvests indicated that Collee was affected by the cassava intercrop.

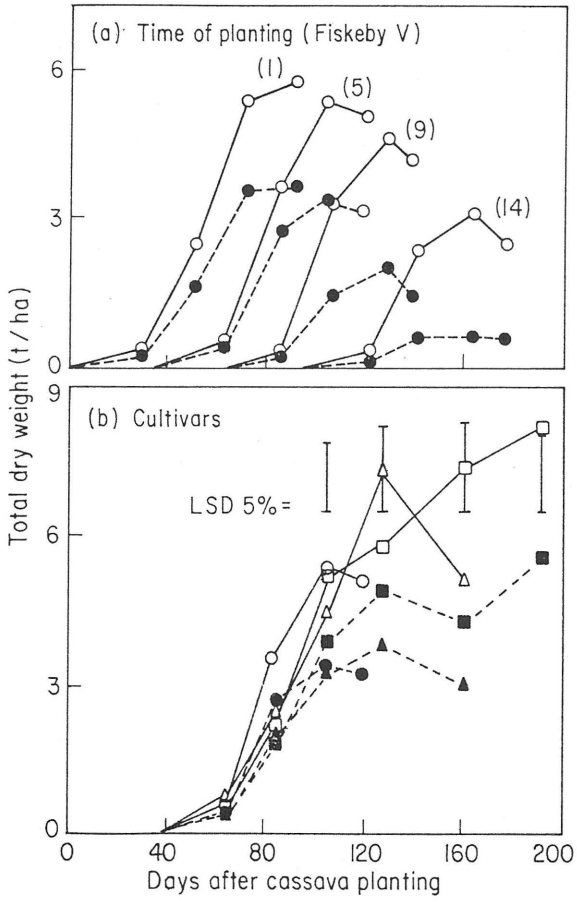

Fig. 3.
Changes in total dry matter of Fiskeby V, sown 1, 5, 9, and 14 weeks after cassava planting in sole and intercropping plots (a), and of Fiskeby V, Collee, and Bragg sown five weeks after cassava planting in sole and intercropping plots (b). For symbols, see Fig. 2 caption.

Leaf Area Development

Changes in leaf area index (LAI) during the growth of sole- and intercropped Fiskeby V sown on different planting dates are shown in Fig. 4a. Maximum LAI was reached about seven weeks after sowing in all four plantings. The maximum LAI were 2.04, 3.45, 3.02, and 1.64 for sole-cropped Fiskeby V sown 1, 5, 9, and 14 WACP, respectively. The ratios of maximum LAI of Fiskeby V in intercropping to the corresponding sole-crop were 0.65, 0.70, 0.52, and 0.20, respectively. This indicates that the leaf area development of Fiskeby V (5 WACP) was not affected by the cassava while it was severely affected in Fiskeby V (14).

Bragg (5) had a higher maximum LAI than Fiskeby V (5) and Collee (5) (Fig. 4b), but high leaf area persisted longer in Collee than in Fiskeby V (5). Bragg reached maximum LAI later than Collee and Fiskeby V, and experienced a gradual decline in LAI until maturity. The ratios of maximum LAI of the intercrop to the corresponding sole-crop were 0.88 and 0.77 for Collee and Bragg, respectively, indicating that the leaf area of the intercrops compensated to some extent for the reduced area sown to soybean.

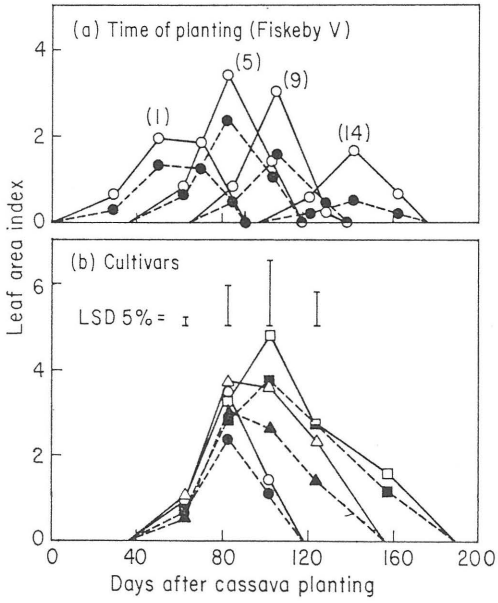

Fig. 4.
Changes in leaf area index of Fiskeby V sown 1, 5, 9, and 14 weeks after cassava planting in sole and intercropping plots (a), and of Fiskeby V, Collee and Bragg sown five weeks after cassava planting in sole and intercropping plots (b). For symbols, see Fig. 2 caption.

Light Transmission

No light was intercepted at the mid-interrow position of the sole-crop cassava until 80 days after planting. The cassava canopy developed rapidly and covered the space between the rows at 120 days, after which less than 10% of the light was transmitted (Fig. 5a).

When Fiskeby V was intercropped between cassava rows 1 WACP (Figure 5b), the soybean canopy developed shortly after sowing, and only 15% light was transmitted through the intercrops 56 days after cassava planting (about the time of peak LAI). Light transmission then increased because of soybean leaf senescence. Light transmission of sole-cropped Fiskeby V (1) followed almost the same pattern. At the time of the second soybean sowing following Fiskeby V (1) (Fiskeby V (14)), full light transmission still reached ground level. Light transmission decreased gradually as both soybean and cassava developed a leaf canopy 160 days

after cassava planting (about the same time that the soybean senesced). Light transmission in sole-cropped Fiskeby V (14) decreased rapidly (to about 30%) at the peak LAI of 1.64, but then increased as the leaves senesced.

Light transmission through the intercropped Fiskeby V (5) declined more rapidly than sole-cropped Fiskeby V (5), and the minimum light transmission of 12% was about half that of the sole-crop (Fig. 5c). However, it was noted that in the sole-cropped soybean plot where light transmission was measured, plant growth was poor compared with the other replicated blocks. Light transmission in the sole-crop was therefore probably overestimated. Light transmission patterns were similar between intercropped and sole-cropped soybean for Fiskeby V (9), Collee (5), and Bragg (5) (Fig. 5d,e,f). The longer period of minimum light transmission through Bragg canopies is related to the fact this cultivar retained high LAI for a long period of time.

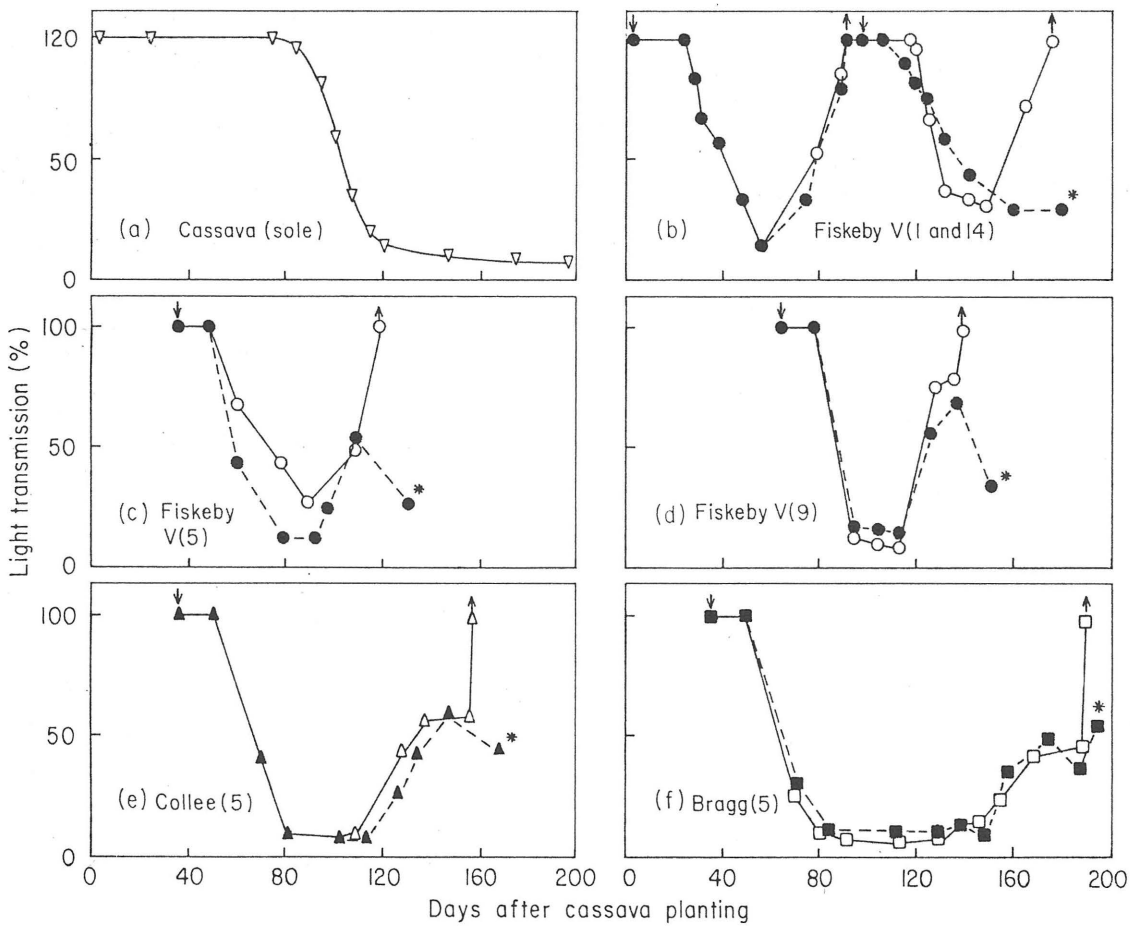

Fig. 5. Changes in light transmission (%) measured at mid-interrow position of adjacent cassava rows for sole cassava (a) and sole and intercropped soybean cultivar Fiskeby V sown 1 and 14 (b), 5 (c), and 9 (d) weeks after cassava planting and Collee (e) and Bragg (f) sown 5 weeks after cassava planting. For symbols, see Fig. 2 caption. Symbols with the * sign * indicate light transmission data obtained after removal of soybean from the field.

Light transmission at soybean maturity was almost the same between all intercropped and sole-cropped soybeans, except Fiskeby V (14). Therefore, the effects of cassava on the availability of solar radiation to intercropped soybean appear small, provided that the soybean is sown within 9 WACP. However, light transmission values after the intercropped soybean was removed were always higher than corresponding values under sole-cropped cassava, thereby reflecting the adverse effects of the soybean intercrop on cassava development. The longer the soybean growth, the longer the delay in cassava development.

Yield and Yield Components

The seed yield of sole-cropped Fiskeby V decreased as sowing was delayed from 1 to 9 WACP (Fig. 6). Decreases in yield after late sowing were more pronounced under intercropping, and the ratio of the yield of the intercrop to the sole-crop decreased from 0.70 and 0.69 in early plantings to 0.34 and 0.16 in the late plantings. The yields of the first two crops were close to the expected value of 0.67, while cassava affected the yield of intercropped soybean sown 9 and 14 WACP.

Despite the higher maximum biomass produced by sole-cropped Collee (5) and Bragg (5), their seed yields were lower than that of Fiskeby V (5). The seed yields of intercropped Collee (5) and Bragg (5) were higher than the expected 67% of the sole-crop yield, probably because of an unplanned increase in plant numbers in the intercropped plots. All three cultivars produced similar yields when intercropped.

Yield component analysis (Table 1) shows that the lower grain yield in the intercrop of Fiskeby V (9 and 14), relative to the corresponding sole-crop, was mainly due to a reduction in the number of pods per plant. Pod number, and to a smaller extent 100-seed weight, contributed to the variation in grain yield of Fiskeby V sown at different times. There was no significant difference in any yield components between sole- and intercropped Collee and Bragg. The harvest index of Fiskeby V was much higher than that of Collee and Bragg, but this was not affected by intercropping in any cultivar. (Table 1 on the next page)

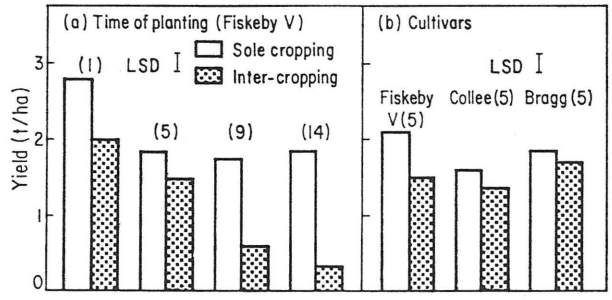

Fig. 6. Soybean seed yield for sole-cropped and intercropped Fiskeby V sown 1, 5, 9, and 14 WACP (a) and Fiskeby V, Collee, and Bragg sown 5 WACP. The LSD applies for all combinations.

Discussion

These results show that the growth and seed yield of soybean intercropped with cassava depends on the time that the soybean is sown relative to the planting of cassava. When soybean was sown within 5 WACP, seed yield was close to that expected from the sole-crop yield on a land equivalent ratio basis. This is

Table 1. Yield component analysis of six soybean crops grown as sole-crops and intercrops with cassava.

Cultivar	Sowing Time	Pod No./ Plant		Seed No./ Pod		100-Seed Wt.(g)		Harvest Index	
	(WACP[z])	S[y]	I[x]	S	I	S	I	S	I
Fiskeby V	1	35.6	35.3	1.57	1.62	17.6	16.4	0.57	0.57
	5	28.3	31.3	1.61	1.57	17.0	15.5	0.56	0.53
	9	26.6	15.7	1.76	1.68	13.9	12.6	0.52	0.51
	14	21.3	9.3	1.72	1.56	15.1	12.2	0.58	0.53
Collee	5	32.1	31.2	1.87	1.87	13.1	12.0	0.35	0.35
Bragg	5	48.6	49.4	1.56	1.64	15.3	15.8	0.31	0.34
LSD (0.05)		7.3		NS		1.7		0.06	

[z] weeks after cassava planting (WACP)
[y] S=sole-cropping
[x] I=intercropping

in contrast to the finding by Thung and Cock (1979) who reported that the yield of soybean sown one month after cassava planting was severely affected by the intercropped cassava. Thung and Cock (1979) also found that vigorous, early-branching cassava suppressed soybean yield more than the less vigorous, late-branching cassava. Because of relatively low temperatures in October and November and the use of small planting pieces, it is likely that the cassava crop in the current experiment grew more slowly during its establishment stage than that used by Thung and Cock, thereby providing more solar radiation to the soybean intercrop. Using 20 cassava genotypes intercropped with soybean, Kawano and Thung (1982) found that the yield of intercropped soybean sown two weeks after cassava was negatively correlated with shoot dry matter of cassava after three months, but not with final tuber yield. It is therefore possible to obtain high soybean yields when intercropping with a less vigorous cassava genotype or with cassava grown under sub-optimal conditions. It is likely that the yield of soybean sown five weeks after cassava will be more affected by cassava in our environment if the cassava is planted at mid-summer with subsequent rapid growth and ground cover (Keating et al. 1982). Spring planting of cassava appears to be suitable for intercropping with soybean in our environment as this also provides a long growing season (nine months) and gives the cassava an opportunity to recover from the effects of the intercropped soybean. Top growth often dominates storage organ growth in cassava in southeast Queensland, and the effect of the early intercrop is to influence top growth without reducing tuber yield.

The results from the present experiment suggests that 100% light transmission at the time of soybean sowing does not necessarily produce favorable conditions for the entire soybean growth period. As a result of shading from associated cassava, late sown Fiskeby V produced a lower number of pods per plant and lower 100-seed weight. Kuo et al. (1977) pointed out that soybean pod number per plant was reduced when plants were continuously shaded and that 100-seed weight was reduced when plants were shaded during the pod filling stage. A soybean intercrop sown 9 and 14 WACP appeared to be continuously shaded by the taller cassava plants.

Relative plant height of the component crops appears to be an important factor in determining the growth of each crop. Leihner (1979) suggested that plant growth in a cassava-legume intercropping system is optimum when the cassava canopy is maintained slightly above the associated crop. This was the case with Fiskeby V (5), while cassava associated with Collee and Bragg increased in height

to the same level as the soybean. Cassava appears to have the ability to adjust its height, particularly eight weeks after planting when rapid elongation takes place in the sole-crop. Soybean seems to have a limited ability in this regard.

The two later-maturing soybean cultivars had been expected to produce higher total dry matter and higher seed yields than the early maturing Fiskeby V, both as sole-crops and as an intercrop. Although Bragg produced a higher total biomass, seed yields of both cultivars were slightly less than that of Fiskeby V. This was associated with decreases in the efficiency of light energy conversion, rather than decreases in light interception during the grain filling stages. It is likely that lodging and red spider mite infestation caused reductions in photosynthetic efficiency, as well as an increase in the loss of dry matter accumulated earlier in the season. This resulted in low harvest indices for these cultivars.

The growth of the three soybean cultivars sown 5 WACP were only slightly affected by the cassava intercrop, and seed yields were close to expected from the corresponding sole-cropped soybean. However, the growth of cassava was affected differently, with the least disturbance being caused by the early maturing Fiskeby V. The later maturing soybean cultivars were taller and occupied cassava interrow spaces for long time periods. This resulted in a long delay in the development of the cassava canopy, and consequently affected yield. Thus, tall soybean cultivars with long growing seasons are unsuitable for cassava intercropping. Soybean cultivars that mature slightly later than Fiskeby V, but with higher yield potential, appear to be ideal for intercropping with cassava in our environment. They should be sown within five weeks of cassava planting in the spring. Since the soybean cultivars currently available in southern Queensland are more suitable for summer planting, semi-dwarf, early maturing, photoperiod insensitive, and higher yielding cultivars are needed for cassava-soybean intercropping.

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Soybean in Rice-Based Farming Systems: The IRRI Experience

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Introduction

Soybean (Glycine max) is one of several upland crops that can be grown after rice (Oryza sativa). China, Indonesia, Thailand, and India each grow large areas of soybean after one or two rice crops. In dryland areas, wet season rice is generally followed by soybean or other upland crops during the dry season, either as a monocrop or as an intercrop. Soybean is also grown in rice-upland crop-upland crop cropping patterns. In rainfed rice areas, where water is a limiting factor, soybean can be grown after one rice crop.

In the early 1970s IRRI began to study rice intercropping with soybean and corn (Zea mays). With an expansion of the program in 1974, the potential of soybean as an upland crop after puddled rice was also researched. Present studies concentrate on the identification of better soybean cultivars, optimum plant populations, inoculation and fertilization practices, establishment techniques after rice, intercropping, and drought and water-logging tolerance.

A network of farming systems research sites provides a means for IRRI and national programs to generate farming systems technology for different rice environments and for different crops (soybean, corn, peanut (Arachis hypogaea), mungbean (Vigna radiata), cowpea (V. unguiculata), sweet potato (Ipomoea batatas), and sorghum (Sorghum vulgare)). Collaborative research includes the testing of cropping patterns, upland crop cultivars, long-term cropping patterns, fertilizer regimens, and farm implements.

Cropping systems research is divided into two components: Research conducted at IRRI and research that takes place in farmers' fields. IRRI research concentrates on component technology problems associated with crop intensification for rainfed, irrigated, and dryland rice areas. Potential cropping systems are also studied.

On-farm research focuses on developing and refining farming systems research methodologies. This process directly involves the farmer in such a way that he or she is, in essence, a member of the research team. The methodology used in the Network involves several steps, i.e. the selection of target areas, selection of farming system sites representative of target areas, description of the farming system site, cropping pattern design, cropping pattern testing, multilocational testing, pilot production programs, and production programs. A research team composed of an agronomist, economist, and a crop protection specialist lives at or near the testing site.

There were 108 sites in ten Asian countries as of 1982 (Table 1). The sites represent a range of climatic zones, soil types, soil textures, and socioeconomic conditions. The Philippines, Sri Lanka, Indonesia and Nepal are implementing the multilocational and pilot production phases of the methodologies developed thus far.

Table 1. Number of cropping systems research sites in collaborating countries, 1982.

Country	No. of Sites	Rainfed Wetland	Partially Irrigated	Irrigated	Rainfed Dryland	Deep Water
Philippines	23	15	1	6	14	-
Bangladesh	25	14	2	10	-	2
Indonesia	21	6	-	-	16	1
Burma	7	2	4	2	-	-
Nepal	6	5	2	1	-	-
Sri Lanka	7	3	1	1	-	-
Thailand	7	7	-	1	-	-
Korea	9	-	-	9	-	-
India	1	-	-	-	1	-
China	2	-	-	2	-	-
Total	108	52	10	32	31	3

Cropping Pattern Testing

In 1982, 31 sites, representing the major rice growing environments in Asia, were involved in cropping pattern testing. Testing is conducted under a variety of conditions: Rainfed wetland, partially irrigated, irrigated, rainfed dryland, and deep water. The focus in almost all cases is to increase production, net income, and cropping intensity. Cropping patterns involving soybean have been tested at four sites: Batangas, Iloilo, Phrae, and Indramayu.

Batangas, Philippines

IRRI's first cropping systems research site was located at Cale, an upland rice area in Batangas Province. Work started in 1974 and was completed in 1978.

Farmers practice intensive cropping in this area, and their cropping patterns are complex (162 patterns were identified during the study period). Upland rice and corn are grown by 90% of the farmers; most farmers also grow vegetables. The site is subject to five or six wet months and two dry months. Farm size ranges from 0.9 to 3.0 ha, with an average of 0.93 ha. The soil is a well drained mollisol (pH 4.9 to 6.2).

Research concentrated on testing alternatives to field corn. Soybean, sorghum, peanut, sweet potato, mungbean, and cowpea were tested after upland rice. The yield levels of cowpea, mungbean, and soybean were low in 1974-75 because of insect problems. Two soybean cultivars were studied; TK-5 yielded 1.0 t/ha and Multivar 80 produced only 0.2 t/ha. Net returns, above the variable cost of soybean in the rice-soybean pattern, was US $143 for TK-5 and (-) US $86 for Multivar 80. The net returns for TK-5 were better than those obtained with corn (US $119). Rice-soybean was re-tested the following year under three cropping patterns. Because of high management costs, net returns, over variable cost, was (-)US $502. TK-5 yielded only 0.67 t/ha. In the third year soybean was tested following rice + field corn intercropping. Soybean produced only 0.40 t/ha. The highest net return, above variable cost, was US $1,845 in the rice + corn-peanut cropping pattern. The rice + corn-soybean pattern produced net returns of US $298 above variable costs. Soybean was dropped from the testing program the following year.

Oton and Tigbauan, Philippines

Cropping systems research at Oton and Tigbauan, Iloilo Province, was conducted in collaboration with the Philippine Bureau of Plant Industry from 1975 to

1980. These locations represent rainfed rice areas that are subject to five or six consecutive wet and two to four dry months. Farm size is about 1.4 ha.

Research focused on increasing production and cropping intensity. Rice-rice-rice, rice-rice, rice-rice-upland crops, and rice-upland crops farming systems were tested in farmers' fields using early maturing cultivars. Mungbean, sorghum, peanut, cowpea, soybean, and sweet potato were tested after the first rice crop. Cowpea and mungbean were tested after two rice crops. The yield of the upland crops were generally low. The rice-rice pattern produced about the same net income, over variable cost, compared with rice-upland crops (including soybean, sorghum, cowpea). The rice-rice-rice pattern showed better net returns than the rice-rice-upland crops pattern (including cowpea, soybean, bush sitao [Vigna sesquipedalis], and sorghum). Soybean yields were very low.

Indramayu, Indonesia

The research site at Indramayu is divided into three categories: Ten, seven, and five months of irrigation. Work was conducted from 1975-79 in collaboration with the Central Research Institute for Agriculture, Bogor.

In West Java, two rice crops are usually grown at locations with access to 10 months of irrigation; one rice crop is grown at locations with five to seven months of irrigation.

Rice yields in the two improved patterns, IR28-IR30-soybean and IR28-IR34-cowpea were higher than in the farmers' cropping pattern (Pelita-C4) and in the farmers' cropping pattern without constraints (Pelita-IR26) with seven months of irrigation. The highest net income was obtained from IR28-IR30-soybean (US $989), which was 43% higher than the farmers' traditional cropping pattern or the farmers' cropping pattern without constraints. The two early maturing rice crops, followed by a legume (cowpea or soybean) proved to be promising patterns for the 7-month irrigation scheme. In the 5-month irrigation pattern, cowpea was grown after two rice crops because of its drought tolerance.

In the third year the research team evaluated the improved pattern (rice-rice-soybean) in all categories involving 3 ha of contiguous farm land in three categories (6 farmers/10 months irrigation, 8 farmers/7 months irrigation, and 12 farmers/5 months irrigation). The average yield of the two rice crops was 12.6 t/ha in the 10-month irrigation pattern, 12 t/ha in the 7-month pattern, and 10.2 t/ha in the 5-month pattern. The third soybean crop was affected by heavy rain. Only 1 ha was harvested in the 10-month pattern (0.9 t/ha) and 1.6 ha in the 7-month pattern (1.2 t/ha); no soybean was planted in the 5-month pattern.

Phrae, Thailand

Phrae is a partially irrigated rice area. IRRI, in collaboration with the Thailand Department of Agriculture, began working at the site in 1980. Farmers traditionally grow glutinous rice in July-December and tobacco (Nicotiana tabacum), soybean, or mungbean from late December until March. Average farm size is 1.5 ha with 1 ha for paddy rice, 0.2 ha for field crops, and 0.3 ha for other crops. The cropping patterns tested in 1980-81 were sweet corn-glutinous rice-peanut, mungbean-glutinous rice-soybean, mungbean-glutinous rice-sweet corn, and rice-rice (early maturing, glutinous rice). Soybean and mungbean yields in the mungbean-glutinous rice-soybean pattern were 0.8 t/ha and 0.7 t/ha, respectively. Net income over the variable cost of mungbean-glutinous rice-soybean (US $652) was the same as sweet corn-rice-peanut (US $645), and higher than rice-rice (US $172) and mungbean-glutinous rice-sweet corn (US $322).

The following year corn-rice-mungbean, mungbean-rice-soybean, and sesame (Sesamum indicum)-rice-soybean were tested. The first crop was destroyed by

flooding. Rice yields were about 4 t/ha and soybean yields were 0.6 t/ha in the mungbean-rice-soybean pattern and 0.6 t/ha in the sesame-rice-soybean pattern.

Soybean Establishment After Flooded Rice

One of the major problems identified in terms of crop intensification in rainfed, wetland rice areas is the establishment of upland crops after puddled rice. Puddling breaks down soil aggregates into particles and increases bulk density, which in turn leads to compacting and hardening when the soil dries. Growing upland crops on residual moisture after rice is not advisable because of drought risk. Soybean is one of the upland crops that IRRI recommends for production after rice. In Indonesia farmers broadcast local soybean cultivars just before harvesting puddled rice (relay). Yield levels are generally low because of poor stands and low-levels of management. Soybean is also grown after rice in northern Thailand, but Thai farmers prepare the land, make beds, and irrigate the crop.

Experiments at IRRI compared the effects of several cultural practices on soybean establishment under rainfed conditions (Syarifuddin and Zandstra 1978). Puddled rice fields were drained 21, 11, and 1 day(s) before the rice harvest. After the harvest, soybean seeds were dibbled in five different tillage treatments: No-tillage, furrow-tillage, bed-tillage, one rotovation, and three rotovations. The highest grain yield was recorded in the one rotovation treatment (Table 2). The mean yield in the zero-tillage treatment was only 8% less than in the one rotovation treatment. Soybean yields were higher when grown in fields drained one day before the rice harvest. Lower yields were obtained when the fields were drained 21 days before the rice harvest.

In another experiment drill-relay planting, no-tillage, furrow-tillage, and one rotovation were evaluated together with mulching (Syarifuddin and Zandstra 1978). One rotovation and zero-tillage produced higher soybean yields compared with the other planting methods. Mulching increased soybean yields in the drill-relay, furrow-tillage, and one rotovation treatments (Table 3).

Table 2. Grain yield (t/ha) of soybean as influenced by tillage and drainage prior to harvest of the previous rice crop.

Tillage for Soybean	Number of Days from Drainage to Rice Harvest			Mean[z]
	21	11 (control)	1	
No tillage (control)	1.00 ab	1.15 a	1.24 b	1.13 b
Furrow tillage	0.46 c	0.47 c	0.55 d	0.49 e
Bed tillage	0.53 c	0.61 c	0.63 d	0.59 d
One rotovation	1.09 a	1.19 a	1.39 a	1.23 a
Three rotovations	0.90 b	0.88 b	1.07 c	0.95 c
Means[y]	0.80 ns	0.86	0.98[y]	

[z] Means followed by a common letter are not significantly different at the 5% level by DMRT
[y] significant at the 5% level by LSD
Source: Syarifuddin and Zandstra (1978)

Broadcasting soybean into a standing rice crop two to four days before harvesting is a common practice in Java, mainly because of its simplicity and low expense. Stands, however, are generally poor and yields are low. Soybean stands increased slightly when seed were drilled between rice rows instead of broadcast (Syarifuddin and Zandstra 1978). Soaking the seeds before planting and increasing the seeding rate also increased stands (Table 4). Soybean yields were higher when the seeds were drilled, but this method proved impractical in our studies. A combination of broadcasting, soaking, and increasing the seeding rate proved to be more acceptable to farmers.

Table 3. Grain yield of soybean as influenced by planting methods and mulching.

Method	Grain Yield[z] (t/ha)
Drill-relay planting	
No mulch	0.52 d
Mulch	1.08 c
No tillage-sequential planting	
No mulch	1.37 b
Mulch	1.89 a
Furrow tillage-sequential planting	
No mulch	0.37 e
Mulch	0.27 e
One rotovation-sequential planting	
No mulch	1.63 ab
Mulch	1.96 a

[z] Means followed by a common letter are not significantly different at the 5% level by DMRT

Table 4. Soybean stands at 10 DAS and 2 DBH, and yield of soybean relay-planted into puddled, flooded rice as influenced by seeding method, seed soaking, and seeding rates (IRRI 1978 dry season).

Seeding Methods and Seeding Rates	Stand (plants/m^2)		Expected Stand (plants/m^2)	Mean Yield (t/ha)
	10 DAS	2 DBH		
Broadcast, unsoaked				
60 kg/ha	43 g[z]	42 g	60	1.31 f
120 kg/ha	61 cd	61 cd	120	2.12 bc
Broadcast, soaked				
60 kg/ha	48 f	47 f	60	1.55 e
120 kg/ha	65 bc	64 bc	120	2.24 b
Drill, unsoaked				
60 kg/ha	53 d	53 d	60	1.77 c
120 kg/ha	68 b	67 d	120	2.24 b
Drill, soaked				
60 kg/ha	58 e	58 e	60	2.02 c
120 kg/ha	88 a	88 a	120	2.61 a

[z] Means followed by a commmon letter are not significantly different at the 5% level
DAS = days after seeding
DBH = days before harvest

Comparison of Soybean and Other Legumes

Water-Logging

Upland crops sown after wetland rice usually suffer from excessive moisture during the early growth stages. Because of early maturing rice cultivars, farmers can now plant upland crops earlier in rainfed, wetland areas. However, the flooding hazard for upland crops is greater because of unpredictable weather conditions. Upland crops planted before rice also have moisture problems, especially during the vegetative stage of development.

Two experiments were conducted at IRRI to evaluate the response of corn, sorghum, soybean, mungbean, and peanut to excessive moisture (Herrera and Zandstra 1979). In the first experiment crops were subjected to flooding (five treatments) (complete soil saturation for seven days) at different growth stages. The second experiment involved corn and soybean. Treatments included two growth stages and the duration of flooding (4, 8, and 12 days).

The yields of soybean, peanut, and mungbean were reduced by 37, 56, and 49%, respectively, when flooding occurred 30 days after sowing (DAS)(Fig. 1). Yield reductions were more severe when flooding occurred 15 DAS and during the pod filling stage. Soybean and mungbean yields were reduced by only 25 and 27% when flooding occurred at the pod filling stage; peanut yields were reduced by 66%. Corn and sorghum were not affected by flooding during this period but all crops were stunted when flooded during the vegetative stage.

Water Stress

In rice-based cropping systems rice is generally grown during the rainy season and food legumes are grown with residual moisture during the dry season. In some instances food legumes are grown before rice. Legumes generally suffer from drought during the vegetative stage when grown before rice and during the reproductive stage when grown after rice. An experiment was conducted to compare the response of mungbean, cowpea, peanut, and soybean to water stress (Pandey, Herrera, Villegas, and Pendleton 1983). A line source sprinkler irrigation system was used. The yield of all four crops decreased as the degree of moisture stress increased. Mungbean yield was reduced by 83%, soybean by 66%, and cowpea by 65%. Peanut showed somewhat greater drought tolerance (46% reduction). Pods/m^2 was the most sensitive yield component; seeds/pod and seed weight were less affected.

Mungbean and Soybean Population Study

An experiment was conducted in which the performance of early maturing soybean and mungbean cultivars were compared in order to determine if early maturing soybean would be a profitable alternative to mungbean in rice-based cropping patterns (Furoc and Pendleton 1983). An AVRDC dwarf soybean line (G-2261) that is early maturing and high yielding was compared with two mungbean cultivars, Pagasa 1 (recommended in the Philippines and Korea) and VC 1647-B, an AVRDC line. UPL SY-2, a recommended soybean cultivar in the Philippines was also tested.

G-2261 significantly outyielded UPL SY-2 during the dry and wet season (Table 5). Mungbean yields were significantly lower than soybean yields. Increasing the plant density of G-2261 significantly increased yield. Yields were not significantly different when the crops were grown at constant plant densities in 25 cm and 50 cm row widths. G-2261's rate of maturity was about the same during the two seasons, whereas mungbean matured earlier during the wet

season. Although soybean yields were higher, mungbean produced higher economic returns because of higher market prices.

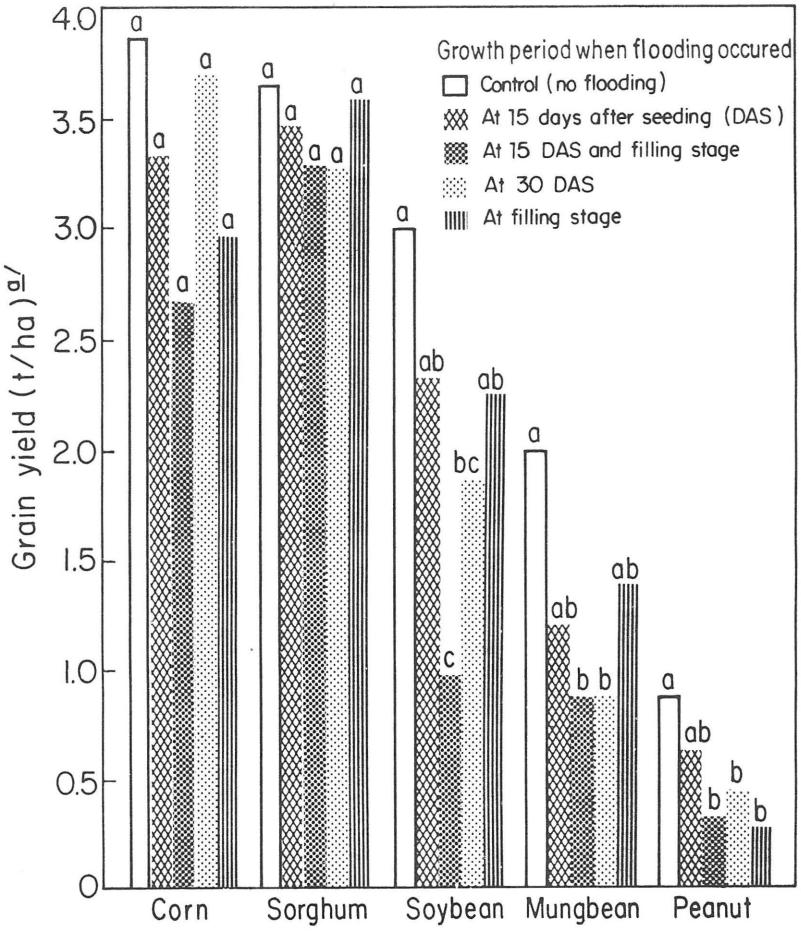

Fig. 1. Effect of flooding (one week) at different growth periods on the grain yields of five upland crops, IRRI, 1977.

[a] In each crop, bars with a common letter are not significantly different at the 5% level by DMRT.

Table 5. Yields and other characteristics of mungbean and soybean as influenced by row spacing and plant density, IRRI dry and wet seasons 1982.

Treatments	Spacing Between Rows (cm)	Population (plants/ha)	Dry Season		Wet Season	
			yield (t/ha)	days to maturity	yield (t/ha)	days to maturity
Pagasa I	50	300,000	1.89	71	0.34	65
VC-1647 B	50	300,000	2.06	71	0.16	65
UPL SY-2	50	300,000	2.29	76	0.92	79
G-2261	50	300,000	2.43	72	1.17	73
G-2261	25	300,000	2.65	72	1.25	73
G-2261	25	600,000	2.75	72	1.37	73

Source: Furoc and Pendleton (1982)

Varietal Evaluation of Soybean After Rice

Another Network responsibility is to conduct varietal testing of upland crops grown before and after rice. The Institute of Plant Breeding (IPB), University of the Philippines at Los Banos, is responsible for breeding upland crops (soybean, peanut, and mungbean) for rice-based farming systems. Genetic materials from international centers such as ICRISAT, IITA, and AVRDC are tested by IPB.

Mungbean is screened before rice, while soybean and peanut are screened after rice. The most promising lines and cultivars are sent to IRRI for seed increase and testing. In the past we conducted one or two trials per country. The program was expanded in 1982, and we now provide as many trials as national programs request. In 1983-84 we distributed 12 pre-rice soybean trials to Nepal, Thailand, Vietnam, China, and, Indonesia, and 25 post-rice trials to Indonesia, Thailand, Vietnam, Sri Lanka, Bangladesh, Burma, China, Nepal, and the Philippines.

Soybean varietal testing is conducted in the Philippines at the IRRI cropping systems sites at Oton, Manaoag, Tanauan, Solana, and at the IRRI farm. Trials are conducted without irrigation after rice, with or without tillage. Fertilizer rates and management practices are the same as those recommended in the cropping pattern trials. Soybean yield levels are generally low when grown on residual moisture after rice. In 1978-79, cultivars GC 30290-11-11 (AVRDC), Clark 63, UPL SY-2 (IPB), and GC 30047-2-36 (AVRDC) were the most promising lines tested at four locations (Table 6); UPL SY-2, GC 30047-2-36, and Clark 63 were the best lines in the 1979-80 trials. The most promising entries in 1981-82 (at Solana, Cagayan, and IRRI) were 7207-1 (Thailand), UPL SY-2, and Clark 63 (Table 7). New entries were also included in the 1983 dry season trials. GC 50106-4-7 (AVRDC) and Guntur (Indonesia) were the most promising entries tested (Table 8).

Table 6. Grain yield (t/ha) of soybean evaluated after rice, 1978-80 dry season.

Yield Rank	Cultivar	1978 - 1979				1979 - 1980					Average Yield (t/ha)	Days to Maturity
		IRRI	Iloilo	Pangasinan	Batangas	Camarines Sur	Pangasinan	Pangasinan	IRRI	Iloilo		
1	Clark 63	1.50	0.49	0.82	1.05	2.34	0.41	0.22	0.44	0.38	0.85	79
2	UPL SY-2	1.30	0.45	0.57	1.05	2.24	0.52	0.32	0.38	0.43	0.81	79
3	GC 30047-2-36	1.42	0.38	0.51	0.73	1.65	0.74	0.43	-	0.33	0.77	79
4	2120	-	-	-	-	0.55	1.00	1.21	-	0.23	0.75	83
5	Orba	1.17	0.38	0.45	1.13	1.12	0.75	0.56	-	0.32	0.74	79
6	GC 30299-8	1.17	0.67	0.38	0.82	1.32	0.72	0.38	-	0.33	0.72	83
7	GC 30293-6-10	1.29	0.34	0.29	0.83	1.67	0.63	0.35	-	0.29	0.71	82
8	GC 30290-11-11	2.01	0.48	0.47	0.99	-	0.57	0.34	0.41	0.28	0.69	82
9	GC 30050-2-17	1.39	0.42	0.33	0.97	1.17	0.49	0.31	0.38	0.37	0.65	78
10	TK 5	-	0.36	0.37	0.96	-	-	-	-	-	0.56	79
	Mean	1.41	0.40	0.47	0.95	1.51	0.65	0.64	0.40	0.35	0.73	80
	CV (%)	7	28	25	14	11	37	38	17	11		
	Tillage	Zero	Zero	Low	Zero	High	High	Zero	Zero	Zero		
	Total rainfall (mm)	201	217	0	336	864	592	592	130	300		

Intercropping Corn and Soybean

Asian farmers usually grow a solid stand of a short-statured crop and then grow a taller crop at varying populations and row spacings. The most popular tall crop for intercropping is corn; the most popular low-statured crops are mungbean, soybean, peanut, sweet potato, and rice. At IRRI, agronomic research on intercropping focuses on physiological studies, plant populations, varietal effects, timing of overlap periods, insect and weed management, and soil ferti-

lity. We have studied intercropping involving corn + peanut, corn + upland rice, corn + soybean, corn + sweet potato, and corn + cowpea. The corn + soybean intercrop can be grown as the first crop during the wet season or as the second crop during the dry season. It can also be grown after wetland rice provided there is sufficient water.

Table 7 Average grain yield (t/ha) and maturity of soybean cultivars evaluated after rice, 1980-1982 dry seasons.

Yield Rank	Cultivar	Yield (t/ha)				Average	
		IRRI		Cagayan		yield	days to
		80-81	81-82	80-81	81-82	(t/ha)	maturity
1	7207-1	1.84	1.79	0.59	0.13	1.09	87
2	UPL SY-2	1.60	1.28	0.76	0.53	1.05	81
3	Clark 63	1.93	0.94	1.06	0.14	1.02	83
4	GC 50106-4-7	2.22	1.15	0.52	0.11	1.00	87
5	Multivar 80	1.84	0.61	0.86	0.62	0.99	84
6	7024-2	1.44	1.13	0.86	0.51	0.99	86
7	11-4	2.46	0.98	0.29	0.09	0.96	87
8	7024-3	1.50	1.14	1.01	0.10	0.94	86
9	GC 30290-11-11	1.76	1.05	0.63	0.07	0.88	85
10	GC 30050-2-17	1.58	0.72	0.70	0.39	0.85	85
	Average	1.82	1.08	0.73	0.27	0.98	85
	CV	21	19	15	39	-	-
	Tillage	Zero	Zero	Zero	Low		
	Total rainfall (mm)	435	129	6	128		

Table 8. Yield and other agronomic characteristics of ten soybean cultivars evaluated after wetland rice under zero-tillage conditions, IRRI 1982-83 dry season.

Yield Rank	Cultivars	Yield (t/ha)	Days to Maturity	100-Seed Weight (g)
1	GC 50106-4-7	1.8 a	100	9.7 g
2	Guntur	1.6 b	77	10.3 fg
3	UPL SY-2	1.5 b	91	14.5 a
4	Lokon	1.4 bc	91	11.0 defg
5	7207-1	1.4 bc	91	13.2 ab
6	62261	1.4 bc	77	13.6 bc
7	11-4	1.4 bc	100	11.9 bcde
8	Clark 63	1.4 bc	91	12.4 bcd
9	GC 30050-2-17	1.2 c	100	11.3 cdef
10	GC 30290-11-11	0.9 d	91	10.5 efg
	Mean	1.4	91	11.7
	CV (%)	8.2	-	6.9

Means followed by a common letter are not significantly different at the 5% level by DMRT

Herrera and Harwood (1973) studied the effect of intercropping soybean with different corn populations. Corn cultivar Philippines DMR 2 and soybean cultivar Shih Shih were tested. Corn populations were 10,000, 20,000, 33,000, 40,000, 50,000, and 60,000 plants/ha. The soybean intercrop with corn did not affect corn yields up to 40,000 plants/ha. The yield response of different corn populations (60,000, 50,000, and 40,000) was the same with or without soybean, but soybean was significantly affected by the corn population. Soybean yields were

0.6 t/ha at 10,000 plants/ha, 0.4 t/ha at 40,000 plants/ha, and 0.3 t/ha at 60,000 plants/ha, compared with monocropped soybean (0.9 t/ha). The productivity of the intercrop combinations was higher than either the corn or soybean crop alone.

Studies on nitrogen response in a corn-soybean pattern were conducted by Liboon and Harwood (1975), using Philippine DMR 2 (corn) and Multivar 80 (soybean). Monocultured and intercropped corn were planted at 60,000 and 30,000 plants/ha, respectively; soybean was planted at 40,000 plants/ha. Two-thirds of all nitrogen fertilizer was applied to the corn crop and the remainder was applied to the soybean. Fertilizer rates were 0, 60, 120, 180, and 240 kg N/ha. Soybean alone showed little response to nitrogen (Table 9). Monocropped corn produced up to 60 kg/ha more with fertilizer. The highest LER was obtained without nitrogen. As nitrogen rates increased, corn yields increased and soybean yields decreased.

Table 9. Total dry matter of corn and soybean intercropped at varying nitrogen levels, IRRI March-June 1974.

Crop Combination	Grain Yield (t/ha)			LER
	corn	soybean	corn + soybean	
		Control		
Corn	10.3			
Soybean		3.8		
Corn + soybean[z]	7.0	3.4	10.4	1.57
Corn + soybean[y]	-	3.5	3.5	
		60 kg/ha N		
Corn	12.4			
Soybean		3.5		
Corn + soybean	12.6	2.7	15.3	1.68
Corn + soybean	-[z]	3.6	3.6	
		120 kg/ha N		
Corn	17.8			
Soybean		4.7		
Corn + soybean	12.6	2.7	15.3	1.28
Corn + soybean	-	4.4	4.4	
		180 kg/ha N		
Corn	20.8			
Soybean		4.3		
Corn + soybean	12.1	3.6	15.9	1.42
Corn + soybean	-	3.7	3.7	
		240 kg/ha N		
Corn	22.7			
Soybean		4.2		
Corn + soybean	11.4	3.0	14.4	1.21
Corn + soybean	-	4.6	4.6	

[z] Corn and soybean planted same time
[y] Corn planted 20 days after soybean
[z] no data on corn
Source: Liboon and Harwood (1975)

Shresthra (1982) studied the effects of varietal type, plant population canopy adjustment, time of corn harvest, and soybean population on the grain yield and associated agronomic characteristics of corn and soybean intercropping. He used two corn cultivars (Arun and Khumal Yellow), two harvest times (grain mature and green cob), two canopies (normal and detopped above the ear leaving one leaf 25 days after silking), two corn populations (26,666 ha and 53,333 ha), and two soybean populations (200,000 plants/ha and 266,666 plants/ha). Corn culture canopy adjustment and plant population affected soybean and corn grain yield. Soybean yields were significantly increased by the removal of the corn plants after the green cob harvest (0.9 t/ha) and detopping (0.8 t/ha). Soybean intercropped with Arun produced significantly higher yields than soybean intercropped with Khumal Yellow. Detopping 25 days after silking did not significantly decrease corn yields, but soybean yields were improved by 20%. Green cob harvesting, followed by the removal of the corn plant, increased soybean yield by 33% compared with corn grown to maturity.

Increasing the soybean population from 200,000 to 266,000 plants/ha decreased corn yields by 11% and increased the soybean yield by 14%. When the corn population increased from 26,666 to 53,333 plants/ha, corn yields increased by 69% while soybean yields decreased by 25%.

Soybean as Green Manure

An experiment was conducted at IRRI in which soybean was grown as a green manure to supplement the nitrogen requirements of corn (Pandey and Morris 1983). Three soybean rows were planted between the corn rows. The two outer soybean rows were incorporated as green manure 45 days after planting, and supplied the equivalent of 25 kg N/ha to the corn crop (Fig. 2). Soybean yields from the harvested rows were about 0.5 t/ha.

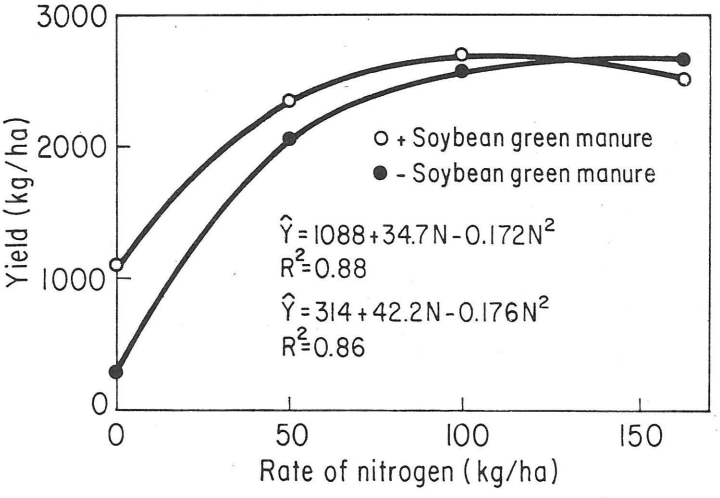

Fig. 2.
The effect of nitrogen application rate on corn with and without soybean green manure.

Long-term Fertilizer and Cropping Patterns

Long-term cropping pattern studies are presently underway at 18 irrigated rice locations, 4 rainfed locations, and 1 upland site. Soybean is studied at IRRI and in Burma and China. Crop residue management studies are conducted at Yezin in Burma using a TPR-corn-soybean cropping pattern. Six cropping patterns are studied in China's Zhejiang Province. Two involve soybean: Barley (Hordeum vulgare)-soybean-hybrid rice and rape seed (Brassica napus)-indica rice-soybean.

Ten dryland cropping patterns are being studied at IRRI, including rice-soybean, rice-corn-soybean, and rice-mungbean-soybean. There is a high fertility treatment (15-30-30 NPK kg/ha) and a low fertility treatment (no fertilizer) for each pattern. Soybean yields were very low in the 1982-83 rice-soybean-pattern: 0.6 t/ha with high fertility and 0.6 t/ha with low fertility. Soybean yield was also low in other cropping patterns: 0.2 t/ha for rice-mungbean-soybean (high fertility) and 0.1 t/ha for rice-corn-soybean (high fertility).

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Soybean Sole Cropping and Intercropping in Temperate and Subtropical Environments

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Introduction

Sole cropping describes a field situation where one crop is grown alone with normal management. Intercropping is defined as the planting of two or more crops simultaneously in the same field. There are many different types of intercropping, several of which are described in this paper.

Environment

A temperate climate can be characterized as "intermediate" in terms of the difference between the mean annual temperatures of a cold environment and that of a warm, subtropical environment. Average annual temperatures in a temperate zone are usually above 10°C, ranging from -20°C during the winter months to 24°C in the summer. Continental, temperate environments experience cold winters and warm summers, whereas oceanic, temperate climates experience little variation from season to season. Precipitation occurs throughout the year and usually ranges from 50 to 100 cm.

Subtropical environments are found between the temperate environments on the poleward side and the tropical environments on the margin. The poleward margin of the subtropics has a mean average temperature of 10°C for eight months. The tropical boundary of the zone has an average temperature of 18°C during the coolest month of the year.

There are two categories of subtropical environments. The subtropical-dry environment is usually found along the western side of continents where precipitation is concentrated during the winter season; the summers are quite dry. Precipitation generally averages from 40 to 80 cm annually, and temperatures range from 4°C to 27°C.

A subtropical-humid climate is generally found on the eastern side of continents. This environment receives more precipitation than the subtropical-dry, and rainfall occurs throughout the year, with some concentration in the warmer months. Annual precipitation ranges from 80 to 160 cm, and temperatures range from 4°C to 27°C, the same as the subtropical-dry.

Subtropical environments are generally located between 25 and 40 degrees latitude, but do not constitute a single belt around the earth.

Management

Soybean [*Glycine max*) planting is limited in the temperate zone because of cool temperatures at both ends of the growing season. Latitudinal belts of adaptation have been identified that allow soybean cultivars to be classifed into 13 maturity groups. Groups 000, 00, 0, I, II, and III are usually grown in temperate environments, whereas higher-numbered groups are adapted to subtropical and tropical environments.

Indeterminate soybean cultivars are widely grown in the temperate environments of the Americas. The recent development of adapted, semi-determinate and determinate cultivars have resulted in shorter plants that are less susceptible to lodging. These cultivars require proper management to produce maximum yields. Determinate cultivars produce seed pods near the soil surface which can be missed by harvesting equipment unless a special "floating header" is used. Low pods are less of a problem with semi-determinate and indeterminate cultivars. Narrow row-width (or drilled-) plantings are also becoming popular ways of increasing yields, but these planting patterns reduce the options available for weed control. Herbicides are commonly used in both wide and narrow rows, but mechanical cultivation is usually limited to wide row spacings.

Sole cropping is the predominant soybean management system used in temperate environments. Double cropping (growing two crops per year in sequence) is practiced to a limited extent along the equator margin of the zone. The length of the growing season is too short for more extensive use of double cropping. Relay intercropping (growing two or more crops simultaneously during part of the life cycle of each crop) and strip intercropping (growing two or more crops simultaneously in different strips) have greater potential than double-crop soybean production in temperate areas. However, these systems are not widely accepted by farmers. An example of relay intercropping in the north-central United States would be the planting of oats (Avena sativa) in early April, followed in May by the planting soybean in a field of standing oats. The oats are harvested in early July with minimal damage to the young soybean plants. The soybean remains in the field until maturity in October. Simultaneous crop production occurs from May until early July when the oats are maturing and the soybean is in the early stages of development. An example of strip intercropping is the growing of maize (Zea mays) in a 6 m-wide strip alternating throughout the field with a 6m-strip of soybean.

Sole-cropped soybean produces up to 5 t/ha on the farmers' fields in temperate environments and as much as 7 t/ha in research plots. State soybean yield averages in temperate areas of the United States usually range from 2 to 3 t/ha. These types of yields are mostly produced on large, mechanized farms. Commercial fertilizers are used as a source of phosphorus and potassium; nitrogen fertilization varies in terms of use and application.

Cool temperatures are seldom a constraint in subtropical environments, except at higher elevations. Warm temperatures during most of the year, combined with adequate solar radiation, permit flexibility in terms of crop scheduling. The growing season is largely determined by moisture availability. To fully utilize the flexibility available in planting dates, supplemental moisture is necessary during the summer in subtropical-dry environments and during the spring and fall in subtropical-humid environments. Classification of maturity groups, based on latitudinal belts of adaptation, is less common in subtropical environments. Maturity groups IV, V, VI, VII, VIII, and IX are frequently utilized. In subtropical environments, changes in photoperiod greatly influence phenological development. In this type of climate soybean usually performs best if its vegetative development occurs under longer photoperiods and if its seed development takes place under shorter days. If irrigation is not available, the growing period can be planned to coincide with a time when soil moisture is adequate.

Three soybean growing periods are available in the subtropical environments of South and Southeast Asia. Early spring planting provides an effective season of more than 130 days, whereas summer and fall plantings usually have less than 120-day seasons because of decreasing photoperiods and cooler temperatures. Farmers use different growth-type cultivars in these environments, but day-neutral cultivars have many advantages. The use of full-season cultivars for longer growing periods and short-season cultivars with higher plant densities for shorter growing periods is also advantageous.

Cropping systems in subtropical regions can be broadly categorized as maize-based and rice-based. Soybean is planted in various cropping patterns, including sole cropping following rice in the fall, intercropping with maize in the spring, and relay cropping in the summer with cotton or other summer crops. Diverse cropping patterns are feasible in the subtropics of South and Southeast Asia because of favorable environments and the adoption of labor intensive management practices. Although mechanization exists in certain areas, cultural practices are often carried out by hand. Two broad types of soybean production are prevalent in subtropical regions: a) areas where soybean is a traditional crop and b) areas where soybean is being introduced. Intercropping or relay cropping is common in the first category and sole cropping is being tried in the second.

Soybean productivity levels are generally low in Asia's subtropical regions compared with the temperate zones of the Americas. In farmers' fields, soybean yields usually average less than 1 t/ha when intercropped, but can produce as much as 1.5 t/ha when sole cropped. The crop is grown mostly on small landholdings with low-level management. Other reasons for low yields include the lack of adapted cultivars and management practices, high pest incidence, allocation of marginal lands for soybean production, and shorter growing periods. Recent research has shown potential for higher soybean yields in subtropical areas, but this potential has yet to be realized on farmers' fields.

Growth Types

Three types of soybean have been recognized as having production potential. Determinate types complete most of their vegetative growth before flowering begins. Their flowering period is relatively short, and the plants usually exhibit a terminal raceme that develops several pods.

Determinate types are common in the tropics and subtropics, but adapted, determinate types required a longer growing season than semideterminate and indeterminate types when grown in short-day environments. Recent breeding efforts have produced determinate cultivars that are adapted to the temperate environments of the north-central United States. Individual cultivars vary in their phenotypic characteristics, but are shorter in plant height than other growth types. A common problem associated with determinate cultivars is the height of the lowest pods and branches. If mechanical harvesting is used, the lower pods may be inadvertently left in the field. Moreover, determinate soybeans that are adapted to a given environment are usually shorter than other types and are therefore less prone to lodging. Lodging resistance is a desirable characteristic when the crop is grown under optimum conditions.

Semi-determinate growth types can be described as a combination of a determinate and an indeterminate type. The terminal raceme, height of the lowest pod, and plant height are intermediate. Relatively few cultivars are recognized as semi-determinate.

Indeterminate growth types are commonly grown in temperate environments. The flowering stage begins before the vegetative stage has been completed. Competition for photosynthates between pod development and vegetative growth results in smaller leaflets at the top of the plant. The terminal raceme on indeterminate plants is shorter and at times produces only one pod. Plant height is usually greater than that of determinate types, a fact which often results in lodging.

The use of a particular soybean growth type will depend on the length of the cropping season where it will be grown and the yield potential of the cultivar.

The yield potential of a late maturing cultivar is often sacrificed for a shorter season cultivar that will fit into a double- or triple-cropping sequence which has greater total yield potential. Double and triple cropping refers to planting two or three crops in sequence after the previous crop is harvested. When rainfall or temperature patterns allow for the production of only one crop per year, cultivars are usually selected that can utilize the entire growing season.

Farmers prefer that a soybean crop does not reduce the yield of their primary crop. For this reason non-aggressive soybean cultivars are usually preferred. For the same reason, short-duration cultivars with lower plant heights are preferred over long-duration, taller cultivars which compete with the primary crop.

Cropping System Evaluation

The comparative advantages of a cropping system can be calculated in a number of ways. The land equivalent ratio (LER), for example, is useful for comparing grain yield. LER is computed by determining the relative yield of each crop in an intercropping system with the yield of the sole crop. The relative yield of each crop in the system is then combined to calculate the LER according to the following formula:

$$LER = \frac{Ia}{Sa} + \frac{Ib}{Sb}$$

(I = intercrop yield; S = sole-crop yield; a and b = component crops)

LER values of 1.00 indicate that sole-crop and intercrop systems are equally efficient. Values of less than 1.00 mean that sole cropping is more efficient, while values greater than 1.00 indicate that intercropping is more efficient.

Other methods of evaluating the comparative advantages of cropping systems are based on the monetary value of a unit of yield for each crop. This system is useful if crop market values and input values do not change for the seasons or systems that are compared. However, the cost of inputs and the market value of the crops usually differ. Willey (1979) suggested the combined use of LER and crop values to evaluate the relative merits of different cropping systems according to the following formula: Monetary advantage = value of combined intercrop yield x LER - 1/LER.

Intercropping

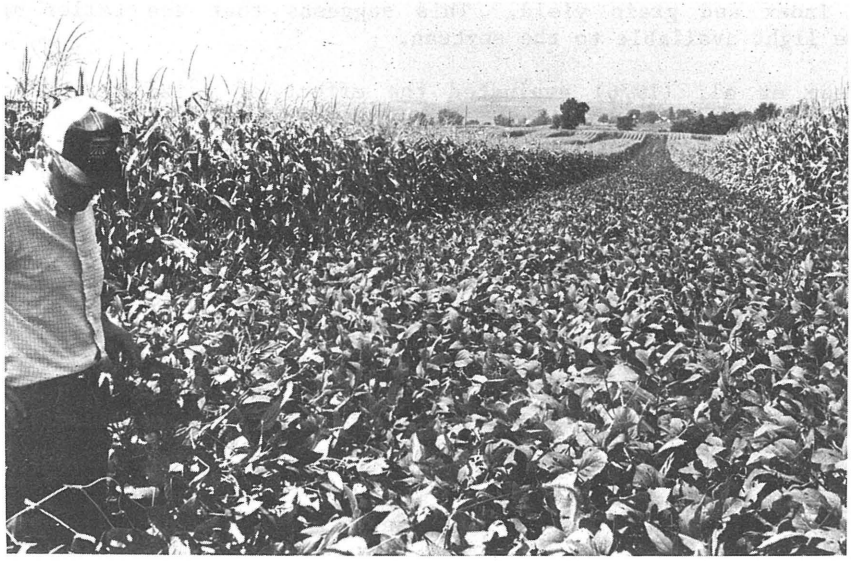
Multiple-cropping systems that include soybean are numerous, as are combinations of more than one multiple-cropping system and several species. In southern China soybean is intercropped with sweet potatoes (*Ipomoea batatas*) in the spring and summer, with rice (*Oryza sativa*) in the autumn, and with wheat (*Triticum aestivum*) in the winter (FAO 1980). This is an example of both intercropping and sequential cropping combined. Soybean grain yield in this system was reported to be 1.1 t/ha, which is about equal to China's national average. Total production from a single field per year is impressive considering that sweet potato, wheat, and rice production totaled 22.5, 2.3, and 6.0 t/ha, respectively. Examples of both more complex and simpler cropping systems involving soybean are found throughout the temperate and subtropical zones.

Research results indicate that sole cropping produces the highest soybean yields, and that yield reductions related to intercropping depend mostly upon the companion crop, the crop management practices used, and the environment in which the crops are grown.

Strip-Intercropping

Strip intercropping involves the simultaneous production of crops grown in strips wide enough for independent cultivation, but narrow enough for the crops to interact agronomically (Andrews and Kassam 1976).

Alexander and Genter (1962) reported that alternating pairs of soybean and maize rows resulted in an LER of 1.10. Soybean yields were about the same as those produced under sole cropping in 91 cm rows, but maize yields increased approximately 30% in an intercrop system. A 20% soybean yield decrease was offset by a 20% yield increase in maize when four- and six-row strips were alternated (Pendleton et al. 1963). Both crops benefited from 61 cm-row spacings compared with 102 cm spacings. Row direction did not significantly affect the yield of either crop, but individual soybean rows adjacent to the maize yielded about 30% less than the sole-cropped soybean. Crookston and Hill (1979) evaluated soybean and maize intercropping in alternating rows and alternating strips of 3, 6, and 12 rows. The reduction in soybean yields and the increase in maize yields resulted in LER values ranging from 0.97 to 1.01, i.e. no advantage for intercropping.



Strip intercropping of soybean and maize in the USA at mid-season

When soybean and maize were planted in the same row, soybean yield was reduced 87% compared with sole cropping (Chui and R. Shibles, Iowa State University, unpub.). The reduction was primarily due to reduced plant growth and pod set. The rate of soybean development was unaffected, but intercropping delayed maize tasseling and silking. The planting of two or three maize plants per hill opened up the canopy and allowed more light to reach the soybean. The open canopy resulted in less soybean lodging, more growth, higher pod set, and greater yield.

Finlay (1975) showed the effect that soybean has on maize and sorghum (Sorghum bicolor) intercropped in different row systems (Table 1). When soybean and maize were grown in the same row, soybean and maize yields were reduced by 39% and 92%, respectively, compared with the sole-cropping treatments (LER 1.31). When the soybean and maize rows were alternated, soybean yield improved by 66% but maize decreased by 64% (LER 1.30).

Table 1. Effect of intercropped soybean on maize and sorghum.

Crop	System	Grain Yield (t/ha) cereal	soybean	LER
Soybean	Sole		1.8	1.00
Maize	Sole	5.7		1.00
Sorghum	Sole	3.9		1.00
Soybean + maize	Same row	5.2	0.7	1.31
Soybean + maize	Alternate rows	3.6	1.2	1.30
Soybean + maize	Alternate pair rows	3.1	0.9	1.05
Soybean + sorghum	Same row	3.2	0.6	1.15
Soybean + sorghum	Alternate rows	2.5	0.8	1.08
Soybean + sorghum	Alternate pair rows	2.4	0.8	1.08

Adapted from Finlay (1975)

Dalal (1977) noted that soybean yields were severely reduced in each of the intercropping patterns studied. However, maize yields were only reduced when soybean was planted in the same row. A correlation was found between soybean leaf area index and grain yield. This suggests that the taller maize crop reduced the light available to the soybean.

Thompson et al. (1976) evaluated the effect of maize height on soybean growth and yield when the two crops were intercropped. Soybean yield was 17% greater when grown with short maize than with tall maize. Days to flowering and the physiological maturity of soybean were unaffected by the different maize plant heights. However, the number of pods per soybean plant were reduced by the taller maize.

Reduction in soybean grain yield was attributed to shading when maize and soybean were strip intercropped, principally because of decreases in the number of branches and pods per plant (Srivastava et al. 1980). Roquib et al. (1973) reported yield reductions in each case where soybean was intercropped with several different crops. The height of the companion crop determined the amount of yield reduction. The planting of maize and pigeon pea (Cajanus cajan) produced yield reductions of 68% and 21%, respectively, whereas rice and groundnut (Arachis hypogaea) reduced soybean yield by only 3% and 7%, respectively. Grain yield reduction was attributed primarily to the height of the companion crop and to fewer pod-bearing nodes and pods per plant.

Soybean yields were reduced by 17% and 75% when intercropped with two different sorghum cultivars (Wahua and Miller 1978); LER's were 1.08 and 1.11, respectively. The relative yields of soybean were 24.3 and 82.0%, whereas the relative yield of the two sorghum cultivars was 86.3% and 26%, respectively. Soybean yield reduction was attributed primarily to lower pod number.

In northern India, Mohta and De (1980) found that maize yields were unaffected by intercropping with soybean, whereas sorghum yields were reduced. LERs of 1.31 and 1.48 were produced by intercropping soybean with sorghum and maize, respectively. The sorghum rows were planted 90 cm apart and were intercropped with one row of soybean, whereas the maize rows were 120 cm apart and were intercropped with two rows of soybean. When soybean and sorghum were planted on the same date, the soybean developed rapidly but suppressed the development of the sorghum.

Research in Iraq has shown that two rows of soybean alternated with two rows of maize (2:2) resulted in higher soybean grain yield than two rows of maize and

one row of soybean (2:1) (Ibrahim et al. 1977). Soybean plant height was not influenced by maize density, soybean density, or by intercropping. The 2:2 intercropping system resulted in earlier flowering than the 2:1 system.

When soybean was intercropped with cassava (Manihot esculenta), LER values increased as the number of intercropped soybean rows increased (Table 2) (Na-Lampang 1982). Increased soybean plant density resulted in greater soybean yields, and adding rows of soybean resulted in a progressive yield reduction of cassava due to increased competition. Cassava yield was also reduced by competition when cassava planting was delayed 20 or 40 days after soybean planting.

A tall crop may be strip intercropped to protect a short crop from wind damage. Maize rows planted perpendicular to prevailing winds effectively sheltered soybean in the central United States (Radke and Hagstrom 1976). Two maize rows planted at intervals of ten times the effective height of the maize resulted in slightly taller soybean compared with unsheltered soybean. Shading and root competition by the maize resulted in lower dry matter accumulation in soybean planted adjacent to the temporary wind barrier. Soybean grain yield was increased when the crop was sheltered (Table 3). Yield increases were attributed to a reduction in transpiration. LER values varied from year to year, but strip intercropping proved to have an advantage over other systems. Maize grown with temporary wind barriers usually yielded less than sole-cropped maize, but increased plant population and additional fertilizer may increase yield potential.

Table 2. Effect of soybean row number on soybean and cassava yield.

Row Pattern	Yield (t/ha)		LER
	soybean	cassava	
Sole	1.50[z]	28.86	1.00
C-S-C[y]	0.66	23.57	1.26
C-S-S-C	0.79	22.82	1.32
C-S-C-S-S-C	1.07	20.96	1.45

[z] Sole crop soybean not included in the experiment, but assumed to be 1.5 t/ha
[y] C = cassava row; S = soybean row
Adapted from Na-Lampang (1982)

Table 3. Soybean yields as affected by maize wind barriers.

Year	Yield (t/ha)		LER
	sheltered area	unsheltered area	
1964	1.3	1.1	1.16
1965	1.4	1.3	1.06
1966	0.9	0.7	1.19
1968	2.0	1.8	1.11
1969	1.2	1.1	1.05

Soybean cultivar was the same in each year; the maize barrier consisted of two rows spaced 13.3 m the first three years and 11.4 m apart in 1968 and 1969
Adapted from Radke and Hagstrom (1976)

Finlay (1975) found that intercropped soybean cultivars responded differently than sole-cropped soybean. An evaluation of 12 cultivars indicated that high yields under sole cropping may not be a good indicator of yield under intercropping. Changing the companion crop also seemed to alter the rank of soybean cultivar performance. A maize companion crop resulted in a similar yield ranking of soybean cultivars, as did sole cropping. Sorghum and bulrush millet (Pennisetum americanum) as companion crops altered the cultivar yield rankings from the maize rankings. Cultivar selection may therefore be critical to the success of an intercropping system.

Relay-Intercropping

Relay intercropping involves the production of two or more crops simultaneously during part of the life cycle of each crop (Andrews and Kassam 1976). In temperate environments, relay intercropping allows the producer to harvest more than one crop per growing season. A cool-season cereal crop is often planted in the fall or early spring, and soybean is then interseeded into the standing cereal crop prior to the heading stage. The soybean germinates and slowly develops before the cereal crop is harvested in the early summer; the soybean can then develop in the field without competition. Aerial seeding of soybean into the cereal crop frequently results in poor stand establishment and has been abandoned in most areas. Machinery has been developed for direct inter-seeding of soybean without severe physical damage to the cereal crop.

In the midwestern USA, relay-intercropped wheat and soybean produced 70 and 80% of the total yield of the same crops grown as sole crops (Jeffers and Triplett 1978). When the same crops were double-cropped (two crops grown in sequence in the same year) wheat yield was 100% of the sole crop and soybean yield was 60% of the sole crop. Planting time for soybean was critical; early planting resulted in poor emergence and lower yields. Late planting resulted in greater physical damage to the wheat and lower yields for both crops. Increased seeding rates for soybean are recommended to compensate for low stand establishment.

Relay intercropping of soybean and oats in the USA

Chan et al. (1980) found that inter-seeding soybean into oats and wheat had no significant effect on the cereal crops' grain yield. Intercropped soybean was shorter in height and yielded less than sole-crop soybean. Favorable LERs were produced when relay intercropping was practiced (Table 4). McBroom et al. (1981) evaluated 14 soybean cultivars in relay-intercropping systems with oats and wheat. Their results showed that the relay-intercropped soybean yielded less, was shorter, and lodged less than soybean grown as a sole crop. However, they did not find evidence of a genotype x cropping system interaction for grain yield. Based on this study there is no evidence to indicate the need for a separate soybean breeding program for relay intercropping, but further study is needed to evaluate more diverse soybean germplasm.

The success of relay intercropping depends on timely management and conducive climatic conditions. Researchers have reported different optimum planting times for relay-intercropped soybean planted with cool-season cereal crops. However, most scientists agree that soybean planting should be timed to avoid physical damage to the companion crop. This usually means planting soybean before the cereal crop has headed. Planting soybean into a standing crop may lead to increased competition for light, moisture, and nutrients. Early planting can also result in similar plant heights for both the cereal and soybean crops at the time that the cereal crop is harvested. Tall soybean plants may interfere with the cereal crop harvest and may be damaged during the harvesting process. After pruning, the vegetative growth of indeterminate soybean cultivars will be retarded, but the crop may recover if environmental conditions are favorable. The vegetative growth of determinate cultivars would probably be retarded after pruning if the crop had already reached the flowering stage.

Table 4. Effect of soybean on cool-season cereal crops grown under relay-intercropping.

Year	Grain Yield (t/ha)				LER
	sole crop		relay intercrop		
	wheat	soybean	wheat	soybean	
1976	2.5	2.8	2.8	1.0	1.48
	oats	soybean	oats	soybean	
1976	4.4	2.9	4.0	2.0	1.60
1977	3.2	3.6	3.2	1.8	1.50

Results from 41 cm row spacings and the earliest planting date each year
Adapted from Chan et al. (1980)

Sequential Cropping

Sequential cropping can occur in the form of double, triple, quadruple, or ratoon cropping. Ratoon cropping of soybean has not been successful, but other forms of sequential cropping can be used with soybean. The selection of an appropriate system depends upon the length of the growing season and the duration of the crops planted. Many techniques have been used to squeeze another crop into a season. Transplanting, early harvesting, no-tillage, creating moisture stress, and the selection of short-season cultivars are common techniques.

Under a sequential-cropping system, soybean grain yield does not differ greatly from the yields of sole crops grown under similar management. However, planting soybean at the optimum time is not always possible in a sequential-cropping system. Photoperiod, season length, moisture availability, and temper-

ature may differ. Different seasonal conditions will also affect soybean yield. Cultivar selection for sequential cropping does not differ from cultivar selection for sole cropping if conditions are equal.

The success of sequential cropping depends on the length of time between the harvest of the first crop and the planting of the next. If moisture and temperature are not limiting factors, a short interruption between crops is usually preferred. Intensive labor and machinery are used to plant the next crop; there is little idle land between sequences.

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Yield Stability of Sole-Crop and Intercrop Planting Systems

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Introduction

Most agricultural systems evolved as farmers learned to use the physical, social, and economic resources in their environment (Harwood 1976). Today's farming systems exist because of their proven superiority to less stable and productive systems. Unlike farming systems in the United States, where large tracts of land are farmed under one type of crop (mono or sole-cropping), small farm holdings in the tropics are planted to a mixture of crops. In developing countries individual security is the farmer's prime consideration. Farmers who operate under subsistence conditions use strategies that ensure minimum levels of system performance. It is because farmers' decisions are made in uncertainty that they regard security or risk minimization so seriously. Farmers are primarily concerned with the extremes, both favorable and unfavorable, which exist in their environment. For this reason they choose from one of a number of possible actions, i.e. farming system that will maximize an expected gain, provided that the possibility of ruin is slight or negligible (Boussard and Petit 1976). A low probability of loss and low expected loss values are prerequisites. Minimizing risks and achieving production stability are the factors that most affect the farmers' willingness to adopt new technologies (Biggs 1974, Boussard and Petit 1976, Perrin et al. 1976, Webster and Kennedy 1975).

The biological stability of an agro-ecosystem depends upon performance and persistence. Mixed-cropping provides species diversity (Holdridge 1959 and Igbozurike 1971), the system's major advantage over sole-cropping. Diversification tends to promote yield stability because all of the crops in a mixed-cropping culture are not likely to be equally affected by weather variations or pests. Surveys indicate that farmers consider yield stability and protection from crop failures as primary reasons for using mixed-cropping (Dickinson 1972, Flinn and Lagemann 1980, Jodha 1976, and Olukosi 1976). There is some empirical evidence that supports the belief that growing crops in mixtures reduces risks and increases yield stability. Mixed-cropping or intercropping can create a less favorable environment for insects. Researchers have demonstrated that the non-host plant can act as a habitat for insect predators (Crookston 1976 and Doutt and Nakata 1965). An interfering rowstrip (in an intercropping system) can act as a physical barrier to insects (Altieri et al. 1978, Gerard 1976, Satpathy et al. 1977, and Suryatna and Harwood 1976). Other studies have shown decreases in the spread of diseases as a result of mixed-cropping, further confirming the yield stability of the system (Koli 1975 and Shoyinka 1976).

Mixed-cropping also stabilizes grain yield by allowing one crop to compensate for the yield loss of another. In this case, yield losses are a result of species-specific insect or disease attack. This type of compensation is not possible if crops are grown separately.

The objective of the study reported here was to test the "risk-aversion hypothesis," often stated as a primary reason for mixed plantings under subsistence conditions. The hypothesis maintains that mixed plantings, intercrops, or random mixtures are less susceptible to the yield losses that result from adverse climatic or environmental conditions than are corresponding sole-crops. The measure used for testing the stability of a cropping system in this experiment was the ability of a crop to perform or yield well under adverse conditions. By subjecting a mixed crop of maize (Zea mays) and soybean (Glycine max) and corresponding sole-crops to simulated insect and disease defoliations, a measure of the relative degree of production stability was derived for each system.

Materials and Methods

The effect of differential defoliation on maize and soybean grown under both sole-crop and intercrop systems was studied in an experiment conducted in 1980 at the Agronomy South Farm of the University of Illinois at Urbana Champaign. A mid-season maize cultivar, FR 632 x FR 16, and soybean cultivar Williams 80 were each subjected to varying degrees of leaf removal at different times in the season.

A randomized block design consisting of treatments in a factorial combination of five levels of defoliation (0, 25, 50, 75, and 100%) at three dates (25, 45, and 60 days after seeding (DAS)) was used. Within each of the fifteen factorial treatment combinations (main plots), a split-split plot design was arranged. Subplots consisted of either sole-cropping or intercropping. Each sub-subplot specified the crop to be defoliated. There were three replications.

Maize was planted in rows spaced 50 cm apart (69,000 plants/ha sole-cropped and 23,000 plants/ha intercropped). Soybean rows were also spaced at 50 cm (354,000 plants/ha sole-cropped and 230,000 plants/ha intercropped). Plant arrangement within the intercrop were two rows of soybean to one row of maize. Planting was carried out on May 30, 1980 on a Drummer silty clay loam soil using a hand planter. Plots were harvested by hand from October 13 to 15, 1980. No nitrogen fertilizer was applied to the experimental area; the field had previously been planted to alfalfa. Weeds were controlled by hand. Insects and foliar diseases did not seriously affect crop growth or yield.

Leaf removal on the maize and soybean plants was carried out at various dates and stages of growth:

Date of Defoliation	DAS[z]	Maize Growth Stage	Soybean Growth Stage
25 June	25	8 LS[y]	V3
14 July	45	12 LS	R1
29 July	60	Tasselling (70%)	R2-R3

[z]Days after seeding
[y]Leaf stage

Percent removal (0, 25, 50, 75, and 100) was not precise and should be viewed as relative leaf area loss only. For the 50% leaf removal treatment, all leaves on one side of the plant (either maize or soybean) were removed. Adjustments were made accordingly for the other treatments. Yield losses due to defoliation were recorded, and relative comparisons of yield stability were made for the sole-crop and intercrop plantings.

Results and Discussion

Under both sole-crop stands of maize and soybean, defoliation treatments depressed grain yields in relation to severity and time of defoliation. The results obtained here (Tables 1 and 2) are in general agreement with earlier studies on defoliation for both crops (Allison et al. 1975, Crookston 1976, Enyi 1975, Fehr et al. 1977, Hanway 1969, Hinson et al. 1978, Kalton et al. 1949, Kiesselbach and Lyness 1945, Pinter and Kalman 1979, and Turnipseed 1972). Yield reductions followed a negative linear trend with respect to rate and time of defoliation. Exceptions were observed for maize defoliated at the earliest date, the 8-leaf stage, and when maize was defoliated at the 25% rate for all dates. In these cases a yield increase of up to 9% was observed.

Table 1. Monocrop maize yields following three rates of defoliation at three dates.

	Time of Defoliation			
Rate of Defoliation	25 DAS[z]	45 DAS[z]	60 DAS	Average
	t/ha			
0	-	7.7	-	7.7
25	7.9	7.9	8.2	8.0
50	7.9	6.7	6.3	6.9
75	8.4	5.9	4.7	6.4
Average	8.1	6.8	6.4	

[z]DAS = days after seeding

Table 2. Monocrop soybean yields following three rates of defoliation at three dates.

	Time of Defoliation			
Rate of Defoliation	25 DAS[z]	45 DAS	60 DAS	Average
	t/ha			
0	-	3.7	-	3.7
25	3.6	3.5	3.5	3.5
50	3.7	3.7	2.8	3.4
75	3.5	3.4	2.8	3.3
Average	3.6	3.6	3.0	

[z] DAS = days after seeding

Yield reductions in defoliated, intercropped maize and soybean were more acute than in the defoliated sole-crops. This was presumably due to the presence of the competing companion crop which was able to increase its yield as a result of the other's injury. This effect was more pronounced under maize-defoliated conditions than under soybean-defoliated conditions. Soybean intercrop yields increased in proportion to the degree and time of maize defoliation (Table 3). Maize intercrop yields under soybean-defoliated conditions, although higher than the control (undefoliated treatment), did not show increasing trends in proportion to the degree and time of soybean defoliation (Table 4). The reason for this phenomenon is not clear, but the unavailability of light may have limited yields in the soybean intercrop. Removing (partially or fully) the maize plants allowed more light to reach the soybean canopy and thereby increased yields.

Table 3. Intercrop maize and soybean yields for varying maize-defoliated treatments with regression and correlation coefficients.

Rate of Defoliation	Time of Defoliation: 25 DAS maize	25 DAS soybean	45 DAS maize	45 DAS soybean	60 DAS maize	60 DAS soybean
	t/ha					
0	-	-	3.7	2.2	-	-
25	3.5	2.3	3.4	2.4	2.7	2.6
50	2.9	2.4	2.4	2.5	2.4	2.5
75	3.2	2.1	2.0	2.6	1.9	2.8
100	0	3.4	0	3.4	0	3.2

r = -.98
b = -.31

Table 4. Intercrop maize and soybean yields for varying soybean-defoliated treatments with regression and correlation coefficients.

Rate of Defoliation	Time of Defoliation: 25 DAS maize	25 DAS soybean	45 DAS maize	45 DAS soybean	60 DAS maize	60 DAS soybean
	t/ha					
0	-	-	3.7	2.2	-	-
25	4.7	1.9	3.6	2.0	4.1	1.6
50	3.7	2.1	3.9	1.9	3.3	1.6
75	4.2	1.9	3.8	2.1	3.7	1.4
100	5.1	0	3.8	0	4.3	0

r = -.48
b = -.27

Maize, being a taller crop, may not have benefited to the same degree from soybean leaf removal. No light meter readings were taken, however, so this hypothesis cannot be substantiated.

Defoliation, either in maize or soybean, caused greater proportional yield reductions when the defoliated crop was intercropped rather than planted in solid stands. Therefore, in order for an intercrop system to suffer lower losses due to defoliation, yield compensation from the non-defoliated crop must exceed the difference in loss between the intercrop and sole-crop defoliations. There are obvious problems in comparing yield compensation values of one crop to crop yield losses in another. For this analysis an assumption was made in order to equalize the productivity between a hectare of sole-crop maize and the productivity of a hectare of sole-crop soybean, so that a conversion factor of 2.1 t of maize is equivalent to 1.0 t of soybean. (This was very near the price ratio between soybean and maize for the area.) Accordingly, after the conversion adjustment, direct comparisons between sole-crop yields and intercrop yields could be made on the basis of total combined grain yields for each of the defoliation treatments (Table 5 and 6). Under normal conditions (undefoliated), an intercropping system, maize + soybean, was 8.7% more productive than the corresponding sole plantings of the same crops. Under maize-defoliated conditions, maize + soybean was an average of 8.1% more productive than the corresponding sole-crop plantings. The value increased under conditions of more severe defoliation, reaching 26.3% at the 75% rate of defoliation on the last date. For the soybean defoliation treatments, intercrops were an average of 4.9% more productive than the maize and soybean sole-crops. There was no trend for either an increase or a decrease in this value as defoliation severity increased.

Table 5. Comparison of monocrop yields of maize and soybean to intercrop yields of maize + soybean under maize-defoliated conditions.

Defoliation Treatment rate	time	Monocrop Yields[z] (t/ha) maize	soybean	Adjusted[y]	Total	Intercrop Yields (t/ha) maize	soybean	Adjusted[y]	Total	Percent Increase of Intercrop Over Monocrop
0		3.8	1.8	3.8	= 7.7	3.7	2.2	4.6	= 8.4	8.7
25	25	4.0	1.8	3.8	= 7.8	3.5	2.3	4.8	= 8.3	6.5
25	45	3.9	1.8	3.8	= 7.8	3.4	2.4	5.1	= 8.5	8.7
25	60	4.1	1.8	3.8	= 8.0	2.7	2.6	5.4	= 8.1	2.2
50	25	3.9	1.8	3.8	= 7.8	2.9	2.4	5.1	= 8.0	2.8
50	45	3.3	1.8	3.8	= 7.2	2.4	2.5	5.3	= 7.8	8.0
50	60	3.1	1.8	3.8	= 7.0	2.4	2.5	5.3	= 7.8	11.6
75	25	4.2	1.8	3.8	= 8.0	3.2	2.1	4.5	= 7.7	-4.7
75	45	3.0	1.8	3.8	= 6.8	2.0	2.6	5.5	= 7.6	11.5
75	60	2.4	1.8	3.8	= 6.2	1.9	2.8	6.0	= 7.9	26.3
100	25	0	1.8	3.8	= 3.8	0	3.4	7.3	= 7.3	88.9
100	45	0	1.8	3.8	= 3.8	0	3.4	7.1	= 7.1	84.2
100	60	0	1.8	3.8	= 3.8	0	3.2	6.8	= 6.8	77.5

[z] Values obtained from Tables 1 and 2, for maize, and soybeans, respectively, and divided by 2

[y] Assuming that it is equally profitable to plant maize as soybeans, value assigned to each unit t of soybean; therefore, 7.7 t of maize = 3.7 t of soybean

Table 6. Comparison of monocrop yields of maize and soybean to intercrop yields of maize + soybean under soybean-defoliated conditions.

Defoliation Treatment rate	time	Monocrop Yields[z] (t/ha) maize	soybean	Adjusted[y]	Total	Intercrop yields (t/ha) maize	soybean	Adjusted[y]	Total	Percent Increase of Intercrop Over Monocrop
	0	3.8	1.8	3.8	= 7.7	3.7	2.2	4.6	= 8.4	8.7
25	25	3.8	1.8	3.8	= 7.7	4.7	1.9	4.0	= 8.7	13.6
25	45	3.8	1.8	3.7	= 7.5	3.6	2.0	4.2	= 7.9	4.4
25	60	3.8	1.7	3.7	= 7.5	4.1	1.6	3.4	= 7.6	0.7
50	25	3.8	1.9	3.9	= 7.8	3.6	2.1	4.4	= 8.1	4.0
50	45	3.8	1.9	3.9	= 7.8	3.9	1.9	4.0	= 8.0	2.3
50	60	3.8	1.4	3.0	= 6.8	3.3	1.6	3.4	= 6.7	-0.8
75	25	3.8	1.8	3.7	= 7.6	4.2	1.9	4.0	= 8.3	9.4
75	45	3.8	1.7	3.6	= 7.4	3.8	2.1	4.5	= 8.3	11.6
75	60	3.8	1.4	3.0	= 6.8	3.7	1.4	3.0	= 6.7	-1.0
100	25	3.8	0	0	= 3.8	5.1	0	0	= 5.1	33.1
100	45	3.8	0	0	= 3.8	3.8	0	0	= 3.8	-1.0
100	60	3.8	0	0	= 3.8	4.3	0	0	= 4.3	12.3

[z] Values obtained from Tables 1 and 2 for maize and soybeans, respectively, and divided by 2

[y] Assuming that it is equally profitable to plant maize as soybeans, value assigned to each unit t of soybean; therefore, 7.7 t of maize = 3.7 t of soybean

In regard to production stability, a risk minimization concern, the maize + soybean intercrop provided higher "highest-returns", higher average-returns, and higher minimum returns than the corresponding maize and soybean sole-crops. The yield returns for maize- and soybean-defoliated conditions under single sole-cropping, two sole-crops, and intercropping are presented in Table 7. Under maize-defoliated conditions the intercrop system had an average return of 7.9 t/ha, with a range of 0.8 t/ha between highest and lowest returns. For the single crop planting, an average value of 7.1 t/ha and a range of 3.6 t/ha between highest and lowest returns were observed. This implies that as the cropping system moved away from diversity (intercropping) and towards homogeneity (sole-cropping), average returns were lower, range of yield values increased, and, most importantly, possibilities for very low returns increased - a concern of top priority for small farmers operating at or near the minimum subsistence level. Hence the data suggest that the risk-aversion principle for intercropping applies to maize-defoliated conditions.

Table 7. Yield returns under maize- and soybean-defoliated conditions for three cropping systems: Single-monocropping, double-monocropping, and intercropping.

Yield Returns[z]	Maize Defoliation			Soybean Defoliation		
	maize monocrop	maize, soybean monocrops	Intercrop	soybean monocrop	maize, soybean monocrops	intercrop
	t/ha					
Highest	8.4	8.0	8.5	7.9	7.8	8.7
Average	7.1	7.4	8.0	7.2	7.4	4.8
Lowest	4.7	6.2	7.7	5.9	6.8	6.7

[z] Combined total grain yields after adjustment by 2.1 t maize = 1.0 t soybean

The picture changes for the soybean-defoliated treatments. Average grain yield for the intercropping, two sole-crop plantings, and single sole-crop planting, were 7.8, 7.4, and 7.1 t/ha, respectively - a much closer margin than that observed under maize-defoliated conditions. Under soybean-defoliated conditions, which were generally not as sensitive to yield losses as the maize-defoliated treatments, the risk-aversion hypothesis would not be a valid justification for intercropping since minimum yield returns from the two sole-crop plantings and intercrop plantings were about the same. Justification for intercropping by risk-aversion would require higher minimum returns rather than just comparable minimum returns. Still, average returns and highest returns were higher in the intercrop treatment than in either of the sole-crop systems.

It appears that intercropping does offer a measure of risk aversion based on the treatments tested in this experiment. Lowest grain yield (excluding 100% defoliation) was found in the single sole-crop planting (4.7 t/ha from 75% maize defoliation on last date) followed by the two sole-crop planting system (6.2 t/ha from 75% defoliation on the last date). Lowest grain yield for the intercrop (6.7 t/ha for soybean defoliation on the last date) was over 0.5 t/ha higher than the two sole-crop plantings.

Although a complete loss in one crop is not uncommon, because of the alternative for replantings - especially under sole-crop conditions - it is difficult to assess the real advantage of intercrops over sole-crops in this situation. If, however, the assumption is made that a replant situation is not feasible (too late in the growing season or labor shortages early in the season) the intercrop system is markedly superior to sole-cropping. The difference is most dramatic under maize-defoliated conditions. Yields of intercropped soybeans where maize was completely defoliated averaged 87% of sole-cropped soybean yields. Hiebsch (1980) found that the earlier that the maize plants are removed, the greater the

land-use advantage by the intercrop. Similar findings observed in this experiment with the complete defoliation treatments would concur with these results; the earlier the maize was removed from the intercrop the more soybean yields increased.

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Soybean-Coconut Intercropping

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Introduction

The income derived from coconut (Cocos nucifera) farming in tropical Asia cannot sustain an average small-farm family, especially if the crop is poorly managed. In pure stands, annual production is estimated at about 17 t/ha (Nelliat et al. 1974), which is far less than the yields produced by crops such as sugarcane, Saccharum officinarum, (Blackman and Black 1959). Low coconut productivity is mainly attributed to the fact that the trees use only about 25% of the available soil mass (Kushwah et al. 1973) and that they intercept only about 44% of available solar radiation (Nair and Balakrishnan 1976).

Coconut is a major crop in Sri Lanka's intermediate rainfall zone. The soil and micro-climate under the canopy of young (5 to 6 years) and mature coconut (>45 years) is suitable for the intercropping of a range of annual food crops.

Grain legumes are becoming increasingly important in Sri Lanka. They are grown in coconut-based cropping systems either as an intercrop or as a catch-crop. Their importance is based not only on their use as a source of dietary protein and vegetable oil, but because of their ability to help maintain soil fertility. Soybean (Glycine max) is one of the six legumes grown in Sri Lanka. In recent years demand has increased, and considerable interest has developed in improving soybean production.

Coconut-soybean intercropping is a relatively new practice, and, until recently, little was known about its long-term potential. Average yields of local soybean cultivars are low compared with improved cultivars, but comparatively little has been done to introduce high yielding, high quality cultivars. Accordingly, an experiment was conducted to evaluate the agronomic performance of 15 soybean cultivars and to select those with potential for intercropping under coconut.

Materials and Methods

The experiment was conducted under mature coconut (60 years) planted in 9 m squares at the Ratmalagara Research Station (intermediate rainfall zone; elevation 30 m). The soil was a sandy clay-loam with a pH of 5.3. Prior to the experiment, 2.2 kg of CRI'C' fertilizer mix was broadcast in a circle (1.65 m) around the base of each coconut tree and incorporated into the soil.

The soybean crop was sown at the onset of the April-June rains, ca. May 20. The seeds of the 15 test cultivars were treated with Captan prior to slurry inoculation with a commercial inoculum (Nitragin S) at the rate of 75 g/kg seed. The pre-treated seed was sown in rows 60 cm apart in 6 x 2.4 m plots arranged in a randomized block design with four replications (total area = 900 m^2). A pre-emergence herbicide (Lasso) was sprayed in all plots. The seedlings were spaced 5 cm apart within the rows 10 days after sowing. NPK was applied at the rate of 20 kg N, 60 kg P_2O_5, and 40 kg K_2O/ha at planting. The crop received 456

mm of rainfall during the experimental period (supplemental irrigation was provided when necessary). Pests were controlled with chemical sprays.

Cultivar performance was evaluated on the basis of:

a) Days to flowering - date on which approximately 50% of the plants in a plot had their first flower;
b) Plant height - average height of ten randomly selected plants/plot at flowering;
c) Nodule number and size - recorded three weeks after flowering on the basis of ten randomly selected plants from two border rows in each plot;
d) Nodule size (expressed as dry weight);
e) Days to maturity (95% ripening);
f) Lodging - visual score of 1 to 5 (1 = all plants erect, 5 = all plants down);
g) Plant density - estimated as the total number of plants/m^2 harvested at maturity from two center rows;
h) Pods per plant - determined from ten randomly selected plants/plot; and
i) Yield dry weight/6 m^2.

Results

Growth and Development

Days to Flowering: The majority of cultivars produced their first flower in less than four weeks (Hardee, Bossier, and the two local checks commenced flowering in less than five weeks) (Table 1). Improved Pelican and Jupiter were the latest-flowering cultivars. A significant negative correlation between the number of days to the onset of flowering and plant height was observed (r = -0.51**) (Table 3).

Plant Height at Flowering: Only Improved Pelican, Jupiter, Pb-1, and SK-2 were significantly taller than other cultivars (Table 1). Hampton, Hardee, Davis, Forrest, and Bragg reached a height of approximately 30 cm; Bonus was the shortest cultivar (24 cm). Plant height was positively correlated to seed yield (r = 0.64**) (Table 3).

Nodulation: Pb-1 and Hardee had the highest number of nodules/plant, 204 and 180, respectively (Table 1). The nodulation of other cultivars (Hampton, Bragg, Bossier, and Tracy) was moderately high; Bonus produced the least number of nodules (45). On a dry weight basis, however, Jupiter, Tracy, Bonus, and Clark 63 had the largest nodule size (0.58 to 1.55 g/plant). Improved Pelican, Hill, Hampton, Pb-1, and SJ-2 had smaller nodules (0.56 to 1.33 g/plant) (Table 1).

Days to Maturity: Hill had the shortest maturity period (80 days) and Jupiter the longest (134 days) (Table 1). All cultivars, except Bossier and Improved Pelican, reached maturity in 3 to 3.5 months.

Lodging: Although only taller cultivars were expected to lodge, i.e. Improved Pelican and Jupiter, both short and moderately tall cultivars proved susceptible (Bossier, Bragg, Davis, Hill, Clark 63, and Williams).

Yield Components and Seed Quality

Plant Density: Plant density did not differ significantly between cultivars at harvest, ranging from 32 to 33 plants/m (Table 2).

Table 1. Agronomic characteristics of soybean test cultivars.

Cultivar	Days to Flowering	Plant Height at Flowering (cm)	Nodules/Plant 3 Weeks After Flowering (no)	Nodule Dry Weight/Plant 3 Weeks After Flowering (g)	Days to Maturity	Lodging
Jupiter	39	54	65	0.91	134	1.25
Hampton 266 A	27	30	125	0.79	98	1.00
Hardee	33	30	180	1.47	106	1.00
Improved Pelican	51	63	87	0.56	133	2.25
Bossier	36	31	127	1.20	113	1.25
Bragg	27	30	131	1.03	106	1.25
Davis	26	28	93	0.75	103	1.25
Tracy	27	27	112	1.55	89	1.00
Forrest	27	32	86	0.77	89	1.00
Hill	29	27	82	0.57	80	2.00
Clark 63	27	38	85	0.90	86	2.00
Bonus	27	24	45	0.58	98	1.00
Williams	25	28	91	0.71	96	1.25
Pb - 1	35	48	204	1.33	93	2.25
SJ - 2	35	49	86	0.57	105	1.75
LSD (0.05)	12	10	51	0.61	7	0.67

Table 2. Soybean seed yield and quality.

Variety	Plant Density (no/m)	Pods/Plant (no)	100-Seed Weight (g)	Seed Yield (t/ha)
Jupiter	33	17	23	0.4 (1.5)[z]
Hampton 266 A	33	17	21	1.4 (1.5)
Hardee	32	23	16	1.5 (2.2)
Improved Pelican	32	26	14	1.1 (1.5)
Bossier	33	17	17	0.8 (2.0)
Bragg	33	18	20	1.2 (1.7)
Davis	33	17	18	1.4 (2.2)
Tracy	32	12	20	1.0 (1.2)
Forrest	33	18	16	1.4 (1.6)
Hill	33	13	16	0.9 (1.6)
Clark 63	32	15	16	1.0 (1.6)
Bonus	32	8	21	0.8 (1.4)
Williams	33	8	22	1.0 (1.7)
Pb-1	33	27	13	1.4 (1.8)
SJ-2	33	32	12	0.9 (1.6)
LSD (0.05)	-	8.0	0.81	0.53

[z] Monocropped yield

Table 3. Correlation co-efficients (r) between growth and yield.

Characteristic	Plant Height (cm)	Pods/Plant	Seed Yield (t/ha)	100-Seed Weight (g)
Days to flowering	-0.51***	-0.17	-0.20	-0.01
Plant height (cm)	-	0.65***	0.64***	0.26
Pods/plant	-	-	0.55***	-0.52**
Seed yield (kg/ha)	-	-	-	0.10

**, *** = P < 0.01, < 0.001, respectively

Pods Per Plant: Local cultivars Pb-1 and SJ-2 had significantly more pods/plant (P<0.01), with a mean of 29 pods/plant (Table 2). Hampton, Hardee, Forrest, Davis, Bragg, Bossier, Improved Pelican, and Jupiter produced a more moderate number of pods (mean 20/plant, range 17 to 27), while Bonus and Williams produced the lowest numbers (mean 8/plant). Pod number was significantly correlated to seed yield (r = 0.55**) (Table 3).

Seed Yield: Hardee, Hampton, Davis, and Forrest produced significantly greater seed yields (P<0.01) than other test cultivars (mean 1.45 t/ha). Jupiter had the lowest yield (0.4 t/ha) (Table 2).

When yield was computed on a daily basis, Hampton, Hardee, Davis, Forrest and Pb-1 produced similar yield responses, ranging from 14 to 16 kg/day/ha. When the yields obtained under coconut were compared with those grown in monoculture (Table 2), Hampton was shown to have suffered the lowest yield reduction (2.9%), followed by Forrest (9.6%) and Pb-1 (25.9%). In contrast, the yields of Hardee, Davis, Bragg, and Improved Pelican were reduced by 28 to 33% when compared with monocultured crops.

Among the 15 cultivars tested, Hampton, Hardee, Davis, Forrest and Pb-1 were found to be the most acceptable cultivars for intercropping under coconut in Sri Lanka's intermediate zone.

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Soybean Intercropping With Rubber and Oil Palm

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Introduction

Soybean (Glycine max) is not indigenous to Malaysia, but research has shown that some cultivars can yield up to 2 or 3 t/ha under experimental conditions (Yap 1979). Estimated average soybean consumption in Malaysia is 5.3 kg per capita. Based on this figure, annual consumption may be nearly 100,000 t, but is probably higher if feed soybean is also considered.

Soybean is not a commercial crop in Malaysia, but it could be in the future. Major production constraints include soybean's susceptibility to insects and diseases and the lack of a dry season for harvesting.

Most farmers feel that soybean is less profitable to grow than other crops. In recent years, however, some farmers have begun to intercrop soybean with young rubber trees (Hevea brasiliensis) and oil palm (Elaeis guineensis).

Intercropping Systems

A survey of small-scale rubber farmers in the 1960s revealed that 50% intercropped their immature rubber trees with banana (Musa sapientum) (10% pineapple (Ananas comusus); 6% vegetables, 5% chillies (Capsicum annum), and 7% other crops) (Lim 1969). Today, most farmers prefer to intercrop with watermelon (Citrullus vulgaris), groundnut (Arachis hypogaea), and chillies, mainly because of higher profits.

Recent surveys show that leguminous crops such as Centrosema pubescens, Pueraria phaseoloides, and Calopogonium mucunoides are commonly grown on large plantations to control weeds and soil erosion and to improve soil fertility. Soybean can serve the same function, and, at the same time, provide extra income.

Soybean and Rubber

When soybean is intercropped with rubber, plant spacings should be adjusted to avoid competition with the rubber crop and to provide maximum space for soybean growth and development. As the trees grow, the roots extend into the area where the intercrop is planted. To avoid damaging the roots and shading the soybean, the soybean intercrop should be planted successively further away from the rubber crop as the trees mature. Shading of the soybean can also be avoided by aligning the trees east to west. Minimum tillage may help to protect the roots of the rubber crop. In general, soybean intercropping should be discontinued after two years.

The recommendations of the Rubber Research Institute of Malaysia (RRIM 1974) for intercropping rubber and soybean are shown in Table 1. Plant spacing is basically a function of the cultivar planted. Chee (1975a,b) found that the optimum density for cultivar 66D-14, a short-statured plant, was 46 cm x 10 cm; Cheng (1974) suggested that a 60 cm x 10 cm configuration be used for cultivar Palmetto.

Table 1. Planting distances between rubber and soybean.

No.Trees (ha)	Distance Between Trees (m)	Distance of Soybean From Tree Rows (m)	
		1st year	2nd year
445	2.4 x 9.1	1.2	1.5
480	2.7 x 7.6	1.2	1.5

Soybean and Oil Palm

Chew (1975) conducted a comprehensive study on oil palm intercropping. Various systems were examined so as to determine the effect of intercropping on the growth and yield of the main crop. The treatments were as follows:

a) Leguminous cover crops - the inter-rows of the palm were grown with Pueraria phaseoloides and Centrosema pubescens, a standard cultural practice in Malaysia;

b) Tilling only - inter-rows were tilled, but no crop was grown;

c) Soybean for two years - soybean was grown in the inter-rows for two years (5 crops) with tillage carried out prior to each planting;

d) Tapioca (Manihot esculenta) for two years - tapioca was planted in the inter-rows for two years with tillage preceeding each planting;

e) Fallow: The inter-rows were sprayed with herbicides, but no crops were planted;

f) Soybean for two years with minimum tillage - the inter-rows were planted with soybean for two years (five crops) with minimum tillage prior to each planting;

g) Soybean for one year - the inter-rows were planted to soybean for one year (3 crops) with tillage prior to each planting.

The trial area was tilled 1.8 m from the palms at the beginning of the study. With the exception of the minimum tillage plots, all inter-rows were plowed once, harrowed twice, and then rototilled. The soil in the minimum tillage plots was also rototilled a few days after the application of the herbicides. All treatments were applied in plots planted with 10.5-month-old commercial oil palm seedlings.

During the first nine months of harvesting, palms in the fallow plot outyielded all other treatments, and produced 28% more than those grown with leguminous cover crops. Plots intercropped with tapioca produced the lowest yield. When compared to the standard culture plot in the latter stages of development,

oil palm yields in the fallow plot declined, whereas yields in the other treatments increased. With the exception of the trees intercropped with soybean for one year, none of the other treatments provided yields higher than the standard. The performance of oil palm grown under different intercropping systems are summarized in Fig. 1.

Chew's research showed that intercropping with crops other than leguminous cover crops may have some adverse effects on oil palm, especially when deep plowing is carried out before the planting of the secondary crop. However, if appropriate management practices are followed, soybean can be a good intercrop; the plot where soybean was intercropped for one year did not have any adverse affect on oil palm yield and development compared with the standard plot (Chew and Khoo 1976).

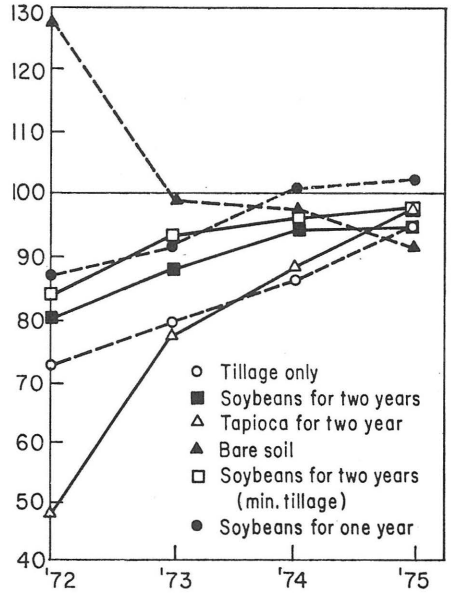

Fig. 1.
Annual oil palm fruit yield expressed as a percentage of legume cover crop yield.

Problems of Soybean Cultivation

The Sime Darby Plantation conducted three feasibility trials using soybean as an intercrop (West 1976). The first trial was conducted on a fertile, loamy soil (Sungei Buluk Series) at Pilmore. Most of the 90 genotypes tested yielded less than 1 t/ha, mostly because of rust and beanfly infestation. A second series of trials (using the genotypes selected in the feasibility trials) suffered from poor seed viability, inadequate weed control, pod borers, as well as beanflies and rust.

The Joint Malaysian Soybean Breeding Project, which uses both mutation and conventional breeding techniques, was launched in 1978 to resolve many of these problems. Research is still in progress, and some promising genotypes have been developed which are now being tested on a regional basis.

Economic Considerations

Although soybean demand in Malaysia is strong, commercial production has yet to be established. The problems mentioned earlier discourage planters from

intercropping with soybean. If the ex-farm price for 1 kg of soybean is US $0.44, then 1.06 t/ha would be the break-even point. If the price is US $0.27, the break-even point would be 1.73 t/ha (Fig. 2). The current retail price in Malaysia is US $0.71/kg. Hence, the ex-farm price should be about US $0.36/kg. Accordingly, soybean production must total 1.29 t/ha for the farmer to break even. To encourage planters to grow soybean, yields should not be less than 1.8 t/ha. Many improved soybean genotypes have this type of yield potential under experimental conditions. However, more trials are needed before they can be recommended for commercial production.

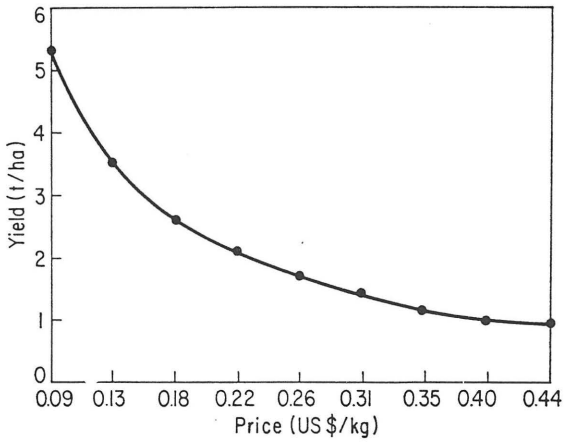

Fig. 2. Break-even point at various soybean prices and yield levels.

Discussion and Conclusion

To minimize damage to the roots of the tree crop, soybean genotypes that grow well under minimum tillage conditions need to be identified. This kind of genotype would be particularly useful during the latter stages of intercropping, when the roots of the main crop begin to extend.

For ease of management, most plantation managers prefer to intercrop with perennial cover crops rather than with short-duration soybean. However, studies conducted by Mak and Pillai (1982) have shown that some soybean genotypes, grown in conjunction with cover crops, are able to produce high yields in mixed cultures. Consequently, intercropping with soybean and cover crops may warrant further study.

Research should also address the question of liming. Most oil palm in Malaysia is grown in low pH soils (pH 4 to 5). There is also a need to reduce labor costs. At present, 60% of soybean production costs are the result of labor (Table 2). If genotypes can be developed that are both pest resistant and suitable for mechanical harvesting, commercial production in Malaysia could be increased.

Table 2. Production costs of soybean intercropped with plantation crops.

	US $/ha
Land preparation	36
Fertilizer	89
Seed	13
Pesticides	44
Labor (80 day @ US$ 3.2/day)	284
Total	446

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Minimum Tillage Soybean Following Rice in Thailand

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Thailand's 1972 soybean crop (Glycine max) totaled 72,000 t produced from a land area of 83,000 ha. By 1974 production reached 252,000 t, and since then has remained relatively stable with some fluctuation due to prices and rainfall distribution. In the northern part of the central highlands, Thailand's largest soybean production area, the crop is usually grown following rice (Oryza sativa) during the dry season with irrigation. The farmer's system is to plant soybean in rice stubble. Improved practices such as appropriate spacing, fertilizer application, and pest control are not widely practiced. Average yields range from 0.6 to 1.0 t/ha.

Minimum tillage has been studied by the Department of Agriculture as an alternative to the rice stubble system. The objectives of this research are to determine the production potential of soybean following rice under zero-tillage or minimum tillage and to identify appropriate management practices.

Minimum tillage studies have been conducted at the Mae-Jo Field Crop Station, Chiangmai Province (northern region) and at the Chainat Field Crop Station and Chainat Rice Station (central region). The fields used in these studies were planted to rice during the preceeding season using recommended management practices.

Results and Discussion

At Mae-Jo, soybean yields under no-tillage (rice stubble) did not differ significantly from other treatments (ridging, mulching, hand-weeding and/or alachlor application). Although the weed score in the alachlor plots was 2.44 compared with the non-weeded check's 5.00, there was no significant difference in yield between the two treatments (Table 1). Low yield, regardless of treatment, was attributed to poor soil fertility and inadequate drainage.

At the two locations in the central region, however, tillage significantly increased yield (Table 2). Both hand-weeding and the use of alachlor were beneficial compared with the non-weeded control. Although ridging and mulching helped to increase yields at the Chainat Field Crop Station, compared with tillage alone, neither treatment increased yields at the Chainat Rice Station (Table 2).

Plant population trials under no-tillage were also conducted at Mae-Jo. A split-plot design with four replications was used. The main plots consisted of two different row spacings (25 and 50 cm); the subplots had 2, 4, and 6 plants/hill. Trial results suggested that 25 cm is superior to 50 cm. Four to six plants significantly outyielded the two-seeds per hill treatment. A combination of 25 cm between the rows and 4 to 6 plants/hill would seem to provide an optimum plant population density (Table 3).

Table 1. No tillage compared with land preparation, Mae-Jo Field Crop Experiment Station.

Treatments	Yield (kg/ha)	No. of Pods per Plant	100-seed Weight(g)	Weed[z] Score
Rice stubble	798	39	15	4.19
Straw burning	902	36	14	4.00
Tillage	880	39	15	4.25
Ridging[y]	787	43	15	4.31
Mulching[y]	880	50	16	5.00
Hand weeding[y]	830	53	15	4.31
Alachlor[y]	830	44	14	2.44
No weeding[y](CK)	838	39	15	5.00
F Ratio	NS	NS	NS	
CV (%)	21.3	12.2	6.2	

[z]Weed score 1-5
Soybean cultivar: SJ 2
[y] These treatments were given in addition to tillage

Table 2. No tillage compared with land preparation following rice.

Chainat Rice Experiment Station

Treatments	Yield (kg/ha)	No. of Pods per Plant	100-Seed Weight(g)	Weed[z] Score
Rice stubble	885	23	17	2.44
Straw burning	982	26	17	1.88
Tillage[y]	1175	27	17	2.88
Ridging[y]	1072	25	17	3.19
Mulching[y]	1072	27	17	2.45
Hand weeding[y]	1063	26	17	2.19
Alachlor[y]	1065	24	17	2.31
No weeding[y]	947	23	17	3.13
F Ratio	**	NS	NS	
LSD (5%)	57.0	-	-	
CV (%)	9.4	12.0	3.0	

Chainat Field Crop Experiment Station

Rice stubble	835	15	18	3.44
Straw burning	821	16	18	3.56
Tillage	991	20	18	3.44
Ridging[y]	1200	21	19	4.00
Mulching[y]	1148	19	18	4.38
Hand weeding[y]	1307	19	19	1.94
Alachlor[y]	863	17	19	3.50
No weeding[y]	775	16	18	4.63
F. Ratio	**	**	**	
L.S.D. (5%)	88.69	2.2	0.9	
C.V. (%)	16.0	4.2	6.9	

[z]Weed score 1-5
Soybean cultivar: SJ 4
[y] These treatments were given in addition to tillage

Table 3. Plant population studies of no tillage soybean following rice, Mae-Jo.

Treatments	Yield (kg/ha)	Height (cm)	No. of Pods.	100-Seed Weight (g)
Between rows				
25 cm	1921	76	23	13
50 cm	1622	62	32	13
Plant/hill				
2	1714	64	35	12
4	1807	73	27	13
6	1794	71	20	13
Row/plant/hill				
25+2	1805	72	29	13
25+4	2103	83	24	13
25+6	1855	75	16	13
50+2	1624	57	42	13
50+4	1511	63	29	12
50+6	1732	66	24	13

Soybean Cropping Systems in Tamil Nadu, India

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Introduction

Soybean (Glycine max) has attracted considerable attention in India because of its oil and protein content. The government, for example, recently launched a "National Soybean Project" which earmarked more than US $15 million for soybean development in the states of Maharashtra, Madhya Pradesh, Rajasthan, Uttar Pradesh, and Bihar.

These types of programs, however, have had very little impact in southern India. Nevertheless, agricultural universities and the departments of agriculture in the states of Karnataka, Andhra Pradesh, and Tamil Nadu have conducted extensive studies concerning the introduction and development of soybean. Their results suggest that soybean in southern India has a yield potential of approximately 1.5 to 2.0 t/ha.

Because of the production opportunities that exist in Tamil Nadu State, the private sector has established soybean processing factories with a total capacity of 400 t/day. The factories use 100,000 t of grain per year, most of which is imported. Accordingly, soybean trials and farm demonstrations have been conducted in the Coimbatore and Periyar Districts as a step towards meeting the demand with a locally produced product.

Cropping Systems in Tamil Nadu

The agricultural economy in Tamil Nadu State encompasses a balance between essential food grains for subsistence farming and commercial crops that provide cash income for non-food requirements. Irrigation is limited to only 30% of the area under cultivation; the majority of farmers depend upon the monsoon.

To help meet the demand of the processing plants, some commercial companies are attempting to introduce soybean as a component in one of several different cropping systems, i.e. mixed-cropping, intercropping, companion-cropping and catch-cropping.

Mixed-Cropping

Large rainfed areas of Tamil Nadu State are planted with food grains from August to November. Sorghum (Sorghum vulgare) and pearl millet (Pennisetum tyhoides) are the most popular crops. In one experiment, soybean was drilled between millet at a spacing of 10 cm between plants and 45 cm between rows. The millet and soybean were sown simultaneously immediately after the onset of the monsoon rains. Cultivar CO 1 yielded an average 0.65 t/ha without reducing the yield of the millet crop.

In a similar experiment, groundnut (Arachis hypogaea) was sown under rainfed conditions by dibbling the seeds at a spacing of 15 x 25 cm. After sowing, soybean was drilled in the same field at a spacing of 10 x 60 cm. The soybean produced 0.5 t/ha with no apparent effect on the groundnut crop.

Intercropping

Intercropping is usually associated with coconut (Cocos nucifera), banana (Musa sapientum), and sugarcane (Saccharum officinarum) production. A green manure crop such as sunhemp (Crotalaria Juncea) is planted between the tree crops, and is subsequently ploughed in situ to improve soil fertility. Several trials were conducted to evaluate the potential of growing soybean in place of the green manure crop.

Coconut: Coconut seedlings are generally planted in 6 or 8 m squares, and take about 7 to 10 years to bear fruit. Two soybean crops can be sown per year (May/June and September/October) in association with coconut at spacings of 30 x 10 cm. In the present trials, the May/June soybean crop yielded an average of 0.9 t/ha, while the September/October crop yielded 0.75 t/ha.

Banana: Banana is usually planted in 2 or 3 m squares. The trees, which take 10 months to bear fruit, are planted in February/March or June/September. In the current study, the soybean crop, which was sown shortly after the banana was planted, produced average yields of 0.8 t/ha.

Sugarcane: Farmers usually plant sugarcane in furrows set 1 m apart. Immediately after the sugarcane was planted, soybean was sown in two rows on either side of the furrows (10 cm spacings). Cultivar CO 1 was ready for harvesting in 90 days and produced yields of 0.75 t/ha.

Companion-Cropping

Large areas of irrigated land in Tamil Nadu State are used to produce cotton (Gossypium hirsutum), red pepper (Capsicum annum), tomato (Lycopersicon esculentum), and tobacco (Nicotiana tabacum). These crops take from 3.5 to 6 months to mature and are generally planted in ridges or furrows. Irrigation ditches are dug at spacings of 3 to 5 m. Trial results indicate that soybean dibbled on the inner side of the ditches can produce yields of 0.3 t/ha.

Catch-Cropping

Local farmers generally plant food crops such as sorghum or pearl millet at the onset of the monsoon rains (local sorghum cultivars take 4 to 5 months to mature). After the harvest the land is usually left fallow for a period of several months. To evaluate the potential of soybean cropping during the "off-season," soybean was monocropped at a spacing of 10 x 30 cm. Yields totaled 0.85 t/ha 96 days after planting.

Conclusions

These studies can best be described as observational; only yield data was taken and no scientific assessment was made as to the yield potentials of the main crops. The trials indicated, however, that there is substantial potential for soybean cropping in Tamil Nadu. Furthermore, the response from the farmers involved in the trials has been quite encouraging. Interest appears to be high and may warrant the extension of soybean cropping systems in the future.

Soybean Cropping Systems in Southern India

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Introduction

Pulses are one of the major protein sources in India. Although the total area planted to pulses has increased slightly in recent years, productivity is somewhat static and per capita availability has decreased from 70 g/day to 45 g/day.

In 1967 the Indian Council of Agricultural Research inaugurated the All India Coordinated Research Project on Soybean (Glycine max). Extensive testing resulted in the identification of the following cultivars for use in the country's southern zone: Improved Pelican, Hardee, KHSB 2, DS-74-40, and PK-74-292.

In 1971, the Government of Tamil Nadu State started its own soybean program at the Agricultural Experiment Institute at Kudumiamalai, Pudukkottai. This work resulted in the release of cultivars KM 1 and CO 1 (Table 1).

Table 1. Characteristics of two Tamil Nadu soybean cultivars.

	KM 1	CO 1
Year released	1980	1980
Origin	Pure line selection from AVRDC G 2120	Reselection from a UGM. 20 Thailand
Days to maturity	95 - 100	85
Plant height (cm)	45 - 50	58
Flower color	Light purple	Light purple
Seed characteristics	Creamy green Protein 42.6% Oil 16.6%	Cream Protein 41.3% Oil 20.1%
100-seed weight (g)	7.0	12.5
Yield (t/ha) non-irrigated	1.1	1.1

Soybean as an Intercrop

Intercropping With Pigeonpea

Ninety percent of the pigeonpea (Cajanus cajan) in Tamil Nadu State is intercropped with soybean, sorghum (Sorghum vulgare), pearl millet (Pennisetum

tyhoides), maize (Zea mays), finger millet (Eleusine coracana), peanut (Arachis hypogaea), cowpea (Vigna unguiculata), mungbean (Vigna radiata), blackgram (Vigna mungo), cotton (Gossypium hirsutum), castor (Ricinus communis), or cassava (Manihot esculenta).

A trial was conducted in 1980-81 to determine the effect of intercropping soybean with pigeonpea, maize, and finger millet. The results indicated that one row of soybean planted between two rows of pigeonpea (60 cm apart) produced the highest gross returns of all combinations tested (US $1,110/ha) (Table 2).

Results from the 1981-82 season demonstrated that two rows of soybean (30 cm apart) grown between two paired-rows of pigeonpea (45 cm), could produce 0.8 t/ha of soybean and 1.6 t/ha of pigeonpea. Total gross income was US $814/ha (Table 3).

Table 2. Gross returns from soybean intercropping, 1980-81[z].

Crop	Yield (t/ha)		Total Income
	main crop	intercrop	(US$)
Monocrop soybean (30 cm rows)	1.8	-	442
Monocrop maize (60 cm rows)	5.5	-	819
Monocrop pigeonpea (60 cm rows)	2.3	-	878
Monocrop finger millet (45 cm rows)	5.2	-	928
One soybean row/two maize rows (60 cm)	4.0	0.6	754
One soybean row between two pigeonpea rows (60 cm)	2.4	0.8	1,110
One soybean between two finger millet rows (45 cm)	2.5	0.3	514
Two soybean rows (30 cm) between two paired maize rows (45 cm)	2.9	0.5	556
Two soybean rows (30 cm) between two paired pigeonpea rows (45 cm)	1.8	0.8	852
Two soybean rows (30 cm) between two paired finger millet rows (30 cm)	1.8	0.4	425

Soybean price = US $250/t; maize = US $150/t; pigeonpea = US $375/t; finger millet = US $180/t
Source: Rajappa 1981
[z] Net returns not available (eds.)

Soybean-Cotton

One row of soybean produced 0.2 t/ha when planted with two rows of cotton (0.5 t/ha) as a winter crop (September/October). Paired-rows of soybean with paired-rows of cotton produced higher yields: 0.3 t/ha of soybean and 0.6 t/ha of cotton. Monocropped soybean and cotton produced 0.6 t/ha and 0.5 t/ha, respectively.

Other Crops

In the Coimbatore and Periyar Districts of Tamil Nadu many farmers intercrop soybean with peanut, tobacco (Nicotiana tabacum), turmeric (Curcuma longa), and green pepper (Capsicum sp.). Trials indicated that 0.5 to 1.2 t/ha of soybean can be produced by planting soybean on both sides of irrigation channels (see previous paper - eds.).

Soybean raised as an intercrop with sugarcane produced 0.8 t/ha. This system involves planting sugarcane setts in rows 80 cm apart, with three rows of soybean sown between two rows of sugarcane.

Table 3. Gross returns from soybean intercropping 1981-82[z].

Crop	Yield (t/ha) main crop	Yield (t/ha) intercrop	Total Income (US$)
Monocrop soybean (30 cm rows)	1.2	-	310
Monocrop maize (60 cm rows)	3.3	-	450
Monocrop pigeonpea (60 cm rows)	2.1	-	781
Monocrop finger millet (45 cm rows)	2.9	-	514
One soybean row between two maize rows (60 cm)	2.5	0.6	478
One soybean row between two pigeonpea rows (60 cm)	1.7	0.7	799
One soybean row between two finger millet rows (45 cm)	1.5	0.9	504
Two soybean rows (30 cm) between two paired maize rows (45 cm)	2.6	0.6	498
Two soybean rows (30 cm) between two paired pigeonpea rows (45 cm)	1.6	0.8	814
Two soybean rows (30 cm) between two paired finger millet rows (30 cm)	1.3	0.7	412

Soybean price = US $250/t; maize = US $135/t; pigeonpea = US $375/t; finger millet = US $185/t
Source: Rajappa 1982
[z]Net returns not available (eds.)

Farmers also plant soybean between banana (Musa sapientum) and coconut (Cocos nucifera). Yields range from 0.8 to 1.5 t/ha.

Constraints

Soybean in India was grown on 0.6 million ha in 1980-81 (447,000 ha in Madhya Pradesh and 131,000 ha in Uttar Pradesh). Soybean production in southern India is negligible, mainly because of marketing constraints. This problem could be resolved if an organization was established to buy the crop at a pre-determined price.

Another constraint is the fact that soybean seed deteriorates rather quickly. Research has shown that harvesting at the proper stage of maturity helps to maintain viability. Harvesting should not occur before the plant has shed its leaves and the moisture content of seeds has dropped to 14%. Viability can be further enhanced by storing the seeds at 5°C and 40% relative humidity.

Care should also be taken to reduce insect infestation. Leaf roller, (Stomopteryx sp.), for example, infests soybean in Tamil Nadu State from September to October and is responsible for significant damage. This pest can be controlled by spraying Endosulfan 35 EC at 500 ml/ha immediately after the first sighting and again two weeks later.

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The Potential of Soybean in Indian Cropping Systems

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Introduction

India can be broadly divided into four agronomic zones: Northern hill, northern plain, central, and southern. Soybean (Glycine max) can be grown in each of these zones, either as an irrigated or as a rainfed crop. It is primarily grown, however, in the rainy season (July to October) because its agroclimatic requirements are similar to those of traditional crops, e.g. maize (Zea mays), sorghum (Sorghum vulgare), pigeonpea (Cajanus cajan), finger millet (Eleusine coracana), and mungbean (Vigna radiata).

In the northern hill zone (1,500 to 2,000 m) soybean is eight to ten times more productive than traditional finger millet. For this reason, production is increasing in certain areas, either replacing finger millet entirely or as a filler crop during fallow periods. The predominant cropping pattern in the northern hills is to plant soybean in conjunction with maize or young fruit trees or on the bunds of rice (Oryza sativa) paddies.

Rainy season soybean is grown in the northern plain zone either during a fallow period or as a replacement for low yielding maize or sorghum. Experience has shown the crop to have significant potential as an intercrop with maize, sorghum, pigeonpea, upland rice or cotton (Gossypium hirsutum). Both the agronomic and economic feasibility of intercropping with soybean has been experimentally established in this region. At certain location soybean is quite lucrative, mainly because its cost of production is low and its yields can exceed 2.5 t/ha. Soybean also has potential as dry season crop in the northern plain zone following potato (Solanum tuberosum), rapeseed (Brassica napus), or sugarcane (Saccharum officinarum). Its high yield potential in this season apparently compensates the farmer for its heavy irrigation requirements. In the central zone soybean is currently grown only on fallow land during the rainy season. In the low rainfall areas of this region farmers traditionally keep their land fallow during part of the rainy season to conserve irrigation water for winter season crops of wheat (Triticum aestivum), gram (Cicer arietinum), or lentil (Lens culinaris). Studies on farmers' fields, however, have shown that soybean grown during the rainy fallow period far outyields the traditional crops grown after the fallow period. Furthermore, if the rains are substantial, farmers can still grow their traditional crops once the soybean has been harvested. There is also potential for growing soybean in the region as an intercrop with sorghum, maize, pigeonpea, cotton, or sugarcane.

Soybean has good potential in the southern zone as an intercrop with sorghum, cotton, sugarcane, pigeonpea, and peanut (Arachis hypogaea). It can also be grown in this region in rice fallows or as a replacement for low-productivity, rainfed crops. The most promising cropping patterns in the southern zone include: Wheat-soybean-finger-millet-beans (Phaseolus vulgaris), oats (Avena sativa) -cowpea (Vigna unguiculata) -barley (Hordeum vulgare) -soybean, soybean-finger millet-beans, and soybean-wheat-peanut. In coastal areas, there is potential for growing soybean as an intercrop with tapioca (Manihot esculenta) or coconut (Cocos nucifera).

Research and Extension

Indian soybean hectarage has grown from a mere 300 ha in 1967 to 0.7 million ha in 1982-83. While impressive, these figure belie the fact that major improvements are required both in the area planted to soybean and in average productivity per hectare. At present, efforts are being made to increase soybean production through research and extension. The following are selected examples of the work conducted by various agencies to stimulate soybean cultivation in various parts of the country.

Double-Cropping Demonstrations

Demonstrations with soybean-wheat and soybean-potato rotations were conducted on farmers' fields at 20 locations in Uttar Pradesh by researchers at Pantnagar University. Attempts were made to assess the feasibility and profitability of both rotations, with soybean serving as the rainy season crop (Trikha and Singh 1983).

Soybean-Wheat: Two hundred and seventy-nine demonstrations with soybean-wheat rotations were conducted from 1971 to 1982 using soybean cultivars Bragg and Ankur and wheat cultivar Sonalika (RR-21). Average yield, based on all trials, was 1.8 t/ha for soybean and 4.3 t/ha for wheat. Low soybean yields were generally due to poor seed germination rates, lack of nodulation, and susceptibility to yellow mosaic virus. Cost of production and net profits for both crops are shown in Table 1.

Soybean-Potato: Eight years of farm demonstration trials with a soybean-potato rotation produced average soybean yields of 2.0 t/ha and average potato yields of 26.8 t/ha. Production costs and net returns are shown in Table 2.

Fertilizer Usage

Almora: In an experiment conducted at Almora (1979-81), an attempt was made to determine if any saving in N fertilizer could be realized by planting soybean prior to wheat. Wheat was planted after the harvest of finger millet and soybean. N fertilizer was applied at the rates of 20 and 40 kg/ha. The trials indicated that wheat yields in the 20 kg N soybean treatment were equal to those of the 40 kg N finger millet treatment. Similar studies at Almora have shown that soybean contributes about 45 kg N/ha to the successive wheat crop. This amount almost matches the recommended application rate for N applied to rainfed wheat in the area surrounding Almora.

Pantnagar: In an experiment conducted at Pantnagar (northern plain zone), wheat yields (without N) following inoculated soybean were considerably higher than those following an uninoculated crop. However, when nitrogen was applied directly to soybean, yield differences between the wheat harvested from inoculated and uninoculated treatments were not significant.

Jabalpur: Experiments conducted at Jabalpur, also in the northern plain zone, showed that wheat yields increased to a larger extent when grown after soybean than when grown after any other crop, regardless of the level of N application. Soybean's contribution to the wheat crop was approximately 60 kg N/ha.

Intercropping

Intercropping of soybean and various field crops has been tested at a variety of locations; trial results have generally shown a positive interaction between soybean and its companion crop. The following are selected examples.

Table 1. Summary of soybean-wheat rotation demonstrations on farmers' fields.

Year	Yield t/ha		Cost of Production	Net Profit
	soybean	wheat	US $/ha	US $/ha
1971-72	2.30	4.40	232	325
1972-73	1.85	4.32	228	323
1973-74	1.98	4.17	248	487
1974-75	1.98	4.42	396	564
1975-76	1.69	4.35	405	484
1976-77	1.59	4.46	380	428
1977-78	1.78	4.41	357	503
1978-79	1.60	4.43	376	508
1979-80	1.98	4.15	380	393
1980-81	1.68	4.31	503	399
1981-82	1.61	3.97	441	523
Average	1.82	4.31		

Table 2. Summary of soybean-potato rotational demonstrations on farmers' field.

Year	Yield t/ha		Cost of Production	Net Profit
	soybean	potato	(US $/ha)	(US $/ha)
1974-75	3.00	37.5	790	1,085
1975-76	1.98	27.7	690	702
1976-77	1.44	23.8	678	1,039
1977-78	2.14	30.4	697	1,380
1978-79	2.13	22.2	681	309
1979-80	1.66	19.4	729	849
1980-81	1.93	30.2	1047	1,155
1981-82	1.90	23.5	819	537
Average	2.02	26.8	766	882

Soybean and Finger Millet: Soybean-finger millet intercropping was found to be advantageous both in the central and northern hill zones. In the latter location, paired-rows of finger millet produced 2.3 t/ha when grown in conjunction with a single row of soybean (0.5 t/ha). A similar cropping pattern also proved optimal in the central zone.

Soybean and Sorghum: At Pantnagar, the yield of sorghum was not significantly affected by its association with soybean in different combinations. A soybean-sorghum intercrop proved significantly better than other crop combinations, and produced the highest net returns of all combinations tested, US $248.

In the central zone soybean was tested in combination with sorghum, pigeonpea, rice, and sugarcane. The pure stand of sorghum produced average yields of 1.9 t/ha. With alternate rows of sorghum and soybean, the yields of the two crops were 1.3 and 0.5 t/ha, respectively; net returns increased from US $923 to US $1,372/ha.

Soybean and Pigeonpea: At Junnagadh paired-rows of soybean grown between two rows of pigeonpea produced net returns of US $504/ha. Yields totaled 1.2 t/ha and 0.61 t/ha for pigeonpea and soybean, respectively. Two rows of soybean grown

between two rows of pigeonpea produced net returns of $534. Pigeonpea yield was 1.5 t/ha and soybean yields totaled 0.2 t/ha.

At Bangalore, one row of soybean grown between two rows of pigeonpea produced net returns of US $1,070. Pigeonpea yield was 1.71 t/ha; soybean yielded 0.82 t/ha. In this experiment soybean was shown to have a positive effect on pigeonpea yields.

Acknowledgements

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Cropping Systems and Soybean Production in Bangladesh

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Introduction

Bangladesh is a riverine country with 17 major soil types (Anon. 1971). The dry season lasts two to four months, depending upon location (Manalo 1976). Since crop production depends almost entirely on natural rainfall, farmers have developed a variety of location-specific cropping patterns. Fig. 1 shows the complexity of the cropping systems found in Bangladesh.

Soybean (Glycine max) is a comparatively new crop. It was first introduced during the Second World War, re-introduced during the 1960s, and it appeared a third time in 1972-73. Previous failures to establish soybean production were mainly due to a lack of early maturing cultivars, the absence of research, and the failure to promote soybean as a food and industrial commodity.

Research began in 1975 under the auspices of the Bangladesh Coordinated Soybean Research Project. Various studies have indicated substantial potential for soybean in Bangladesh, both agronomically and from the point of view of consumer acceptance. Large-scale production has yet to be established, largely because of extension problems.

Soybean Cultivars

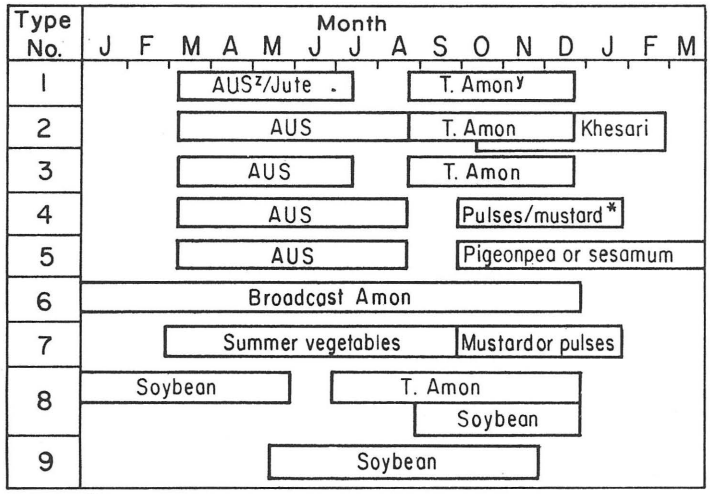
Only two cultivars have been released by the National Seed Board: Bragg and Davis. These materials are stable under a variety of conditions; yields are approximately 1.7 t/ha for both cultivars (Anon. 1981). Davis is recommended for the winter season, while Bragg seems to perform well year-round.

Management Studies

Land Preparation and Planting

Haque et al. (1979) showed that land preparation in the dry season, combined with row-planting, produced higher yields (2.0 t/ha) than wetland preparation and row-planting (1.8 t/ha). Broadcasting under wetland conditions produced higher yields than broadcasting under dryland conditions (Table 1).

Studies were also conducted to determine the sowing dates that favor yield and maximum utilization of land and water resources. Because early maturing cultivars are sown in May-June, and therefore compete with rice (Oryza sativa and jute (Corchorus olitorius), soybean was planted in the September-October and December-January fallow seasons. Bragg and Davis produced good yields in 90 to 115 days, depending upon location (Anon. 1981). Three sowing dates were subsequently recommended: December 15 to January 15; September 15 to October 15, and July 15 to August 15. These recommendations provide the flexibility required to fit soybean into different cropping patterns within the parameters of prevailing climate, soil, and agronomic requirements.



*Vegetables, tobacco, cotton or potato

[z]Early summer rainfed rice
[y]Transplanted (T. Aman) or broadcast rainfed monsoon rice

Fig. 1. Partially modified cropping pattern schedule in Bangladesh.

Table 1. Effect of different cultivation methods on the growth and yield of soybean cv. Bragg.

Method of Land Preparation		Plant Stand/ Plot	Plant Height (cm)	Pods/ Plant	100-Seed Weight (g)	Grain Yield (t/ha)
Dry land preparation	row planting	1005	35	21	18.4	2.0
	broadcast	536	33	23	17.6	1.3
Wet land preparation	row planting	650	36	25	18.3	1.8
	broadcast	641	34	24	18.2	1.4

Source: Haque et al. (1979)

The December 15 to January 15 period is suitable for large-scale cultivation following rice, or where wheat (Triticum aestivum), mustard (Brassica campestris), or other crops provide low economic returns. September-October or December-January are appropriate for planting soybean as an intercrop with sugarcane (Saccharum officinarum), banana (Musa sapientum), mulberry (Morus multicaulus), or potato (Solanum tuberosum). December-January sowing has been found to be particularly productive when 2 m-strips of wheat are planted with 2 m-strips of soybean.

In lowland areas, after the November rice harvest, soybean can be planted with or without tillage. Yields range from 1.2 to 1.5 t/ha (Shires and Brockmueller 1981), suggesting that soybean cultivation can be effective in lowland areas with high dry season water tables. In many instances, the profits derived from soybean grown under this system are higher than those of competing crops. Soybean cultivation in September appears to influence the following wheat crop. Khaleque et al. (1981) showed that wheat yields were substantially higher after soybean than after rice (Table 2). Although the income derived from the rice crop compensated for the yield loss, a soybean-wheat rotation is superior from a soil management point of view.

Planting Bragg in July-August produces somewhat higher yields than planting in December-January (1.5 t/ha versus 1.2 t/ha) (Siddique and Khaleque 1982). Davis is equally good in both seasons (ca. 1.6 t/ha). This was confirmed by Newaz and Ali (1981) who reported that Davis had a high rate of yield stability (b = 0.252) compared with cultivars Jupiter, K-30, K-16, PL-1039, and G 2120 (b = 0.815 to 1.257).

Inoculum

A number of inoculum strains have been isolated, characterized, and tested in Bangladesh (Ahmad 1979). Trial results show that strain GII-5 is better than Nitragin (Table 3), except in alkaline soils where strain 0-4 is superior (Anon. 1981, Shires and Brockmueller 1981). Strain GI-13 did well in red soils (acidic reaction) (Shahidullah et al. 1979, Siddique and Khaleque 1982). The performance of GI-13, GII-5, and BAU-107 appeared to be equally good in many areas, including those with slightly acidic to slightly alkaline soils. Davis and Bragg were both responsive to GI-13 and BAU-107.

Input Levels

Experiments have been conducted to determine the status of soybean at different input levels. Bragg seemed to perform best under medium or high levels of management. Yield differences between high and medium input levels were insignificant, however (Table 4).

Zero-Tillage

Rice, the country's major crop, is harvested primarily in December. Although a great deal of land is available after the rice harvest, there is usually little time for additional land preparation. One answer may be zero-tillage. Shires and Brockmueller (1981) showed that zero-tillage and dibbling soybean in rice straw mulch (1.76 t/ha) was superior to zero-tillage and dibbling in rice stubble (1.2 t/ha) and dibbling after one plowing (1.19 t/ha). Straw mulching in tilled, row-planted soybean also produced adequate yields (1.3 t/ha).

Cropping Patterns

A number of cropping pattern studies were carried out with soybean as a component crop. The first study, conducted in the Joydebpur area, showed 310 days of potential land utilization in a pattern where soybean was grown with pearl millet (Pennisetum typhoides) and rice. The pattern produced net returns comparable to other promising systems (Haque et al. 1979). The results of experiments conducted in different seasons with various crops also showed that soybean can be accomodated into other patterns (Table 5).

Soybean is intercropped in Bangladesh with sugarcane, maize, sweet potato (Ipomoea batatas), banana, and mulberry. Soybean grown between sugarcane rows can produce 1.0 t/ha when irrigated once after germination (Rahman 1979). The performance of Bragg and Davis varied significantly; overall Davis was superior. Soybean intercropped with sweet potato produced a significantly better land equivalency ratio than lentil (Lens culinaris) (Shires and Brockmueller 1981). The gross return from soybean + sweet potato was US $352 compared with US $193 from sweet potato + lentil. Soybean sown with banana and mulberry produced yields ranging from 0.8 to 0.9 t/ha to 1.1 to 1.2 t/ha, respectively (Anon. 1981).

Table 2. Performance of soybean, rice, and wheat; September-December.

Crop	Sowing Date	Days to Maturity	Grain Yield (t/ha)	Cost (US$)	Total Income (US$)	Net Return (US$)
Soybean	9- 9-80	96	1.50	135	312	177
Wheat after soybean	16-12-80	97	1.46	127	179	51
Rice	9- 9-80	90	3.46	140	433	288
Wheat after rice	16-12-80	97	0.80	127	100	- 27

Source: Khaleque et al. (1981)

Table 3. Performance of Bragg and Davis inoculated by different Rhizobium strains (average of three experiments in each of two years).

Strains	Soybean Yield (t/ha)				Average
	BAU Mymensingh	BARI Joydebpur	BCSIR Dhaka	MCC Feni	
Control	1.0	0.8	0.6	-	0.8
GII-5	1.3	1.0	1.2	2.0	1.4
CI-13	1.4	1.0	1.4	1.3	1.3
0-4	1.2	0.8	1.2	2.1	1.3
Nitragin	0.9	1.0	-	2.0	1.3

Modified from Anon. (1981)

Table 4. Yield (t/ha) of soybean cv. Bragg at different levels of management in different locations.

Level of Management[z]	1977-78					1978-79			Mean
	BAU	BRRI	BARI	BCSIR	average	BAU	BRRI	Average	
Poor (M_1)	1.6	1.5	0.8	1.3	1.3	2.2	1.1	1.7	1.5
Low (M_2)	1.5	1.6	0.8	1.4	1.3	2.1	1.3	1.7	1.5
Medium (M_3)	2.3	1.2	1.0	1.6	1.3	2.5	1.4	2.0	1.8
High (M_4)	2.4	1.8	1.1	1.7	1.7	2.7	1.6	2.1	1.8
Average	2.1	1.6	0.9	1.5	1.5	2.4	1.3	1.9	1.7

[z] M_1 - Broadcasting
M_2 - Broadcasting + cow dung (5 t/ha) + one hand weeding
M_3 - Row planting (25 cm x 5 cm) + NPK fertilizers (N, P_2O_5 and K_2O @10, 30, and 20 kg/ha respectively) + inoculum (17 g/kg seed) + two hand weeding + one irrigation after 30 days of sowing + mechanical control of insects
M_4 - Row planting (25 cm x 5 cm) + NPK fertilizers (N, P_2O_5, and K_2O @20, 60, and 40 kg/ha respectively + inoculum (17 g/kg seeds) + two hand weedings + two irrigations after 20 and 45 days of sowing + seed treatment with Granosan-M + spraying of insecticides

Table 5. Major soybean cropping patterns of Bangladesh

Land Types	Cropping Pattern
Hills	Soybean[z]
	Rubber (Hevea brasiliensis) + soybean[z]
Highlands (25 to 30 m)	Sugarcane
	Sugarcane + soybean/other winter crops
	Banana + soybean
	Summer vegetables-mustard/pulses/soybean[z]
Medium Highlands (20 to 25 m)	June rice-transplanted rice-lathyrus[y]/soybean[z]
	Soybean-transplanted rice-wheat/winter crops
Medium elevation (15 to 20 m)	Rice/jute-transplanted rice-wheat/soybean
	HYV Rice-soybean-wheat/maize (Zea mays)
Medium Lowlands (10 to 15 m)	Rice/jute-winter pulses/oilseed
	Rice-mustard-soybean
Lowlands (5 to 10 m)	Rice/deep water rice-lathyrus/mustard/soybean
	Rice + deep water rice-soybean/mustard (zero tillage)
	Deep water rice-soybean (zero tillage)

[z] Potential types
[y] Lathyrus sativus

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Breeding Soybean for Chinese Cropping Systems

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Introduction

Cropping patterns vary greatly in China, but, in general, farmers try to use systems that ensure maximum use of the available growing season.

Soybean (Glycine max) is produced as a subsidiary crop in most multiple cropping patterns. Therefore, its maturation period should accommodate both the harvesting of the preceeding crop and the planting of the following crop.

Northeast and Loess Plateau

In the Northeast and Loess Plateau regions, the growing season is less than 150 days. Because soybean is a full-season crop, the cultivars developed for these areas should reach full maturity before the first frost.

When corn (Zea mays) is planted on fertile fields, the amount of light that penetrates to the inner part of the canopy may be restricted. Farmers therefore plant two to four rows of corn and alternate them with four rows of soybean. The soybean cultivar should have small, stiff leaves, and should not be predisposed to vining under low light conditions. Kirin No. 3, which is widely intercropped with corn, is a good example of this type of cultivar.

Farmers in the northeast also intercrop soybean with spring wheat (Triticum aestivum). Once the wheat reaches the early "booting" stage, two rows of soybean are planted alternately between the wheat. Solar radiation is adequate for the soybean once the wheat has been harvested. Cultivars suited to this system, such as indeterminate cultivar NE 3513, should branch profusely, flower late, and grow vigorously after the R2 stage.

Heilongjiang

Breeding for early maturity (similar to US maturity group 000) is a prerequisite for the soybean produced in northern Heilongjiang Province (Table 1). The growing season in Heilongjiang is often less than 90 days. The transgressive inheritance of earliness in crosses between early parents has provided opportunities for selecting 000 maturity types. Breeding for extreme early maturity also holds promise for increasing soybean production in Tibet and Tsinghai.

Yellow and Huai River Valleys

In the central and northern parts of the Yellow River Valley, soybean is usually planted in early or mid-June, following winter wheat. After the soybean harvest the fields are left fallow. Sorghum (Sorghum vulgare), corn, cotton (Gossypium hirsutum) or peanut (Arachis hypogaea) are planted the following spring. Though most farmers plant three crops during a two-year cycle, there has been a gradual shift to a two-crops per year system. The soybeans developed for

this pattern are classified as group V cultivars; they usually mature by early or mid-October. The soybean growing period is 110 to 120 days when the crop is planted after winter wheat. As with the cultivars developed for the northeastern part of China, soybean for the Yellow River Valley should be indeterminate and produce large numbers of branches.

In the Yellow River and Huai River valleys, the early planting of summer soybean, following winter wheat, permits soybean to be grown under longer photoperiods, which, in turn, allows for prolific growth and high yields. Superior stand establishment and early planting are key to high productivity in this area. If the rains come during the early dough stage of the wheat, farmers try to plant soybean between the wheat rows, a practice which promotes soybean germination. Cultivars with determinate growth habits, good germination potential, and resistance to early lodging are preferred.

In the plain areas between the Huai and Yellow Rivers, the main cropping system is summer soybean (or sweet potato [Ipomoea batatas] or corn) grown in rotation with winter wheat. Soybean cultivars should be suitable for planting as late as the middle of June; harvesting is carried out in mid- or late September. These cultivars belong to the US maturity group IV-V; when grown as a summer crop they mature in 100 to 110 days. Small-seeded cultivars that germinate under dry conditions and grow well in water-logged soils during flowering and pod-filling are required.

Table 1. Soybean production characteristics.

Area	Days to Harvest	Accumulated Temperature	Cultivar Released
Extreme early	95 - 100	1800 - 2100	Fengshou No. 11
Hills	103 - 110	2100 - 2400	Fengshou No. 10 and 12
Harbin area	120 - 125	2500 - 2700	Heinong No. 26 and 10
Eastern plain	115 - 120	2300 - 2600	Hefeng No. 22 Dongnong No. 4
Western sandy	115 - 120	2400 - 2650	Nongfeng No. 7
Saline and alkaline	120 - 125	2400 - 2700	Heinong No. 16
Semi-mountainous	105 - 120	2200 - 2600	Fengshou No. 10, Mufeng No. 5

Yongtze River Valley

In the Yongtze River Valley region, a long frost-free season - combined with extensive topographical variation - has led to the development of complex cropping systems.

A double-cropping system, for example, is practiced in which soybean is usually planted in June, after the harvest of the winter crop. The cultivars used in this system belong to group VI-VII, have a determinate growth habit, and produce 100-seed weights of 10 to 15 g.

In recent years farmers have also begun to practice triple-cropping. When winter barley (Hordeum vulgare) is in the early dough stage, early maturing spring soybean is planted between the barley rows. The soybean seedlings grow to a height of about 7 to 8 cm by the time the barley is ready to harvest. The

soybean harvest is carried out in early or mid-June, and is followed by an autumn rice crop. The cultivars used in this system are semi-determinate, grow vigorously after the R1 stage, produce large seeds that resist deterioration, and meet the requirements of maturity group II-III.

In many locations a traditional winter crop-rice-soybean system prevails. Cultivars for this system belong to maturity group VIII-IX and should grow prolifically under short photoperiods in August and September.

Rice Areas

In the paddy rice growing areas of the south, farmers usually plant soybean on bunds. The dates for soybean seeding and harvesting are nearly the same as the dates for transplanting and harvesting rice. Where a two-crop rice system is practiced, spring soybean is grown on bunds in conjunction with early spring rice; autumn soybean is planted on the same bunds after harvesting the spring soybean. A soybean cultivar with profuse branches is required for this type of system.

In the extreme southern part of China (frost-free belt), soybean cultivars from maturity groups VI and VII can be grown year-round. Recently, farmers have adopted winter soybean cultivars for planting in late November. Two crops of rice are grown after the soybean harvest in April. The cultivars for this system are determinate and can tolerate drought and cool temperatures at the R1 stage.

The soybean (tropical types) grown in the southern part of Guangdong, Guangxi, and Yunnan Provinces are usually planted in July, following early rice. Singh (1976) pointed out that the ideal tropical soybean should be a late, short-day plant with a profuse number of branches (75 to 85 cm; 11 to 15 g/100-seeds). Lantican (1976) noted that tropical soybean should be early maturing and have a determinate growth habit, a high seed/stem ratio, stiff stems, and medium plant height. Hartwig and Kiihl (1979) and Hinson and Hartwig (1982) emphasized that under short-day conditions, late-flowering types provide better yields, allow for machine harvesting, and mature in a reasonable amount of time. The performance of autumn soybean in southern China is generally similar to the cultivars described above. They are typical short-day types, most of which flower quite late (Wang 1956); when planted late they grow adequately under short-day conditions. Determinate types with stiff stems and large yellow seed are planted in highly fertile areas; in less fertile areas small-seeded, profusely branching types are grown. In areas with favorable farming conditions, late flowering determinate types are preferred.

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Soybean Cropping Systems in Taiwan

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Introduction

Soybean (Glycine max) is usually grown in Taiwan following the second rice crop ([Oryza sativa] winter season). Production is concentrated in the Pingtung-Kaohsiung area (Fig. 1-B1, B2). In recent years soybean production has decreased (Table 1), principally because of low prices.

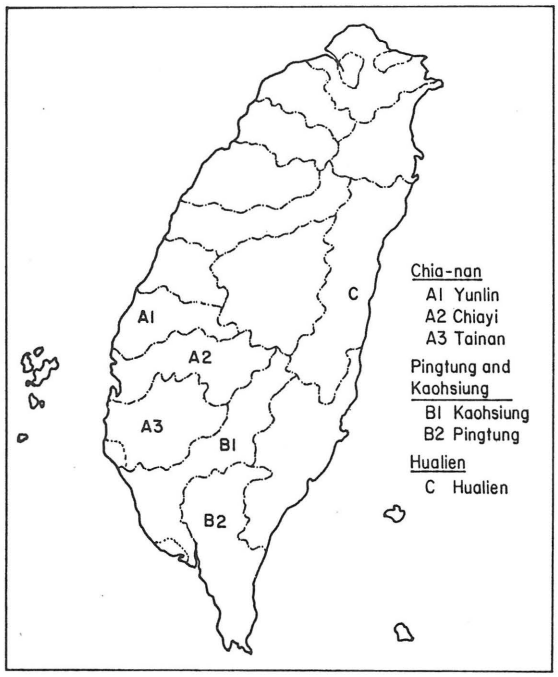

Fig. 1.
Principal soybean production areas in Taiwan.

Paddy Cropping Systems

Soybean farmers in Taiwan practice both double- and single-cropping. Cropping sequences and their locations are shown in Fig. 2-A.

Rice-Rice-Soybean

In a rice-rice-soybean pattern the first rice crop is usually transplanted in late January or early February and is harvested in May or June. The second crop is transplanted in June and harvested in late September or mid-October. The second rice crop is planted as early as possible to extend the growing season for the soybean crop. Soybean is planted soon after the second rice crop and matures sometime in January.

Table 1. Major soybean production areas in Taiwan, 1965-1982.

Season / Year	Pingtung County	Kaohsiung County	Chianan County	Hualier County	Season Total	Annual Total
	ha					
Autumn						
1965-1969	26,546	6,491	1.234	111	36,853	50,304
1970-1974	24,068	4,373	489	48	29,721	39,974
1975-1979	18,487	2,260	266	71	22,439	30,182
1980	7,892	2,074	58	62	10,466	15,329
1981	3,972	1,547	74	63	6,012	10,312
1982	2,301	1,260	114	39	3,980	7,692
Spring						
1965-1969	1,623	846	2,860	324	7,498	50,304
1970-1974	1,321	422	2,050	648	5,618	39,974
1975-1979	1,003	244	2,286	315	4,654	30,182
1980	305	126	1,539	167	2,700	15,329
1981	432	103	1,655	137	2,826	10,312
1982	260	184	1,170	134	2,217	7,692
Summer						
1965-1969	1,571	444	1,043	1,945	5,950	50,304
1970-1974	1,163	270	1,122	1,583	4,635	38,974
1975-1979	658	167	965	999	3,090	30,182
1980	252	66	860	660	2,183	15,329
1981	72	73	525	502	1,474	10,312
1982	119	96	505	497	1,495	7,692

Source: Taiwan Agricultural Yearbooks, 1966-1983

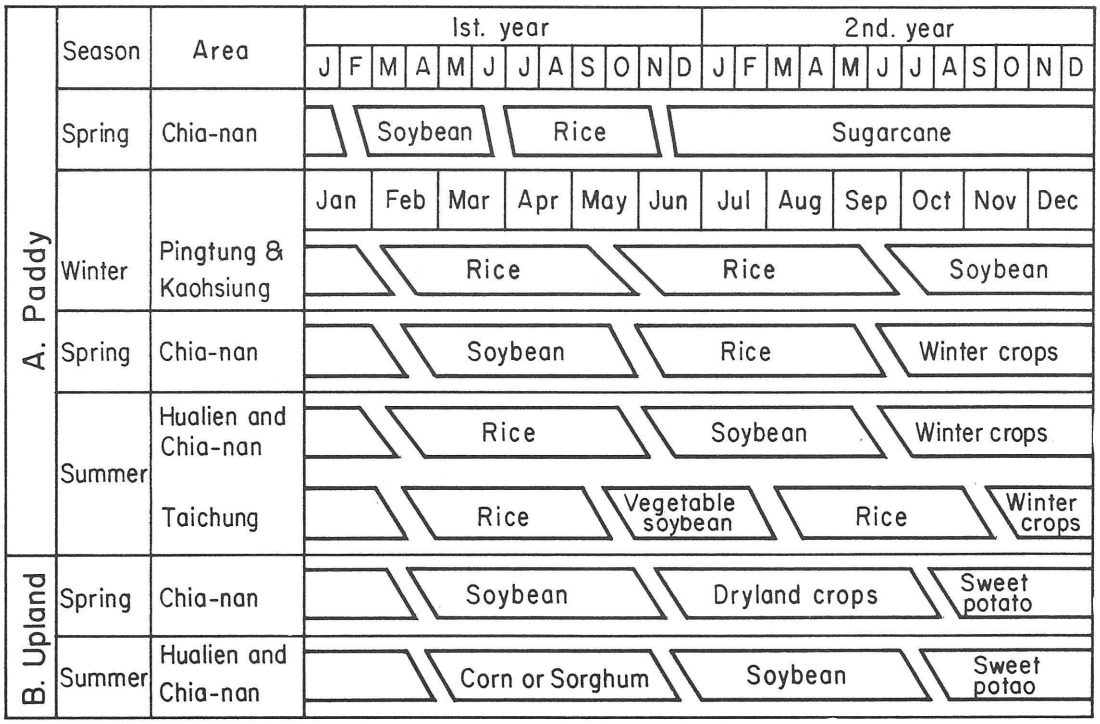

Fig. 2. Soybean cropping systems in Taiwan.

Research indicates that early soybean planting results in higher yields. Decreases of 7 to 28% were observed by planting from early to mid-October rather than in late September (Hung 1967; Anon. 1965) (Table 2).

In this system, soybean is planted in rice stubble without tillage. A small opening is dug with a hand trowel near the rice stubble. Pulling the rice stubble in an upward direction to make a hole between the soil and the stubble is also practiced. Three to four seeds are placed in each hole; covering the seed is not required. The seeding rate is usually 100 to 110 kg/ha (400,000 to 500,000 plants/ha). Plant spacings parallel those of the rice crop, either 22.5 cm x 22.5 cm or 25 cm x 25 cm. A blank row is placed every 10 or 15 rows for drainage and field operations.

Rice straw is usually spread over the field to prevent moisture loss and to control weeds. Some farmers burn the rice straw for the same reasons. This practice controls broadleaf and grassy weeds and generally increases yields (AVRDC 1976, Liu and Lee 1964, Lee 1966) (Tables 3 and 4).

Significant yield differences have been observed between soybean planted at spacings of 27 x 13.5 cm (improved rice) and 22.5 x 22.5 cm (traditional rice) (Hung and Chang 1967) (Table 5).

Hsu et al. (1983) evaluated three row spacings (22.5, 30, and 45 cm) and two seeding methods (drilling and hilling). The highest yields were obtained by combining hilling and spacings patterns of 30 x 15 cm. This suggests that wider row spacings (27 to 30 cm) not only promote yield, but are also more convenient for field operations than the traditional spacing of 22.5 cm.

In recent years grain soybean has been replaced by vegetable soybean in the Pingtung area. This trend should continue because of higher net profits (40 to 60%) for vegetable soybean.

Table 2. Soybean yield and index[z] of different planting dates in autumn (Taitung DAIS 1962-65, Hung 1967).

Cultivar	Year	Date of Planting							
		Sept. 25	Sept. 30	Oct. 5	Oct. 10	Oct. 15	Oct. 25	Nov. 5	Nov. 15
		t/ha							
Shih-shih[y]	1962	1.4 (100)[z]		1.1 (79)		1.1 (77)	1.0 (71)	0.8 (58)	0.8 (56)
	1963	0.7 (56)		0.8 (71)		1.2 (100)	1.1 (91)	0.7 (57)	0.8 (71)
	1964	0.9 (55)		1.3 (80)		1.5 (94)	1.6 (96)	1.6 (100)	1.5 (95)
	1965	1.5 (100)		1.5 (94)		1.4 (87)	1.0 (62)	0.8 (52)	0.6 (35)
TK# 5[y]	1964	1.4 (76)		1.7 (95)		1.7 (95)	1.8 (100)	1.6 (88)	1.4 (77)
	1965	2.0 (100)		1.8 (92)		1.4 (71)	1.0 (48)	0.9 (43)	0.7 (35)
Wakashima[x]	1967		2.6 (100)	2.4 (93)	2.1 (82)	1.9 (72)	- -	- -	- -

[z] Yield indices are in parenthesis
[y] Taitung County
[x] Pingtung County

Table 3. Effects of burning and mulching rice straw on soybean yield and weed control in rice stubble[z].

Rice Straw	Amount (t/ha)	Yield (t/ha)	Fresh Wt. of Weeds (g/m^2)[z]		
			broad leaf	grasses	total
Burned	4	1.7a	7a	222a	229a
Burned	6	1.8a	4a	243a	247a
Burned	8	1.8a	6a	133a	140a
Mulch	2	1.0b	71b	689b	760b
Mulch	4	1.2b	119b	611b	730b
Mulch	6	1.3b	80b	548b	628b
Control		1.2b	98b	574b	672b

Source: AVRDC Progress Report 1976
[z] Predominent weeds: Echinochloa colonum, E. crusgalli, and Aternanthera sessilis

Table 4. Effect of rice straw mulching and straw burning on soybean yields in rice stubble soybean.

Rice Straw	Pingtung		Kaohsiung	
	mean	index(%)	mean	index(%)
1964-1965				
	t/ha		t/ha	
Burning + hand weeding	1.8	122	2.4	123
Mulching + hand weeding	1.7	115	2.2	113
Mulching	1.5	100	1.9	100
1966				
Burning	1.5	111	-	-
Mulching	1.5	106	-	-
No mulching check	1.5	100	-	-

Data are based on 5 experimental locations with 3 replications each; cultivar TK#5 was used in 1964 and Acadian in 1966
Source: Liu and Lee 1964

Table 5. Effects of spacing on soybean yield in rice stubble planting.

Spacing (cm)	Plant/ha (10^4)	Yield (t/ha)			
		A[z]	B[y]	C[x]	D[w]
27.0 x 27.0	41.1	-	1.46	-	-
45.0 x 15.0	44.4	-	1.32	-	-
40.5 x 13.5	54.9	-	-	1.92	-
22.5 x 22.5	59.2	2.37	1.58	2.07	2.51
45.0 x 11.3	59.2	-	1.37	1.93	2.51
45.0 x 10.0	66.6	2.29	1.38	-	-
30.0 x 15.0	66.6	-	-	-	2.59
40.5 x 10.0	74.0	2.38	-	-	-
27.0 x 13.5	82.4	2.49	1.54	2.17	-
40.5 x 9.0	82.4	-	-	1.94	-
30.0 x 10.0	100.0	2.54	-	-	-

Source: [z]Hung 1966; [y]Lee 1966, 1967; [x]Hung and Chang 1967; [w]Liu and Hsu 1981

Soybean-Rice-Winter Crops and Soybean-Rice-Sugarcane *(Saccharum officinarum)*

Where irrigation is not sufficient for the first rice crop, or in the Chia-Nan area where a three-year rotational irrigation scheme is practiced, farmers grow two rice crops every three years. Soybean is usually grown in the spring. This system is also practiced in the Pingtung-Kaohsiung and Chia-Nan areas. It accounts for as much as 59% of Taiwan's spring soybean crop (Table 1).

Spring soybean is usually planted in February or March and is harvested 100 to 120 days later, or just before the second rice crop is transplanted in June. Conventional planting methods are used; rows are spaced at 40 to 50 cm. Drilling is widely practiced, usually at a rate of 100 to 120 kg seed/ha.

Trials have shown that the spring soybean planting date should be varied according to cultivar and location (Table 6).

Annual profits from the soybean-rice-corn (Zea mays) cropping system practiced in the Tainan and Taichung areas and the soybean-corn-broad bean (Vicia faba) system in Hsinchu were 0, 7, and -29% compared with traditional cropping patterns, respectively (Table 7-A).

Labor consumes the largest percentage of soybean production costs (37 to 75%), followed by fertilizer, regardless of cropping pattern (Table 8-A). An AVRDC survey showed that labor costs can be broken down as follows: weeding (7 to 15%) threshing and cleaning (7 to 11%), harvesting (4 to 10%), sowing (2 to 10%), and chemical spraying (5 to 8%) (Table 9).

Because the spring rice crop is often higher yielding than the summer crop, spring soybean can only be planted where the spring rice crop is particularly poor or in areas that lack sufficient irrigation. Indeed, soybean is usually grown in Taiwan on land which cannot be used for summer rice or alternative crops. Therefore, an increase in soybean production under the soybean-rice-winter crop system is unlikely to occur.

Rice-Soybean-Winter Crops

This cropping system is prevalent in the Hualien and Chia-Nan areas (Fig. 1: A1, A2, A3, and C). Rice is planted in the spring and is followed by soybean in the summer and by corn, sweet potato (Ipomoea batatas), or vegetables during the remainder of the year. The soybean area planted under this system in the Chia-nan and Hualien areas accounts for more than 50% of the total spring soybean crop in Taiwan (Table 1).

Experiments have shown that profits increased from 16 to 338% when soybean was grown in improved cropping system: Rice-soybean-cabbage (Brassica oleracea var. capitata), rice-soybean-turnip (B. rapa), sweet potato-soybean-sweet potato (northern Taiwan), interplanted rice-soybean-sweet potato, and rice-soybean-corn (southern Taiwan) (Table 7-B).

Rice-Vegetable Soybean-Rice

In central Taiwan, where paddy fields can produce two crops of rice per year, farmers relay-interplant vegetable-type soybean between the rows of the first rice crop; the soybean is harvested before transplanting the second rice crop. The amount of vegetable-type soybean planted under this pattern is small. However, the pattern has been shown to increase net profits by 51%, compared with the traditional rice-rice cropping pattern (Yang and Tseng 1983) (Table 7-B).

Upland Cropping Systems

A small amount of soybean is cultivated in rainfed, upland areas. No fixed systems have been observed, but the following patterns are widely practiced in the Chia-nan and Hualien areas.

Soybean-Dryland Crops-Sweet Potato

Farmers in the Chia-nan area plant soybean in February and harvest in early June. Corn, sorghum (Sorghum vulgare), sunflower (Helianthus annuus), melon (Cucumis melo), or turnip is planted after the soybean and is ready for harvesting 100 days later. Sweet potato or onion is grown in mid-October. The soybean-corn-turnip system increased net profits by 95% compared with the peanut (Arachis hypogaea) -sweet potato check pattern (Peng 1966) (Table 7-A).

Peanut (Corn)-Soybean-Sweet Potato

This pattern is widely practiced in the Hualien and Chia-nan areas. In Hualien, where the growing season is shorter than in the southern part of the island, farmers prefer early maturing soybean cultivars. Under this system peanut is planted in February and is harvested 110 days later. Soybean is planted in early June and is harvested in late September. Sweet potato is grown in October and is harvested the following February.

Some farmers grow corn or sorghum, instead of peanut, to avoid pest problems during the spring season. Corn has a shorter maturation period than peanut and thereby accommodates the planting of soybean in early June before the onset of the rainy season (Chia-nan area). A four-year experiment in Hualien showed that this cropping system produces 20% higher net profits compared with the peanut-sweet potato pattern (Chung and Shu 1967, Chung 1968, Chung 1969) (Table 7-B).

Conclusions

Soybean cultivars developed for use in multiple cropping systems should be early maturing as well as high yielding. Early maturity is particularly important to farmers who plant spring soybean, mainly because the crop must be harvested before the typhoon season and in time for the planting of the second rice crop. In the spring season, farmers face the problem of rain at harvest time, and may be further handicapped by cold weather. Early maturity is even more important for winter soybean because the crop can be injured by low temperatures in the latter stages of maturity (R_5 to R_7).

Table 6. Effects of planting date on soybean yield in spring and summer.

A. Taipei (Chung 1969,1970)

Planting Date	TK #5		Shih-Shih	
	days to maturity	yield (t/ha)	days to maturity	yield (t/ha)
Spring crop				
March 1	108	1.97	91	1.50
March 16	108	1.89	98	1.41
April 1	107	1.44	89	1.05
April 16	109	1.18	90	0.86
May 1	110	1.07	90	0.86
May 16	112	1.11	88	0.82
Summer crop				
June 16	93	1.34	86	1.03
July 1	93	1.25	84	1.02
July 16	94	1.33	84	0.97
Aug. 1	94	1.17	83	0.85
Aug. 16	96	1.06	83	0.83

B. Taichung (Anon. 1961)

Planting Date	Sunkok		Shih-Shih		Palmatto	
	days to maturity	yield (t/ha)	days to maturity	yield (t/ha)	days to maturity	yield (t/ha)
Spring crop						
Jan. 25	125	1.36	114	1.00	121	1.39
Feb. 15	140	1.46	101	1.14	136	1.51
March 10	-	-	104	1.25	147	1.51
March 30	-	-	82	1.13	-	-
Summer crop						
June 25	119	1.90	91	1.57	107	1.26
July 10	117	1.75	92	1.35	100	1.96
July 25	113	1.61	92	1.34	107	1.45
Aug. 10	107	1.85	89	1.09	104	1.38
Aug. 25	102	1.35	88	0.92	97	1.09

C. Tainan (Anon. 1960)

Planting Date	Sunkok		Shih-Shih		Palmatto	
	days to maturity	yield (t/ha)	days to maturity	yield (t/ha)	days to maturity	yield (t/ha)
Spring crop						
Jan. 24	96	0.35	96	0.80	96	0.50
Feb. 3	98	0.56	96	0.72	95	0.64
Feb. 13	103	0.71	91	0.76	100	0.90
Feb. 24	110	0.64	89	0.71	93	0.77
March 6	120	0.64	81	0.63	100	0.67
Summer crop						
June 25	118	0.75	83	0.30	109	0.72
July 5	111	1.08	83	0.45	105	0.91
July 15	117	0.78	85	0.32	113	0.72
July 25	105	0.70	81	0.33	110	0.58
Aug. 5	98	0.53	86	0.37	98	0.39

Table 7. Yields and net profits of various soybean cropping systems.

A. Spring Crop

Cropping System	Yield (t/ha)						Annual Net Profit (US $)
	soybean	1st rice	corn-peanut	sweet potato	2nd rice	turnip-br. bean	
Paddy							
1. Soybean-Rice-Corn	1.20	-	5.08	-	5.08	-	506
SP-Rice-SP (ck)	-	-	-	34.40	5.12	-	504
2. Soybean-Rice-Corn	1.57	-	2.52	-	4.95	-	762
Rice-Rice (ck)	-	5.42	-	-	5.02	-	711
3. Soybean-Corn-B. bean	2.00	-	4.25	-	-	5.77	1,190
Rice-Rice (ck)	-	4.77	-	-	4.65	-	1,661
Upland							
4. Soybean-Corn-Turnip	0.59	-	3.90	-	-	28.80	402
Peanut-SP (ck)	-	-	0.95	14.62	-	-	207

B. Summer Crop

Cropping System	Yield (t/ha)							Annual Net Profit
	soybean	1st-rice	cabbage-turnip	2nd-rice	s.corn[z] v.soy[x]	SP[y] SP(I)[w]	corn corn(I)	
Paddy								
5. Rice-Soybean-Cabbage	1.48	2.21	43.09	-	-	-	-	1,387
Rice-Soybean-Turnip	1.61	2.21	25.65	-	-	-	-	438
Rice-Rice (ck)[v]	-	2.21	-	2.01	-	-	-	284
6. S. corn-Soybean-SP	2.51	-	-	-	8.13	10.73	-	703
Rice-Rice (ck)	-	3.10	-	2.60	-	-	-	309
7. Rice-Soybean SP(I)[v]	1.93	3.93	-	-	-	15.03	-	781
Rice-Soybean-Corn(I)[u]	1.90	3.94	-	-	-	-	2.04	617
Rice-SP (ck)	-	3.91	-	-	-	16.14	-	530
8. Rice-V. Soybean-Corn	-	5.96	-			-	3.93	257
Rice-Rice	-	5.95	-	5.70	-	-	-	1,703

Table 7-B. Yields and net profits of various soybean cropping systems.

Cropping System	Yield (t/ha)					Annual Net Profit (US $)
	soybean	sorghum corn	cabbage turnip	peanut	sweet potato	
Upland						
9. Peanut-Soybean-Cabbage	0.88	-	49.20	1.09	-	975
Peanut-Soybean-Turnip	0.88	-	38.80	1.18	-	450
Corn-Soybean-Turnip	0.96	6.47	39.10	-	-	672
Peanut-SP (ck)	-	-	-	1.12	25.00	390
10. Peanut-Soybean-Corn	1.80	1.73	-	1.62	-	375
Peanut-Soybean-SP (ck)	1.50	-	-	1.61	18.85	537
Corn-Soybean-Turnip	1.76	3.65	25.36	-	-	552
Sorghum-Soybean-SP	1.63	2.86	-	-	16.66	628
Peanut-SP (ck)	-	-	-	1.70	20.56	445

[z] sweet corn
[y] vegetable Soybean
[x] sweet Potato
[w] intercropped
[v] traditional pattern
[v] and [u] sweet potato and corn were interplanted with preceeding crop soybean, respectively

Source: Hsu 1974, Hsu et al. 1983, Peng 1966, Chang and Chung 1973, Yang and Tseng 1983, Chung and Shu 1967

Table 8. Production cost analysis of various soybean cropping systems.

Cropping System	Total Cost (US $)	Cost Components (% of total cost)				
		labor	fert.	pestic.	seeds	others[z]
A. Spring Crop						
Paddy						
1. Soybean-Rice-Corn	653	39	25	6	4	26
Sweet potato-Rice-SP (ck)	530	37	23	4	5	31
Upland						
2. Soybean-Corn-Turnip	510	68	25	4	3	-
Peanut-SP (ck)	363	75	3	1	7	-
B. Summer crop						
On Paddy						
3. Rice-Soybean-Cabbage	458	71	19	8	2	-
Rice-Soybean-Turnip	510	67	21	9	3	-
Rice-Rice (ck)	365	69	21	7	3	-
4. Sweet corn-Soybean-SP	915	70	15	5	6	4
Rice-Rice (ck)	650	71	18	6	2	3
5. Rice-V.soybean-Corn	3,375	57	15	-	15	13
Rice-Rice (ck)	2,683	60	14	-	10	16

[z] irrigation fees, tax, and loan interest

Table 9. Comparative labor costs for soybean in winter, spring, and summer (1974-1977).

Item	Winter		Spring		Summer	
	74/75	76/77	1974	1977	1974	1977
Yield (t/ha)	1.70	2.16	2.09	2.05	1.06	1.65
Revenue (US$)	501	864	603	862	355	591
Expenses[z]						
Land preparation	4	2	13	12	11	2
Sowing	10	9	4	2	8	5
Fertilizing	2	2	1	9	2	4
Intertillage & weeding	7	13	15	13	15	12
Chemical spraying	7	6	5	8	8	8
Irrigation	1	2	5	6	-	1
Harvesting	7	8	4	5	7	10
Threshing and cleaning	7	8	9	8	8	11
Transportation	2	1	3	2	3	1
All labor	47	52	59	59	62	54

Source: AVRDC Technical Bulletin No. 11
[z]Expressed as % total cost

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Intensifying Land and Nutrient Equivalent Ratios by Intercropping Corn and Soybean in Egypt

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Introduction

The feasibility of growing soybean (Glycine max) in Egypt was first studied about 30 years ago. Subsequent experiments showed that corn (Zea mays) and soybean were compatible as companion crops (Galal et al. 1979a; Galal and Abdel-Rasool 1962; Zahran 1970; Metwally 1973). Other studies demonstrated that farmers who plant corn and soybean on alternate ridges, where each crop occupies 50% of the total land area, can produce high corn yields as well as substantial quantities of soybean.

The feasibility of developing corn cultivars that are tolerant of intercropping was also examined. The yields of 30 intercropped, local corn cultivars varied from a 44% loss to a 4% gain over sole-cropped corn (Galal et al. 1974). A positive association (r=>0.90) was found between the intercropping tolerance of a local parental cultivar and its top crosses. Cultivar Cairo 1 was identified as particularly well-suited for soybean intercropping (Galal 1983).

The search for better yielding corn cultivars and intercropping-tolerant soybean cultivars is still underway (Galal et al. 1979a, Galal and Metwally 1982). Efforts are also being made to: 1) develop soybean and corn cultivars tolerant of higher plant population densities and higher fertilizer application rates; 2) develop Rhizobium inoculum technologies as a replacement for N fertilizer, and 3) evaluate corn and soybean cultivars in different intercropping patterns in an attempt to raise land equivalent ratios (LER), income equivalent ratios (IER), and nutrient equivalent ratios (NER).

Materials and Methods

The nine corn cultivars were evaluated:

Cultivar	Season	Origin
Cairo 1	1980, 81, 82	Egypt
DC Pioneer 514	1980, 81	USA
Giza 2	1981	Egypt
DC 19	1980	Egypt
DC 186	1980	Egypt
American Early	1980	Egypt
DC 4747	1981	USA
DC 4848	1981	USA
DC 4949	1981	USA

Thirteen soybean cultivars obtained from the USA were also studied: Harosoy, Williams, Elf-dwarf, Calland, Columbus, Clark, Eatable, Hill, Metchil, Games, L 263, S 1456, and Bellatti. Range of maturity for all cultivars varied from 80 to 135 days.

Intercropping was practiced using three crop patterns: Two ridges of corn alternated with two ridges of soybean (2:2), one ridge of corn and one ridge of soybean (1:1), and two ridges of corn and one ridge of soybean (2:1) (35,700 or 47,600 corn plants/ha). Soybean cultivar Williams was used in 1980 and cultivar Clark was tested in 1981.

The variability of intercropped soybean was studied from the point of view of N fertilizer and Rhizobium inoculum application. Soybean cultivars were intercropped in a 2:2 or 2:1 pattern with Cairo 1. Either 190 kg N/ha or the granular inoculum Nitragin was applied. The trials were planted in mid-May.

Results and Discussion

Corn Tolerance to Intercropping

Corn yields differed significantly in the solid and intercropped plots (Table 1). Cairo 1 was the best yielder when intercropped in 2:2 and 1:1 patterns. Cairo 1, Giza 2, Pioneer, DC 514, and DC 4747 were the best yielders in solid plantings. Intercropped yield, relative to sole-crop yield, was used as a measure of intercropping tolerance (Galal et al. 1974). Cairo 1 proved to be the most intercropping-tolerant cultivar. The yield of all other cultivars was reduced by intercropping (Zahran 1970, Metwally 1973, Galal et al. 1979a, and Galal et al. 1981).

Soybean Tolerance to Intercropping

Earlier work on intercropping was carried out using medium- and late-maturing soybean cultivars (Galal and Abdel-Rasool 1962, Zahran 1970, Metwally 1973, Galal et al. 1974, 1979a). Late maturing cultivars produced higher yields than early maturing cultivars, both as monocrops or intercrops (Galal et al. 1979b). They were not recommended for intercropping, however, because their harvest dates did not coincide with the earlier maturing corn crop.

Table 1. Relative yields of intercropped and monocropped corn.

Cultivar	Monocropped (t/ha)	Intercropping Patterns (%)			
		2:2	1:1	2:1	Mean
1980					
Cairo 1	7.71a[z]	82.4a	-	92.7a	87.6
Pioneer 514	8.56a	67.1b	-	87.7a	77.5
D.C. 19	7.27ab	69.6b	-	78.7b	74.2
D.C. 186	6.27c	81.3b	-	85.8b	83.6
American Early	7.04b	78.3a	-	72.7b	75.5
Mean	7.37	75.3	-	83.9	79.6
1981					
Cairo 1	7.83a	93.9a	77.5ab	-	85.7
Pioneer 514	6.55b	62.4c	63.8b	-	63.1
Giza 2	7.75a	69.2a	56.9ab	-	63.1
D.C. 4747	7.66a	66.3ab	63.4a	-	64.9
D.C. 4848	5.74c	78.2c	79.6ab	-	78.9
D.C. 4949	6.15b	75.6bc	68.5b	-	72.1
Mean	6.95	74.3	68.3	-	71.3

[z]Values followed by the same letter within each column are not significantly at the 5% level according to Duncan's Multiple Range Test

Tolerance to intercropping varied according to soybean cultivar, corn cultivar, and intercropping pattern (Tables 2 and 3). The relative yield/plant of the intercropped soybean cultivars ranged from 23% to 53% (Table 2). Several cultivars proved to be relatively more tolerant to intercropping than others: Bellatti, Clark, Harosoy, Hill, Williams, Eatable, Elf-dwarf, Cumberland, Columbus, Games, and Metchil. Mixed-intercropping adversely affected soybean more than row-intercropping (Table 3). The 2:2 pattern was more conducive to soybean than other intercropping patterns.

Table 2. Relative performance of intercropped soybean cultivars as compared to solid cropping.

Cultivar	Yield	
	monocropped (t/ha)	intercropped (%)
Bellatti seeds	3.5	35.0
Clark	3.8	29.1
Harosoy	3.3	35.2
Hill	2.9	38.9
Williams	3.6	31.5
Eatable	3.4	41.1
Pomona	3.5	25.1
Woodworth	3.4	27.0
Elf-dwarf	2.9	32.1
Galland	3.9	19.2
Bellatti D-1	3.4	31.2
Bellatti B-W	3.9	22.6
L 263	4.3	20.6
Union	3.1	26.3
Cumberland	3.0	30.0
Columbus	4.0	33.8
Games	3.4	29.4
Metchil	2.8	40.3
Mean	3.5	30.1
New LSD 0.01	0.5	-

Table 3. Relative yield of selected soybean cultivars grown under different intercropping patterns.

Cultivar	Monocropped (t/ha)	Relative Yield of Intercropping (%) row-intercropping			Mixed Intercropping
		2:2	1:1	2:1	
Williams	2.65	-	-	35.9b	30.9a
	3.63	35.6ab	27.5a	-	-
Clark	3.13	-	-	38.9a	18.7b
	3.78	32.7ab	25.4a	-	-
Calland	2.67	-	-	29.1b	18.9b
	3.93	21.9b	16.6	-	-
Hill	3.46	-	-	40.4a	21.9a
	2.92	48.7a	29.1a	-	-
L. 263	4.29	20.6	20.7a	-	-
Columbus	4.01	38.2a	29.5a	-	-
Bellatti seeds	3.54	39.6a	32.4a	-	-
Eatable	3.37	46.1a	36.0a	-	-
New LSD 0.01 (1)	457	-	-	-	-

Source: Galal and Metwally (1982) and Galal et al. (1983)

Nitrogen Application and Rhizobium Inoculation

Nitrogen fertilizer and Rhizobium inoculum were applied to soybean planted at twice the normal plant density. Some differences in varietal response were observed (Tables 4 and 5). The yield of cultivar L 263, for example, was better in the Rhizobium treatment than in the N treatment, whereas the opposite was true for cultivar Hill.

Although varietal differences were observed, all cultivars produced higher yields when plant population density was doubled (Table 5). Yield increases ranged from 127% to 177% in the N treatment and from 97% to 160% in the Rhizobium treatment compared with the same cultivars planted at normal densities.

Land Equivalent Ratio (LER)

Land equivalent ratios were higher in the intercropping treatments than in the monocropping treatments. LER was also higher as plant population densities increased. LER averaged about 1.36, but ranged from 1.13 to 1.69 (Table 6). Cultivar Cairo 1 had the highest LER of all corn cultivars tested. The best yields were achieved in the 2:2 cropping pattern.

Some soybean cultivars proved to be more suitable for intercropping than others (Table 7). Line S 1456 was the most tolerant; its LER ranged from 1.50 to 1.79. Two rows per ridge produced higher LERs than other planting configurations, and LERs were generally higher in the inoculated treatments than in the N fertilizer plots. These results agree with earlier findings (Galal et al. 1979a, 1981, 1983).

Nutrient Equivalent Ratio

Nutrient equivalent ratios (NER) were calculated on the basis of the energy production (calories) of both crops (Anon. 1963). It was assumed that corn contains more starch than soybean (216%), but less protein (26%) and oil (23%). Egyptian corn yields are about twice as high as local soybean yields; however, the relative energy (specific weight) of corn is about 86% that of soybean. This means that replacing corn with soybean will result in a net energy loss.

In general, NER values paralleled LER values (Table 6 and 7). Intercropping corn and soybean therefore seems to offer more energy and yield per hectare than monocropping.

Table 4. Yields of nitrogen- and rhizobium-treated cultivars as influenced by monocropping and intercropping, 1981.

Cultivar	Monocropped (t/ha)		Intercropped			
	+N (t/ha)	inoculated (t/ha)	+N (t/ha)	+N (%)	inoculated (t/ha)	inoculated (%)
Bellatti seeds	1.8	1.9	0.8	42.8	0.7	36.7
Harosoy	2.0	2.0	0.7	34.8	0.8	38.3
Williams	2.2	2.3	1.0	43.9	0.9	38.6
Elf-dwarf	1.5	1.6	0.6	38.6	0.7	43.6
Calland	2.0	2.0	0.7	31.2	0.6	31.8
Clark	2.3	2.4	0.8	33.3	0.9	38.5
Eatable	2.0	2.0	0.8	41.1	0.9	40.9
L 263	2.9	2.8	0.5	17.2	0.8	27.3
Columbus	2.7	2.8	1.0	35.1	0.8	28.4
Hill	1.9	2.0	1.0	50.4	0.8	40.5
Games	2.2	2.2	0.5	31.5	0.7	30.8
Metchil	2.2	2.3	0.7	31.5	0.7	32.0
Mean	2.1	2.2	0.7	34.4	0.8	35.6
New LSD 0.01	0.3	0.2	0.2	-	0.2	-

Table 5. Yield of intercropped soybean cultivars grown under N fertilization, inoculation, and at different plant population densities, 1982.

Cultivars	Intercropped Soybean Yields (t/ha)						General Mean
	N fertilization			inoculation			
	1 row	2 rows	mean	1 row	2 rows	mean	
S 1456	0.6	1.0	0.8	0.6	1.0	0.8	0.8
Bellatti seeds	0.7	1.1	0.9	0.9	1.2	1.1	1.0
Williams	1.0	1.4	1.2	1.1	1.0	1.0	1.1
Eatable	0.9	1.5	1.2	1.1	1.6	1.3	1.3
L 263	0.7	1.2	1.0	1.2	1.5	1.4	1.2
Columbus	0.9	1.4	1.1	1.0	1.4	1.2	1.2
Hill	0.8	1.2	1.0	1.0	1.3	1.1	1.0
Mean	0.8	1.3	1.0	1.0	1.3	1.1	1.0
New LSD 0.01	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 6. Land and nutrient equivalent ratios of selected corn cultivars grown under different intercropping patterns.

Cultivar	LER			NER		
	2:2	2:1	mean	2:2	2:1	mean
1980						
Cairo 1	1.5	1.5	1.5	1.4	1.5	1.5
D. C. Pioneer 514	1.2	1.5	1.4	1.3	1.5	1.4
D. C. 19	1.3	1.3	1.3	1.3	1.3	1.3
D. C. 186	1.4	1.4	1.4	1.4	1.4	1.4
American Early	1.4	1.2	1.3	1.3	1.2	1.3
Mean	1.4	1.4	1.4	1.3	1.4	1.3
1981						
Cairo 1	1.7	1.4	1.5	1.7	1.4	1.5
D. C. pioneer 514	1.3	1.2	1.2	1.2	1.2	1.2
Giza 2	1.3	1.1	1.2	1.3	1.1	1.2
D. C. 4747	1.3	1.2	1.2	1.3	1.2	1.2
D. C. 4848	1.5	1.4	1.4	1.5	1.4	1.4
D. C. 4949	1.4	1.3	1.3	1.4	1.2	1.3
Mean	1.4	1.3	1.3	1.4	1.2	1.3

LER = sum of the ratios of yields of crop mixtures divided by monoculture yields.

Table 7. Effect of plant populations, source of fertilization, and soybean cultivars on LER and NER, 1982.

Cultivar	Land Equivalent Ratio				Mean	Nutritive Equivalent Ratio				Mean
	fertilizaton		inoculation			fertilization		inoculation		
	1 row	2 rows	1 row	2 rows		1 row	2 rows	1 row	2 rows	
S 1456	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8	1.7
Bellatti seeds	1.6	1.7	1.7	1.7	1.7	1.5	1.6	1.6	1.7	1.6
Williams	1.6	1.6	1.6	1.7	1.6	1.5	1.6	1.6	1.6	1.6
Eatable	1.6	1.8	1.7	1.7	1.7	1.6	1.7	1.6	1.7	1.7
L 263	1.6	1.6	1.5	1.6	1.6	1.5	1.6	1.5	1.5	1.5
Columbus	1.5	1.6	1.6	1.7	1.6	1.5	1.5	1.6	1.6	1.5
Hill	1.6	1.6	1.7	1.7	1.6	1.5	1.6	1.5	1.7	1.6
Mean	1.6	1.7	1.6	1.7	1.7	1.6	1.6	1.6	1.6	1.6

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Soybean-Based Cropping Systems in Korea

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Introduction

On the basis of area planted, soybean (Glycine max) is the third most important food crop in Korea, followed only by rice (Oryza sativa) and barley (Hordeum vulgare) (Anon. 1982a). The area planted to soybean, however, fell from 312,000 ha in 1973 to 156,000 ha in 1985 (Anon. 1985) mainly because of higher prices for crops such as red pepper (Capsicum annum), sesame (Sesamum indicum), potato (Solanum tuberosum), peanut (Arachis hypogaea), and vegetables.

Despite this reduction, domestic soybean production in 1985 totaled 234,000 t, compared with 246,000 in 1973, mainly because of a 90% increase in productivity (0.79 t/ha in 1973; 1.50 t/ha in 1982). During the same period, annual domestic consumption increased by nearly 750,000 t.

In general, land use ratios as a whole are decreasing (Table 1). In upland regions the area planted to all pulses is declining, while that of vegetables and other crops is increasing (Table 2).

Major Soybean-Based Upland Cropping Systems

Monocultures

Monoculture cropping, which is common in the north-central and southern mountain areas of Korea, occupied 25% of the total soybean production area in the early 1970s, but has since increased to 44% (Anon. 1982d), mainly because of declining barley and wheat (Triticum aestivum) production. In this type of cropping system soybean is usually planted in early or mid-May. The recommended planting density is 60 cm between rows, 15 cm between hills, and 2 plants/hill. Only a small number of soybean cultivars are available for monoculturing because varietal improvement programs emphasize the development of cultivars adapted to barley-soybean rotations.

Sequential Cropping

Soybean planted at the end of June is referred to as an "after-barley crop," even though the previous crop may not have been barley. The major after-barley patterns are summarized below.

Barley (Wheat)-Soybean: Until the early 1970s nearly 58% of all upland cropping patterns consisted of barley-soybean (Table 3). This pattern can still be found in the central and southern parts of the country.

Because soybean planted after barley has a shorter maturation period than full-season soybean, farmers plant their soybean crops as soon after the barley harvest as possible. Studies suggest that a one-day delay in planting results in a 10 to 20 kg/ha yield loss (Anon. 1969, 1980, 1982a). For this reason, labor-saving planting methods were compared (Anon. 1975). Hill planting between barley rows with no tillage, using a small mechanical planter, significantly reduced labor requirements, compared with the standard planting method, without reducing yield (Table 4).

Table 1. Paddy and upland hectarage and land utilization ratios[z] in Korea.

	1975	1977	1979	1981	1984
Hectarage (1,000)					
Paddy	1,277	1,303	1,310	1,308	1,319
Upland	963	928	896	880	832
Utilization ratio (%)					
Paddy	131	125	123	119	-
Upland	153	150	142	138	-
Average	140	136	131	127	125

[z] Land utilization ratio: Sum of hectarage cultivated per year divided by available hectarage x 100
Source: Anon. (1977, 1982d)

Table 2. Upland crop hectarage in Korea.

	1975	1977	1979	1981	1985
Pulses	317[z]	310	264	260	-
Soybean	274	251	207	202	156
Vegetables	223	267	296	326	-
Fruits	74	94	96	100	-

[z] (x 1,000)
Source: Anon. (1977, 1982d, 1986)

Table 3. Upland cropping patterns in Korea, early 1970s.

Cropping Pattern	Area (ha)	Ratio (%)	Location
Barley-soybean	345	57.6	Whole country
Barley-sweet potato	111	18.6	Southern area
Barley-miscellaneous	26	4.4	Central mountains and southern coastal area
Barley-vegetables	26	4.4	Whole country (suburban area of cities)
Barley-sesame	16	2.6	Whole country (southern area)
Others	24	3.9	
Potato-vegetables	19	3.1	Central mountains
Potato-legumes	14	2.3	Central area
Potato-others	20	8.6	

Source: Anon. (1982c)

Table 4. Comparison of planting methods for after-barley soybean in Korea.

Planting Method	Soybean	Labor (h)	
	yield (t/ha)	human	machine[z]
Tillage, flat-row hill planting (standard)	1.73	117	10
Barley stubble broadcasting	1.84	66	44
Two-plow ridge hill planting	1.90	126	22
No tillage between-barley rows, drill planting	1.92	5	5
LSD (5%)	NS	5.2	6.5

[z] Korean made-cultivator (8 hp)
Source: Anon. (1975a)

The area planted to wheat is less than 20,000 ha (Anon. 1982b), but wheat-soybean cropping is possible in the southern part of the country if farmers use early maturing cultivars (Table 5).

Potato-Soybean-(Spinach): In urban areas, Spinach (Spinacia oleracea) is often planted after the soybean harvest in late September or early October; potato is planted in early March after the harvesting of the spinach.

Soybean-Rape: Rape (Brassica napus) is mainly grown on Jeju Island and along the coastal provinces of Jeonnam and Kyungnam. It is planted in early November and is harvested in late June. Soybean is planted after the rape harvest; soybean harvesting takes place in mid- or late October.

Soybean-Onion: Onion (Allium cepa) is transplanted in the southern part of Korea. following the October soybean harvest, and is harvested in late June prior to the planting of the next soybean crop.

Other Patterns: Minor sequential cropping systems include sweet corn (Zea mays) -soybean, garlic (Allium sativum) -soybean, tobacco (Nicotiana tabacum) -soybean, spring spinach-soybean, spring Chinese cabbage (Brassica pekinensis) -soybean, vegetable soybean-Chinese cabbage, and bean-soybean.

Intercropping

Barley/Soybean Relay-Intercropping: Relay-intercropping has several advantages over after-barley cropping: 1) soybean yield can be increased by extending the growing period, 2) the seedlings are protected by the barley from exposure to cold temperatures, and 3) soybean planting can be carried out when soil moisture conditions are adequate for the soybean crop. The system also assists farmers by reducing labor requirements that may otherwise conflict with barley harvesting or rice transplanting.

Intercropping systems are best described according to row spacing patterns. In one system, barley is planted in the autumn in 100 to 120 cm rows placed next to one or two rows of soybean (50 to 60 cm between rows, 15 cm between hills, and 2 plants/hill). The soybean is relay-intercropped about one month prior to the barley harvest. These practices facilitate the planting and fertilization of the soybean crop and the harvesting of the barley.

Barley and soybean yields are generally poor in single-row systems because of lower planting densities. If row widths are widened, barley yields decline even further, although soybean yields can be improved by increasing the number of soybean rows (Table 6).

Table 5. Yields under sequential wheat-soybean cropping at different planting dates at two locations in Korea.

Kyungbuk PORD 1976-77			Kyungnam PORD 1977-78		
planting date S/W[z]	yield (t/ha) S/W	index S/W	planting date S/W	yield (t/ha) S/W	index S/W
May 29/ Oct. 20	2.63/2.22	100/100	May 28/Oct. 25	2.23/6.38	100/100
June 8/ Oct. 20	2.71/2.46	103/111	June 7/Oct. 25	2.44/5.86	109/ 92
June 18/Oct. 27	2.80/2.87	109/129	June 17/Nov. 1	2.27/5.88	102/ 92
June 28/ Nov. 3	2.51/2.41	95/109	June 27/Nov. 8	2.25/5.84	101/ 92
July 9/ Nov. 10	2.25/1.81	86/ 81	July 7/Nov. 15	1.75/5.64	78/ 88
LSD (5%)	0.35/0.16			0.20/NS	

[z]S/W: Soybean/wheat
Source: Anon. (1978a) and Anon. (1978b)

Another relay-intercropping system involves the narrow row-planting of barley. The barley is planted in 60 cm-row widths, similar to sole-cropped barley; the soybean is relay-intercropped about one month prior to the barley harvest. This pattern benefits soybean yields without reducing the productivity of the barley crop, but it complicates the planting and fertilization of the soybean crop and the harvesting of the barley. Relay-intercropped soybean is reportedly 22% more productive than after-barley cropping (Table 7).

Table 6. Comparison of yield and income for soybean and barley at different row widths of barley in a barley-soybean intercropping pattern.

Barley Row Width (cm)	No. of Soybean Rows	Yield (t/ha)		Net Income (US $/ha)	
		barley	soybean	total	index
40	1	6.36	2.49	1,112	92
60	1	5.94	2.77	1,214	100
80	2	5.91	2.66	1,097	90
120	2	5.55	2.96	1,239	102
LSD (5%)		0.40	0.25	101	

Table 7. Soybean yields at different periods in a barley-soybean intercropping pattern.

No. of Days[z]	0[y]	15	22	29	36	LSD (5%)
Soybean yield (t/ha)	2.04	2.29	2.34	2.41	2.51	0.25
Yield index	100	111	114	118	122	

[z]number of days of soybean planting before barley harvest
[y]0=June 15
Between barley rows: 60 cm.
Soybean yield full-season/monoculture:2.78 t/ha
Source: Anon. (1975a)

Corn/Soybean Strip-Intercropping: This pattern is commonly practiced in mountainous areas (Kwangweon, Chungbuk, and Kyungbuk) where corn is the predominant crop. Yield and income from corn/soybean intercropping differ according to the planting ratios used for each crop. Although the corn/soybean cropping pattern provides no significant monetary benefit, it has been promoted as a way of preventing soil erosion and maintaining soil fertility (Anon. 1974, 1978a).

Potato/Soybean Relay-Intercropping: When potato is planted in late March or early April, soybean can be relay-intercropped in late May or early June, about 20 days before the potato harvest. The soybean is planted next to the potato hills, or between the hills, at a planting distance similar to that of the potato crop (60 cm between rows, 25 cm between hills, and 2 plants/hill). The above-ground parts of the potato plant are removed as soon as the soybean emerges. Potato/soybean relay-intercropping reportedly produces 29% more soybean than soybean-potato sequential cropping, without reducing potato yields (Table 8) (Anon. 1968).

Tobacco/Soybean Relay-Intercropping: This cropping pattern is mainly used in the mountainous central region. Soybean planting takes place in early July when the fifth tobacco leaf is harvested. Soybean seeds are planted on both sides of the tobacco rows (90 cm between rows), with a planting density of 45 cm between rows, 15 cm between hills, and 2 plants/hill. The soybean yield from a tobacco/soybean intercropping system was said to be 1.64 t/ha and 1.19 t/ha when planted on June 25 and July 15, respectively (Anon. 1975a). A yield of only 1.0 t/ha was recorded when planting took place on July 5 (Anon. 1977).

Table 8. Yield and income for sole-, inter-, and sequential-cropping of soybean and potato in Korea.

Cropping Pattern	Potato Yield (t/ha)	Soybean yield (t/ha)	Soybean index	Net Income (US $/ha)
Potato sole cropping	21.1	-	-	1,035
Soybean sole cropping	-	1.90	150	348
Potato-soybean relay intercropping	21.7	1.64	129	1,227
Potato-soybean sequential cropping	21.1	1.27	100	1,117
LSD (5%)	NS	0.21		55

No. of plants (potato and soybean): 66,660/ha
Source: Anon. (1968)

Summer Soybean

Summer soybean is generally planted at the end of March or in early April and is harvested in early June (vegetable-types in the green house) or in early August (grain-types). Autumn vegetables generally follow the soybean harvest. The yield of summer soybean is about 70 to 80% of monocropped soybean (Anon. 1982a). Despite lower yields, summer soybean production is increasing because two crops can be harvested (soybean and vegetables) instead of just one.

Rice-Bund Soybean

Approximately 15,000 ha of rice-bund soybean are grown annually in Korea (Anon. 1983), a figure equal to 7.3% of the country's total soybean hectarage. Because many rice fields are located on hillsides, rice bunds are generally wide enough to grow two rows of soybean.

Rice-bund soybean has a number of advantages compared with an upland soybean crop, e.g. lack of drought and fewer disease and insect problems (the latter is linked to the pesticides applied to the rice). The optimum planting density for rice-bund soybean is 20 cm between hills and 2 plants/hill (Anon. 1976).

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Soybean in Cropping Systems in Thailand: Technical and Socio-Economic Aspects

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Soybean Cropping

Soybean (Glycine max) is usually grown in Thailand as a mixed-crop. Approximately 70% of all soybean production is derived from upland planting; the remainder is grown under irrigation.

There are two distinct upland soybean cropping patterns. In the first, soybean is planted in April to be followed later in the season by a crop such as cotton (Gossypium hirsutum). This system is mainly used in the lower northern part of Thailand. Farmers in central upland areas plant their main crop in April-May, usually corn (Zea mays), and follow it with soybean in August-September as a relay cropping.

Irrigated soybean is planted in December between rice stubble. This system is prevalent in the northern part of the country, especially in areas with heavy, moisture-retaining soils.

Soybean Intercropping

Although soybean production has increased three-fold in the past decade, current demand exceeds local production capabilities. The Department of Agriculture has conducted research to provide a basis for additional expansion. Three of these projects are highlighted in the following sections.

Corn-Soybean Intercropping

Studies were conducted at the Praputtabat Field Crops Experiment Station, a region where soybean is usually relay-cropped with corn. The principal management variable studied was the delay between corn and soybean planting. Paired-rows of soybean were grown in 20 x 10 cm spacings between 100 x 56 cm corn rows (3 plants/hill). Trial results are presented in Table 1. Soybean yields ranged from 0 to 0.73 t/ha when planted within 65 days of corn planting, compared with 1.8 t/ha for sole-cropped soybean grown at the same planting density. Corn yields were only affected when the crop was planted at the same time as soybean. Land equivalent ratio (LER) values ranged from 1.10 to 1.28.

If one assumes that the price of soybean is three times that of corn, the gross returns from the 50- and 65-day-treatments would be about 25% higher than from corn alone. With delays of 80 and 95 days, soybean yields were between 60% and 70% of sole-cropped soybean yields. Under these treatments, gross income could have been at least 80% greater than that of sole-cropped corn. When soybean planting was delayed until after the corn harvest, soybean yield was only about 50% of that of the sole-cropped soybean planted earlier.

Sole-cropped soybean after corn was also studied. The main plots were used to compare conventional tillage after the corn harvest and no-till. Paraquat was applied in the no-till treatment one week before the soybean was planted among standing corn stalks. It should be noted that in areas of Thailand where soybean

follows corn, corn seeds are usually planted in furrows (in some areas corn is planted on hills without a definite row arrangement). The six subplots in this experiment were used to study weed control and mulching with corn residues. The results obtained at the Srisamrong Field Crop Experiment Station are presented in Table 2. Soybean yields were not significantly affected by land preparation. However, without weed control, yield was reduced approximately 50%. Two hand-weedings and mulching produced a yield of 0.9 t/ha. The difference between hand-weeding and herbicide application was not significant. Mulching seemed to be of some benefit, but further studies are needed to determine the economic returns of the weed control and mulching treatments.

Cotton-Soybean Intercropping

Cotton is normally planted in the latter part of the rainy season so that the bolls can be harvested in the dry season. Soybean is planted in the early part of the rainy season, and the cotton is relay-cropped between the soybean rows.

In 1981, soybean was planted at a date when conditions were favorable for soybean production; cotton was relay-cropped at successive intervals following the establishment of the soybean crop. The experiments also involved a range of between- and within-row spacings.

Soybean yields were satisfactory when the crop was planted well before the cotton, but the relayed cotton crop suffered from drought because of late planting. LER values were generally less than 1.00, and no combination of crops produced greater income than sole-cropped cotton planted at the optimum date.

In 1982, the experiments were redesigned so that cotton plantings could be carried out at an appropriate date. Soybean plantings were established at a series of dates before the cotton was planted. Results from the Srisamrong Station are summarized in Table 3. Combinations with soybean planted 20 days before cotton gave LER values of 1.34 to 1.39. Soybean yields averaged 72% of the sole-cropped soybean and cotton yields averaged 61% of sole-cropped cotton. When planted 40 days before cotton, soybean yielded 78 to 95% of the sole-crop; cotton yields were reduced to only 24 to 50% of the sole-crop. Cotton yields were further reduced to 26 to 30% of the sole-crop yields when planting took place 60 days after the soybean was sown. Soybean yields were about 75% of the sole-crop. Treatments with high LER values and cotton yields of 60% of the sole-crop produced about 33% more income than sole-cropped cotton.

Table 1. Intercropped corn and soybean yields, 1982, Praputhabat Field Crop Experiment Station.

Treatment	Grain Yield (t/ha)		LER
	corn	soybean	
Soybean intercropped with corn	2.8	0.7	1.10
Soybean 35 days after corn	4.6	0	1.18
Soybean 50 days after corn	4.0	0.3	1.12
Soybean 65 days after corn	4.1	0.4	1.28
Soybean 80 days after corn	3.9	1.3	1.74
Soybean 95 days after corn	3.9	1.1	1.60
Soybean after harvesting corn (110 days)	3.7	0.9	1.47
Sole-corn (75 x 75 cm)[z]	3.9	-	-
Sole-soybean (50 x 20 cm)[y]	-	2.0	-
Sole-soybean (20 x 10 cm)[x]	-	1.8	-

[z] Three plants/hill
[y] Two plants/hill
[x] One plant/hill
Source: Anon. 1982a

Table 2. Soybean yield after corn as affected by land preparation, weeding, and mulching, 1981, Srisamrong Field Crop Experiment Station.

Treatment	Yield (t/ha)
Main plot (A)	
land preparation	0.8
no land preparation	0.6
F-test (A)	NS
Subplot (B)	
no weeding	0.4
two hand-weedings	0.7
herbicide[z]	0.7
herbicide + mulching	0.8
two hand-weedings + mulching	0.9
mulching	0.7
Average	0.7
F - test (B)	**
LSD (.05)	0.2
LSD (.01)	0.3

Source: Anon. (1982a, 1982b)
[z] Metolachlor

Table 3. Soybean-cotton intercropping yields, 1982, Srisamrong Field Crop Experiment Station.

Treatment	Yield (t/ha) soybean	cotton	LER
Sole-soybean	3.0	-	-
Sole-cotton	-	1.9	-
Single row of soybean and cotton (150 cm)			
soybean 20 days before	2.2	1.2	1.34
soybean 40 days before	2.4	0.7	1.16
soybean 60 days before	2.3	0.6	1.07
Paired-rows of soybean and cotton (150 cm)			
soybean 20 days before	2.2	1.0	1.39
soybean 40 days before	2.8	0.4	1.07
soybean 60 days before	2.4	0.5	1.05
Paired-rows of soybean and cotton (200 cm)			
soybean 20 days before	2.2	1.2	1.38
soybean 40 days before	2.4	0.9	1.37
soybean 60 days before	2.2	0.5	0.70

Source: Anon. (1982d)

Cassava-Soybean Intercropping

The results from two years of cassava (Manihot esculenta) -soybean intercropping at two locations are summarized in Table 4. Cassava was planted in a 100 x 100 cm configurations at the same time as the soybean. Soybean row arrangements included one row between two cassava rows, paired-rows spaced 20 cm apart, and paired-rows spaced 33 cm apart. In all row treatments hills were spaced at 20, 10, and 5 cm. Hill treatments included one and two plants per hill.

Soybean yield increased as plant density expanded, but cassava yield decreased. This trend occurred regardless of whether soybean density increased by row number, number of hills, or by number of plants per hill. This phenomenon was most conspicuous where average yield was calculated for each of the plant densities that were obtained with various row and in-row arrangements. At the highest densities, soybean yields were reduced by 80 to 90% of the sole-crop, whereas cassava yields were reduced by 35%. Other studies have shown that reductions in cassava yields can be limited by using wider spacings between cassava rows.

Discussion

In corn-soybean cropping systems a delay in the onset of the monsoon may result in the late planting of the corn. If presently available soybean cultivars are interplanted less than 75 days after the corn, in the hope of avoiding moisture stress during the pod filling stage, soybean yields may be reduced because of shading.

When a favorable price for soybean is anticipated, farmers may wish to shift their planting schedule for soybean to an earlier date. If cotton is planted at the regular time, competition from the soybean crop may greatly reduce cotton yields. On the other hand, if the cotton is planted early, the bolls may be damaged by late monsoon rains. Another option would be to plant cotton after the soybean harvest, but the cotton might be subjected to moisture stress.

Hence, farmers' choices are limited, and research must continue to seek plant genotypes, crop geometry, and planting schedules that improve the odds of producing successful crops. Where erratic rainfall patterns and commodity prices are important, cropping systems must include probable options rather than being restricted to deterministic models.

Table 4. Average yield of soybean intercropped with cassava at Huay Pong and Ban Mai Samrong, 1980 and 1981.

Treatment	Yield (t/ha) soybean (grain)	Yield (t/ha) cassava (fresh roots)	LER
Rows of soybean			
one row	0.7b[z]	22.8a	1.50
paired-rows at 10 cm	0.9a	19.0b	1.53
paired-rows at 33 cm	0.9a	18.4b	1.50
Spacing of soybean hills			
20 cm	0.6c	20.7a	1.38
10 cm	0.8b	21.0a	1.54
5 cm	1.0a	18.4b	1.60
Plants per hill			
1	0.8b	20.6a	1.50
2	0.9a	19.4a	1.51
Soybean population (plants/ha)			
50,000	0.4	23.5	1.32
100,000	0.6	22.3	1.45
200,000	0.8	19.4	1.44
400,000	1.0	19.4	1.61
800,000	1.1	15.3	1.56
Sole-crop yield	1.2	24.0	-

[z] Values followed by same letter are not significantly different at the 5% level
Source: Anon. 1982c

Production Costs and Profit Margins

The estimated average cost of production of sole-cropped soybean in Thailand (1982) is presented in Table 5. Of the total cost of US $249.30/ha, 88% involved cash and non-cash variables. Labor accounted for 67% of the total. Forty-two percent of that amount was for land preparation, planting, and weeding. Of the remaining labor costs, harvesting, threshing, and drying represented 19% of the total. In contrast inputs such as seed, fertilizer, pesticides, and fuel accounted for only 17% of total production costs. From these data it is apparent that the level of technology for soybean production in Thailand is comparatively low when judged against the modern, mechanized agriculture used in other countries.

When average yields are 1.0 t/ha, the average cost of production is US $0.24/kg. At the average farm price of US $0.27/kg, gross income is US $273.20/ha, leaving a profit margin of only US $23.90/ha. While this figure seems rather minimal, soybean intercropping provides an effective way of obtaining a profitable return from family labor.

Current soybean prices and input costs in Thailand leave little incentive for using fertilizers, pesticides, and improved cultivars. More effective technology transfer programs could help to improve farmers' production efficiency and profit margins.

Table 5. Soybean production costs.

Item	Cost (US $/ha)		
	cash	non-cash	total
Variable cost - total	122.60	96.90	219.50
1. Labor - total	83.00	83.60	166.60
Land preparation	36.50	17.60	54.10
Planting	9.90	17.80	27.70
Weeding	4.40	17.60	22.00
Chemical application	5.20	9.10	14.30
Harvesting	14.50	10.10	24.60
Threshing and drying	12.50	11.40	23.90
2. Materials - total	38.10	4.90	43.00
Seed	11.40	4.90	16.30
Fertilizer	11.50	-	11.50
Chemicals	9.60	-	9.60
Gasoline and miscellaneous	5.60	-	5.60
3. Others - total	1.50	8.40	9.90
Equipment repair	1.50	-	1.50
Opportunity cost	-	8.40	8.40
Fixed cost - total	5.60	24.20	29.80
Land	5.60	22.40	28.00
Depreciation	-	1.80	1.80
Total cost	128.20	121.10	249.30
Income and profit			
Yield (t/ha)			1.031
Cost (US $/kg)			0.241
Average farm price (US $/kg in 1982)			0.265
Farm income (US $/ha)			273.20
Profit margin (US $/ha)			23.90
Profit margin (US $/ha over cash expenses)			145.00

Source: Anon. (1982e)

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Discussion Section I

Question: In your experiments it appears that planting date, shading, and competition for nutritients each have individual effects. Do you have any evidence to show how much influence each component has on the yield of intercropped soybean?

Fukai: The time of sowing had a small effect on yield. One reason is that the soybean planted in October had a little longer growing season than the crop planted in December. There was an extremely high yield from the October planting. We applied nitrogen and other fertilizers at the beginning of the experiment, and by the time we planted the last soybean crop in January we were aware that the nutrients were not at an optimum level. Therefore, time of planting and nutrients are probably both responsible for yield decreases over time. When soybean was sown at the same time with cassava, the soybean grew faster than cassava, and it probably influenced the cassava by shading it. But I also think that if the soybean is quick growing and is planted at the same time with cassava, it exploits more nutrients than the cassava. I would imagine that soybean roots grow faster than cassava. When soybean is sown later, say nine weeks after cassava planting, cassava growth is in an advanced stage and exploits the minor nutrients available in the soil. In addition, the cassava was taller than the soybean and shaded it. Both shading and nutrient competition influences performance.

Question: Among peanut, soybean, mungbean, and cowpea, you said that peanut does better than the others and that mungbean was not so affected by waterlogging. Did you observe the root systems of the four crops?

Carangal: We looked at the root systems. Peanut and mungbean root systems were better than the other two legumes.

Question: Concerning plant population density, you mentioned that there were no significant differences between 600,000 plants and 300,000 plants. Under such circumstances would you advise the farmers to use 600,000? Second, did you identify the factor responsible for the differences in yield between mulching and no mulching?

Carangal: Regarding plant population density, 300,000 plants/ha is a more normal population. But if the farmer broadcasts the seed, then a higher population density is needed to get a better stand. It also depends on the cultivar. But at this point I cannot make recommendations. For the second question we have a paper about it, and if you are interested we can provide a copy.

Question: Have you identified any shade tolerant cultivars?

Whigham: Not yet. As I said, this is our first year. Other researchers are also studying this, and they have not identified cultivars that are shade tolerant.

Question: We have been trying soybean with different intercrops such as sorghum, maize, and pigeon pea. But looking at only land equivalent ratios may not help much. When we look at the net returns, intercropping soybean with sorghum or maize is relatively poor compared with intercropping soybean with pigeon pea. Do you have any comments?

Whigham: The land equivalent ratio is one of many ways to look at intercropping efficiency. By no means do I mean to leave out other possibilities. You are right, in each situation you may need to develop your own formula to determine efficiency.

Question: What are the management practices used for oil palm?

Yap: Normally we grow a cover crop for a few years. This increases the nitrogen level in the soil.

Question: What is the between-row spacing for rubber?

Yap: About 400 plants/ha; row spacing varies with location, depending on topography, but it normally is about 6 m.

Question: What is the best age (of rubber) to plant soybean?

Yap: Quite soon after planting the rubber trees. After 2 years the rubber plant is already tall and it shades the soybean.

Question: Have you tried to grow any other crops under rubber?

Yap: The farmers have tried chili peppers (Capsicum annuum), and they feel that chilies are more profitable than soybean; watermelon (Citrullus vulgaris) has also been tried.

Question: In your intercropping experiment, you indicated that intercropping with pigeon pea and soybean produces a better net income than monocropping. How do these crops perform in comparison with the other crops intercropped with soybean or pigeon pea?

Thulasidass: We have found that soybean compares favorably with other crops. Soybean grows very well in Tamil Nadu, but it is not becoming popular because people are not aware of its many uses. There is also a marketing problem.

Question: The temperature is cold immediately after rice in China. Do you plant soybean right after rice?

Wang: In China we can plant soybean after rice even though the temperature is cool. The main problem is drainage. To improve soil fertility we add fertilizers, but yields are still low. The farmers can use high plant population densities and harvest the crop as green vegetable soybean to make more money. Grain soybean is not profitable.

Section II

Plant Breeding

Soybean Breeding for Multiple and Intensive Cropping Systems in Indonesia

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Introduction

Approximately 800,000 ha of soybean (Glycine max) are harvested each year in Indonesia. Of this amount, 60% is planted after lowland rice and the remainder is intercropped under rainfed, upland conditions, usually with maize (Zea mays, cassava (Manihot esculenta), or sorghum (Sorghum vulgare).

Average soybean yields (0.9 t/ha) have not changed significantly during the past decade. Major production constraints include: 1) low yielding cultivars, 2) poor seed quality, 3) weed competition, 4) pests and diseases, 5) drought during the reproductive stage of development, 6) competition from companion crops, 7) marginal soils (low pH, low phosphorus, and Al toxicity), and 8) low input utilization.

Many of these constraints can be remedied through the use of improved agronomic practices, but, under local conditions, most of these practices are not economical. Soybean breeding efforts are therefore directed towards finding solutions to crop production problems rather than simply breeding for higher yields.

Local Cultivars

Approximately 80% of the soybean planted in Indonesia consists of local cultivars. These are generally mixed populations, but there are specific traits that characterize the cultivars grown in each region.

Soybean in East Java, for example, is similar to cultivar No. 29, a genotype introduced from China in 1918. Its characteristics include small seed-size (7 to 9 g/100 seeds), green-yellow seed color, an indeterminate growth habit, late maturity (100 to 110 days), and adaptability to poor soil drainage.

In Central Java, local cultivars are both more numerous and earlier maturing than those found in East Java. These materials were derived from lines first released in the early 1930s. Cultivars Sumbing and Ringgit are yellow-seeded, mature in 85 to 90 days, and have 100-seed weights of 10 to 11 g. Merapi is a black-seeded cultivar similar in plant type to Sumbing or Ringgit.

Large-seeded cultivars are common in West Java. These materials were probably derived from direct introductions, and have since been adapted to local environments (highlands).

Improved Cultivars

Five improved cultivars have been released by the Agency for Agricultural Research and Development (AARD) for use in Indonesia (Table 1). These materials are higher yielding, earlier maturing, and have larger seed sizes than local

lines. They were tested and selected under conditions different from those of local farmers, however. Consequently, most of these lines are not suitable to lowland production after rice.

Orba and Galunggung

Improved cultivars Orba and Galunggung are relatively large-seeded, and thus suffer from low germination rates and lack of vigor when planted in poorly drained soils. Another objection to Orba and Galunggung, at least in East Java, is that they produce soft-textured tempeh (soybean cake) which is unacceptable on the local market.

Lokon and Guntur

Improved cultivars Lokon and Guntur mature in about 78 days and produce about 1 t/ha. These materials are suitable for regions where the growing season is less than three months long (see following paper - eds.).

B3034 (Wilis)

Cultivar B3034 (Wilis) is small-seeded (9 to 10 g/100 seed), vigorous, matures in 88 days, and yields about 1.6 t/ha. It was released as a replacement for a late maturing, local cultivar - No. 29. Wilis is suitable for lowland conditions after rice, and, if necessary, can be planted without land preparation.

Table 1. Improved soybean cultivars released by the Agency for Agricultural Research and Development (AARD), Indonesia, 1974-84.

Name	Yield Potential (t/ha)	Maturity (days)	Seed Size (g/100 seed)	Year Released
Orba	1.5	85	12	1974
Galunggung	1.5	85	13	1981
Guntur	1.1	78	10	1982
Lokon	1.1	78	10	1982
B3034 (Wilis)	1.6	88	10	1983

Breeding Strategies

General

Soybean yields are usually higher when the crop is grown in the dry season after lowland rice than when it is grown as a rainy season, upland crop. The best yields are produced when soybean is grown after lowland sugarcane (assuming that irrigation is available). Research on cultivar x season interactions is not conclusive. Therefore, the need to develop individual breeding programs for both dry season and wet season cultivation requires further study.

Lowland Cultivars

Earliness: Lowland soybean cultivars that mature in 76 to 80 days are efficient users of residual moisture during the reproductive stages, and are consequently capable of escaping drought. Earliness is also important because only three months are available for soybean production between rice crops.

Early maturing cultivars are available in Indonesia (74 to 78 days) (Table 2). The earliness of these cultivars is not due to shorter photoperiods, as is usually the case with introduced materials. Local, early maturing cultivars range in height from 35 to 50 cm and yield less than 0.8 t/ha. They are, however, suitable hybrid parents, mainly because of their adaptability to local environments.

Table 2. Early maturing soybean cultivars available from the Indonesian germplasm collection.

Cultivar	Maturity (days)	Yield (t/ha)
B-441	76	0.56
B-448	74	0.31
B-467	78	0.52
B-1012	77	0.78
Genjah Slawi	76	0.66
No. 1592	77	0.73

In 1981-82, 40 paired crosses were made with high yielding, early parents. F_2 populations were separated into to four categories: Very early (less than 80 days), early (80 to 85 days), medium (86 to 90 days), and late (more than 91 days). Mass selection, based on maturity, was repeated until the F_3 generation. Single plant selection was carried out with the F_4 population based on maturity, plant type, disease reaction, and agronomic traits. Visual selection was applied to the F_4-derived lines to help in the discarding of undesirable lines (lodging-prone, disease-susceptible, poor agronomic traits). The remaining lines were tested across several locations and seasons. During the selection and yield evaluation processes, early maturing lines were retained even though their yields were not particularly high. The original early parents were included in the yield tests for comparison.

Seed Size: Small-seeded cultivars have three advantages: 1) the seed maintains its viability for relatively long periods of time, 2) they germinate well in excessively moist soils, and 3) a lower seeding rate is needed per unit area of land. Small seed size can be readily combined with early maturing cultivars, and the resulting progeny can be selected visually. The germplasm collection of the Central Research Institute for Food Crops has lines with seed sizes ranging from 5 to 15 g/100 seeds. High yielding, late maturing cultivars No. 29 and No. 1682 (G 2120) are both small-seeded (7 to 8 g/100 seeds).

Semi-Determinate Genotypes: Semi-determinate genotypes usually grow taller than determinate cultivars, but are shorter and mature earlier than indeterminate lines. Early maturity can be selected from semi-determinate populations, which have the added advantages of being able to compete with weeds after lowland rice and produce enough branches to compensate for plants that fail to establish.

Semi-determinate genotypes often yield better than the determinate types. However, the usefulness of semi-determinate cultivars in the tropics is not conclusive.

Upland Cultivars

Shading: Upland soybean is often intercropped in Indonesia with taller companion crops, a fact which generally reduces yields because of shading and companion crop competition. Yield reductions of up to 60% have been reported when soybean was intercropped with maize (Toha 1976). McBroom et al. (1981b) noted yield

reductions of 21 to 57% when soybean was mix-cropped with oats (Avena sativa) or wheat (Triticum aestivum) (Table 3). Although yield reductions were significant, neither researcher found a significant genotype x cropping system interaction, suggesting that separate breeding programs are not required to develop cultivars specifically suited to monocropping or intercropping. A significant yield correlation (0.55 to 0.84) was found between monocropping and intercropping. Kawano and Thung (1982) found yield reductions of 60% when soybean was intercropped with cassava, a fact attributed to shading during the reproductive stages. Francis et al. (1976) recorded yield reductions of 47% when soybean was intercropped with maize.

Table 3. Soybean yield reductions as a function of cropping system.

Competitor	No. of Soybean Genotypes	Soybean Yield (t/ha) monoculture	Soybean Yield (t/ha) mixed-cropping	Yield Reduction (%)[z]
Oats	14	3.5	1.5	57
Wheat	12	4.1	2.8	32
Oats	12	3.4	2.7	21
Wheat	8	3.2	1.7	47
Oats	8	2.3	1.5	35
Maize	1	0.9	0.4	60
Maize	1	2.9	1.6	47

[z] In mixed-cropping
Source: Francis et al. (1976), McBroom et al. (1981b), Toha (1976)

Upland soybean in Indonesia is also planted with tree crops. If the trees are planted reasonably far apart, they may have only a small effect on soybean yield, and in some instances they may function as wind breaks. In one study, soybean sheltered by trees produced higher yields than exposed crops (Ogbuchi and Brandle 1982). Yield increases were attributed to lower leaf area density, lower leaf density, and smaller leaf size in the uppermost portion of the canopy. The sheltered soybean also had a better plant-water status.

Excessive shading undoubtedly reduces soybean yields by intercepting solar radiation. Soybean yields were reduced an average of 32% when shading reduced available sunlight by 40% (Rasco 1982). Of the 16 cultivars tested, yield response ranged from a 58% reduction to a 9% increase.

Breeding populations can be selected for shade tolerance in the F_2 generation. F_2 populations should be planted in a mixed-cropping pattern with maize, similar to the pattern used by farmers. Individual plants that are tolerant of shading can then be mass selected. Selection under mixed-cropping is repeated in the F_3 and F_4 generations. Single plant selection is used in the F_4 based on shade tolerance and other agronomic traits. The F_4-derived lines are then yield-tested under mixed-cropping conditions. To obtain genotypes that are tolerant of shading, crosses should be made with local cultivars adapted to mixed cropping. Lodging and vining indices should be useful criteria for selection. In advanced yield trials, the lines should be tested under both monoculture and intercropping conditions, and selected lines should produce high yields under both types of conditions.

Competition: McBroom et al (1981a) reported that isolines of Harosoy 63 and Clark 63 that contain genes for determinate (Dt_1) and narrow leaflet (ln) characteristics, yielded significantly less than indeterminate, normal leaflet types when

intercropped with oats or wheat. The yields of semi-determinate (Dt_2) and early (e2) isolines, however, were not consistently affected when grown either as a monoculture or as an intercrop. This suggests that semi-determinate plant types are better suited to mixed-cropping than determinate cultivars. The relationship between plant type and the ability to compete was demonstrated by Sumarno and Fehr (1980). When a semi-dwarf, determinate soybean cultivar was planted in alternating rows with an indeterminate, tall genotype, yield reductions for the determinate cultivars ranged from 10 to 38%, while the indeterminate genotypes produced yield increases of 16 to 35% (Table 4). These data suggest that short, determinate soybeans may not be suitable for the intercropping patterns used in Indonesia.

Table 4. Yield changes due to competition between indeterminate (William and Cumberland) and semi-dwarf, determinate (Elf) soybean cultivars.

Cultivar	Arrangement	Yield	Yield Change		
			Elf	William	Cumberland
Elf (E)	pure stand	2.8	0		
William (W)	pure stand	2.7		0	
Cuberland (C)	pure stand	3.0			0
E-W	alternate rows	2.8	-30	+33	
E-W	1:1 blend	2.7	-38	+35	
E-C	alternate rows	3.1	-10		+22
E-C	1:1 blend	3.0	-25		+29
W-C	alternate rows	2.9		+21	-17
W-C	1:1 blend	2.7		+16	-23

Source: Sumarno and Fehr (1980)

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Early Maturing Soybean for Intensive Cropping Systems

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Introduction

In Indonesia, soybean (Glycine max) is usually planted after rice (Oryza sativa) in areas that lack sufficient moisture for an additional rice crop. Early maturity and resistance to insects and diseases are prerequisites for soybean cultivars grown in this type of cropping system.

In West Java, east of Jakarta, the Jatiluhur irrigation system services more than 200,000 ha (Anon. 1978). Irrigation water is available 11 months of the year, but only nine months are needed to produce two rice crops. The land is generally left fallow during the remainder of the year, a period that can be used to grow early maturing soybean.

Varietal Requirements

Early maturity and the ability to withstand drought during certain growth stages are required for soybean grown in a rice-rice-soybean system in Indonesia. Adapted cultivars should also be able to establish themselves in moist soil and compete with weeds.

Early maturity is emphasized because the soybean crop must mature in about 80 days to escape heavy rains and severe insect infestation. The water requirements for short-duration cultivars are less than those of later maturing cultivars, which means that early maturing materials have a good chance of success in rainfed areas.

Good seed quality and resistance to weathering are also necessary. Small-seeded types generally meet these requirements because they deteriorate less than large-seeded soybeans when harvesting is delayed. Small-seeded cultivars are also less prone to threshing and handling damage, have lower seed requirements per unit area, and germinate better under adverse conditions (Hinson 1974, Hidayat 1977).

Early Maturing Cultivars Developed at Surif

An early maturing (<80 days), traditional cultivar (Genjah Slawi) was crossed with TK 5, an introduction from Taiwan, at the Sukamandi Research Institute for Food Crops. Selected cultivars were evaluated for yield at the F_5 generation. Subsequent selections were screened in several of Indonesia's major soybean production areas.

Early maturity was the primary selection criterion. Two lines selected from the F_8 generation were released under the local name Lokon and Guntur. Lokon has white flowers and brown pubesence; Guntur is similar to Lokon but has purple flowers. Both cultivars are resistant to shattering and can be mechanically harvested.

In multilocational trials (1977-81), Lokon and Guntur yielded 60 to 70% more than the local check, but had yields comparable to Orba, a cultivar released in 1974 (Table 1). Dry season yields were generally lower than post-wet season yields.

Lokon and Guntur are 12 and 10 days earlier maturing than the local check and 9 and 7 days earlier maturing than Orba, respectively. The yield/day/ha of both the cultivars is higher than that of Orba (Hidayat 1981). However, both cultivars are moderately susceptible to soybean rust, (Phakopsora pachyrhizi), virus diseases, and insect pests (leaf eaters (Spodoptera litura and Plusia calcites); stink bugs (Nezara viridula); pod borers (Etiella zinckenella); and beanflies (Agromyza phaseoli)).

Table 1. Yield (t/ha) and maturity of soybean cultivars Lokon and Guntur grown after rice in the Jatiluhur area, 1977-81.

Cultivar	Sukamandi	Indramayu		Subang		Kalijati	Bekasi	Mean(t/ha) maturity range	Yield kg/ha/day
	PWS[z]	PWS	DS[y]	PWS	DS	PWS	PWS		
Lokon	1.1	1.3	-	1.7	0.7	1.5	0.8	1.2 72-76	16.9
Guntur	1.0	1.4	0.7	1.8	0.8	1.6	0.8	1.1 74-79	15.6
Local check	-	-	0.5	1.1	0.6	-	0.5	0.7 85-88	8.6
Orba	0.9	1.3	1.0	1.4	0.7	-	0.7	1.0 80-85	12.7

[z]PWS = post wet season
[y]DS = dry season

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Strategies for Breeding Soybean for Intercropping and Multiple Cropping Systems

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Many soybean (Glycine max) breeding programs ignore the influence of local production systems. Asian farmers usually grow soybean in paddy fields after rice or intercrop it with corn (Zea mays) or plantation crops. Most soybean improvement programs, however, select improved cultivars on the basis of results obtained from monocropped plots rather than plots that simulate on-farm conditions.

A project was initiated in the Philippines in 1975 to evaluate grain legumes, including soybean, for adaptation to paddy and partially shaded conditions. The most promising materials were tested in a series of replicated trials by the University of the Philippines at Los Banos (UPLB) and the International Rice Research Institute (IRRI). Results are shown in Table 1.

Table 1. Yields of promising soybean cultivars grown under partial shading and after paddy rice.

Trial Type	Planting Date	No. of Entries	Mean Yield (t/ha)	Range (t/ha)
Partial shading	2-14-76	16	0.71	0.41-1.02
Partial shading	6-11-77	24	0.94	0.72-1.24
Partial shading	10-15-77	24	0.84	0.54-1.16
Post-paddy rice	1-14-76	16	1.57	1.30-2.14
Post-rice	10-23-76	14	1.69	1.42-2.07
Post-rice	1-15-77	24	1.15	0.78-1.38
Post-rice	10-27-77	15	1.24	0.90-1.58
Post-rice	11-24-78	9	1.41	1.17-2.01
Post-rice	12- 1-79	9	0.44	0.34-0.55

The trials showed that soybean grown under partially shaded conditions performs poorly, usually producing less than 1 t/ha. However, in this instance, the screening technique used was too restrictive for normal plant development. There was a 40% reduction in light intensity, and the plants were subjected to shading from germination to maturity. Under normal intercropping conditions, shading is usually a factor during only part of the season.

Yield results were also undependable because the crops were grown under severe stress brought about by their dependence on residual moisture, their exposure to high temperatures, and because of zero-tillage planting. In addition, performance was subject to chance variations in the amount and timing of precipitation.

The cultivars used in the post-rice tests, especially those developed at UPLB, had been selected under favorable, dryland conditions. They occasionally

yielded 2 t/ha, but in most instances yields totaled just over 1 t/ha. This indicates that soybean grown after rice will not produce economical yields unless planting coincides with the prevailing rainfall pattern. If planting falls beyond the normal rainfall period, irrigation may be required.

Because of the poor yields of the soybean cultivars presently grown in Asia's rice-based cropping systems, a breeding program was established to address paddy and inter-cropping conditions. The International Development Research Centre of Canada, which was the sponsor of the 1975 soybean evaluation program, is presently supporting the program. As in the past, the work is being conducted in collaboration with IRRI, in this instance through its Asian testing network (see Caranagal - eds.).

The following management practices are being studied: 1) puddled or un-puddled soil for the first rice crop, with minimal or zero-tillage for the following soybean crop; b) planting at high population densities (500,000 to 600,000 plants/ha); c) straw-mulching of the soybean field during the dry season; d) use of residual moisture, plus one or two flush-irrigations during dry periods; and, e) minimal fertilizer application.

Selection criteria include: 1) rapid vegetative growth during the seedling stage (determined by visual rating and sampling for dry matter); 2) low photo-period sensitivity; 3) 90 to 100 days maturity; 4) low pod-shattering rates; 5) large seed size; and, 6) rapid grain-filling.

Time is the principal constraint involved in selecting cultivars under paddy conditions, and, for this reason, segregating populations are frequently grown under non-paddy or dryland conditions.

The breeding method consists of the following:

1. Crossing blocks (F_1 and F_2) are grown in limited quantities under non-paddy conditions.
2. F_3 segregating families are grown under post-rice conditions in late October or early November. Selection criteria include: Rate of seedling development, reaction to short photoperiods (indicated by precocious flowering), rate of seed-filling, seed size, and intermediate maturity periods. Other paddy-neutral traits, including disease resistance, are also evaluated.
3. F_4 segregating sub-families are subjected to further selection pressure under paddy conditions in early February. The rate of seedling development, reaction to long photoperiods (gauged by prolonged vegetative development and delayed flowering), rate of seed-filling, seed size, and pod-shattering are all considered, as are other paddy-neutral traits. (There is one flush irrigation during the flowering period.)
4. F_5 selected lines are grown under wet season, non-paddy conditions to continue selection for paddy-neutral traits.
5. Selected F_6 lines are placed in preliminary replicated tests under early post-rice conditions in October/November.
6. Preliminary tests continue in the dry season (January/February).
7. Promising lines selected under wet season, non-paddy conditions are multiplied.
8. Multi-locational testing is carried out for lines selected in the post-rice rainy season (carried over in the dry season under irrigated paddy conditions).

The procedures for dryland multi-cropping follow the same approach, except that segregating families and populations are subjected to continuous, partial

shading. There are two levels of shading: Strip-planting with corn to simulate the partial shading produced by intercropping and planting under coconut trees to simulate severe shading. Selection criteria include pod number, harvest index, and disease resistance.

Breeding Tropical Soybean for Superior Seed Longevity and for Nodulation With Indigenous Rhizobia

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Seed Longevity

In the early 1970s experimental soybean plots at IITA often suffered from poor seedling emergence. Subsequent research revealed that poor stand establishment was primarily due to reductions in seed viability that take place during storage.

Fungal Pathogens

Ndimande et al. (1981) studied the role that physiological factors and fungal pathogens play in seed deterioration. Two field experiments were conducted in which four cultivars were subjected to various treatments: 1) seed harvested at maturity without fungicide, 2) seed harvested at maturity and plants sprayed with benomyl fungicide (1 g/weekly from mid-flowering to maturity), 3) seed harvested two weeks after maturity without fungicide, and 4) seed harvested two weeks after maturity and plants sprayed with benomyl.

The plants in the first trial matured under dry conditions and low fungi populations. Harvest date and fungicide application had little effect on seed pathogen populations or percent seed germination at harvest. The second trial matured under moist conditions. Delayed harvesting reduced germination by 25%; plants that were not sprayed with benomyl produced seed that had a lower percentage of germination and a higher incidence of seed pathogens than sprayed plants.

Ndimande concluded that pathogens promote seed deterioration. Seeds from both field experiments were stored at 28 or 30°C (80% relative humidity) and were periodically tested for germination. Percent germination for both benomyl-treated and non-treated seed declined at the same rate (Fig. 1).

In another experiment, seed of cultivar Bossier was equilibrated to 10, 13, or 16% moisture content. Seed that was dusted with benomyl before storage (28°C) had no surface fungal growth. However, the benomyl treatment did not change the rate of decline in seed viability when compared with non-treated seed. The rate of decline in seed viability varied directly with seed moisture content. In addition, embryos extracted from seed stored for nine months did not grow even though less than 5% were infected with fungal pathogens. These studies indicated that seed-borne fungi play a only minor role in seed deterioration during storage and that physiological factors are probably the principal cause of seed deterioration. Thus, when screening for resistance to field weathering, the identification of resistance to specific pathogens may be required. However, when screening for resistance to deterioration in storage, physiological factors may also be important.

Germplasm Screening

The IITA germplasm was screened for seed longevity and several lines from Indonesia were found to have good seed viability after eight months of storage

under ambient conditions (Fig. 2) (Wien and Kueneman 1981). Studies were conducted to develop a technique capable of screening breeding material for this characteristic.

Two methods were used: Ambient storage for four months and accelerated ageing (Figs. 3 and 4). Emergence after four months of ambient storage was correlated with emergence after eight months of storage. However, the fact that most lines had a high percentage of emergence after four month at ambient temperatures complicates selection for good storability. The accelerated ageing technique was not correlated with percent emergence after eight months. When the technique was modified (Fig. 5), a highly significant correlation (r = 0.62**) was found with cultivars stored for eight months (Wien and Kueneman 1981). Dassou (1982) reported that the two methods of determining seed longevity had a highly significant correlation (r = 0.82**). This technique is now being used at IITA to identify breeding lines that have genetically superior storability (Wien and Kueneman 1981).

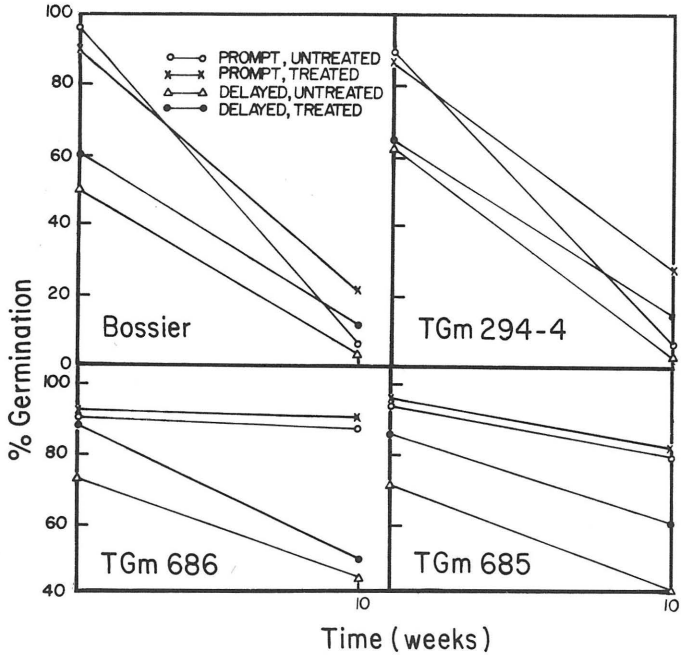


Fig. 1.
Effect of 10 weeks of storage, harvest time, and pre-harvest fungicide application on the germination of four soybean cultivars.
Source: Ndimande et al. (1981)

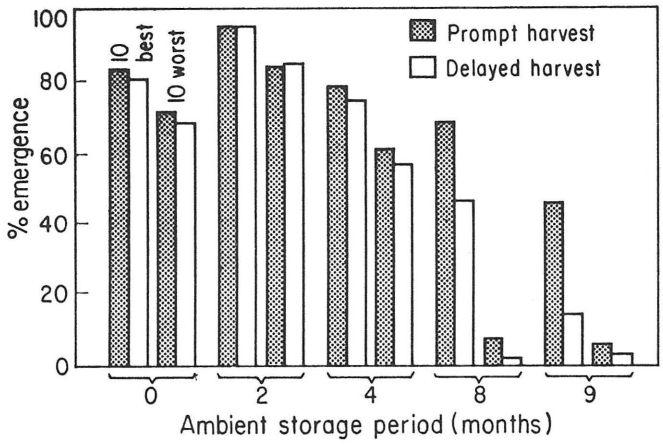


Fig. 2.
The decline in percent emergence in field plantings as related to length and storage period under ambient tropical conditions (24 to 29°C, 40 to 95% RH) and a 2-week delay in seed harvest after optimum maturity.
Source: Wien and Kueneman (1981)

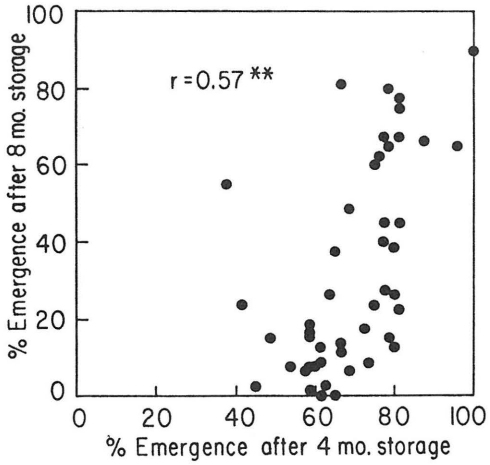


Fig. 3. The relationship of percent field emergence of 50 soybean lines after storage under ambient conditions of 4 and 8 months, respectively.
Source: Wien and Kueneman (1981)

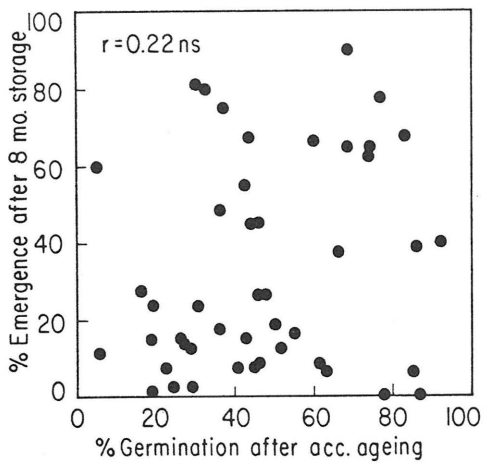


Fig. 4. The relationship of percent field emergence of 50 soybean lines after 8 months of storage under ambient conditions and percent germination after accelerated ageing (40°C and 100% for 72 hr).
Source: Wien and Kueneman (1981)

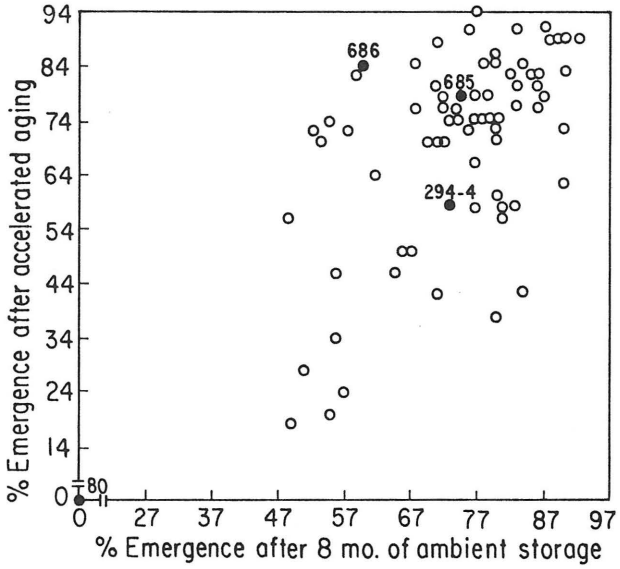


Fig. 5
The relationship between emergence after 8 months of ambient storage and after 6 weeks of accelerated ageing (40°C, 75% RH) based on 60 breeding lines and four checks.
Source: Wien and Kueneman (1981)

An improved screening method has also been developed to identify breeding lines that are resistant to field weathering (Dassou and Kueneman 1983). With this technique, yellow pods are removed from the plants at physiological maturity and are placed in an incubator for 7 days at 30°C and 95% RH. The seeds are then shelled and planted for emergence evaluation. This procedure proved to be more precise than the delayed harvesting technique.

Most of the germplasm that was identified as resistant to seed deterioration in storage was also found to be resistant to field weathering. It is therefore likely that breeding lines selected for seed longevity are also resistant to field weathering.

Inheritance studies on seed deterioration during storage have indicated the existence of a non-cytoplasmic maternal plant influence (Kueneman 1983) that delays segregation for one generation. Parent-offspring regression studies have revealed low heritabilities in the early generations (F_3) and improved heritability in subsequent generations. Therefore, screening for seed longevity at IITA is not carried out at least until the F_4 generation.

The Indonesian lines with excellent seed longevity proved to have poor agronomic characteristics, a fact which complicated the task of incorporating seed longevity and good agronomic characteristics into a single cultivar. Backcrossing recurrent parents with good agronomic characteristics was not successful. Lines from the United States that were used as recurrent parents were all large-seeded and had poor storability. After two or three backcrosses, their progeny were also large-seeded and had poor storability. Complex crosses were used to recover agronomically acceptable lines with good storability. Many breeding lines have now been developed that have good seed longevity and are adapted to the West African savannah zone (Fig. 6).

Symbiosis with Indigenous Rhizobia

In 1978 attempts were made to identify soybean lines that form effective symbiotic relationships with indigenous West African rhizobia. About 400 lines of diverse origin were evaluated for their ability to nodulate at six locations. Eight lines were found to be highly "promiscuous", i.e. they formed an effective symbiosis with rhizobia native to all six sites. Rhizobia strains were isolated from nodules collected at each location. The promiscuous lines were compatible with a large majority of native strains. Improved cultivars of US origin established an effective symbiosis with only a few isolates (IITA 1979). All of the promiscuous lines proved to have poor agronomic characteristics. Therefore, native rhizobia can be inefficient and still meet the crop's nitrogen requirements.

To evaluate the efficiency of symbiosis with indigenous rhizobia, a study was conducted in which the shoot of a high yielding cultivar (Bossier) was grafted onto the root of a promiscuous cultivar (TGM 918) (Table 1). When the Bossier shoot was grafted onto the root of TGm 918 and grown in uninoculated field soil, growth and yields were equal to Bossier grafted onto itself and subsequently inoculated with Rhizobium japonicum. This demonstrated that indigenous rhizobia are capable of providing the nitrogen required by high yielding cultivars (IITA 1979).

In 1978 crosses were made to incorporate promiscuous genes into high yielding cultivars. The frequency of promiscuous progeny in the segregating generation was relatively high (Fig. 7), which suggests that the inheritance of promiscuity is conditioned by a few major genes (IITA 1980). Selection for promiscuity is made by growing breeding nurseries in fields that are low in nitrogen and have never been inoculated with R. japonicum. In the early generations, selection is made on the basis of growth vigor and nodulation. Plants are dug up at physiological maturity to assess nodule mass. This selection method has proven quite successful. Several promiscuous lines with good seed longevity have performed well at a number of locations in Nigeria's savannah zone (Tables 2 and 3).

International testing was initiated in 1982 using elite IITA breeding lines. The objectives is to assist IITA breeders in determining if their materials are adapted to various tropical environments, especially in Africa, and to distribute germplasm to national programs. The breeding lines that perform well in these trials will eventually be entered in the INTSOY global testing program.

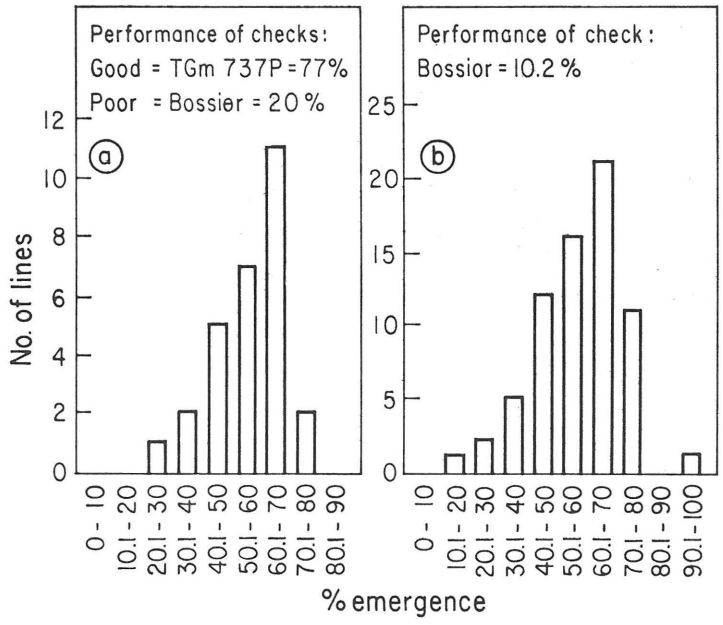
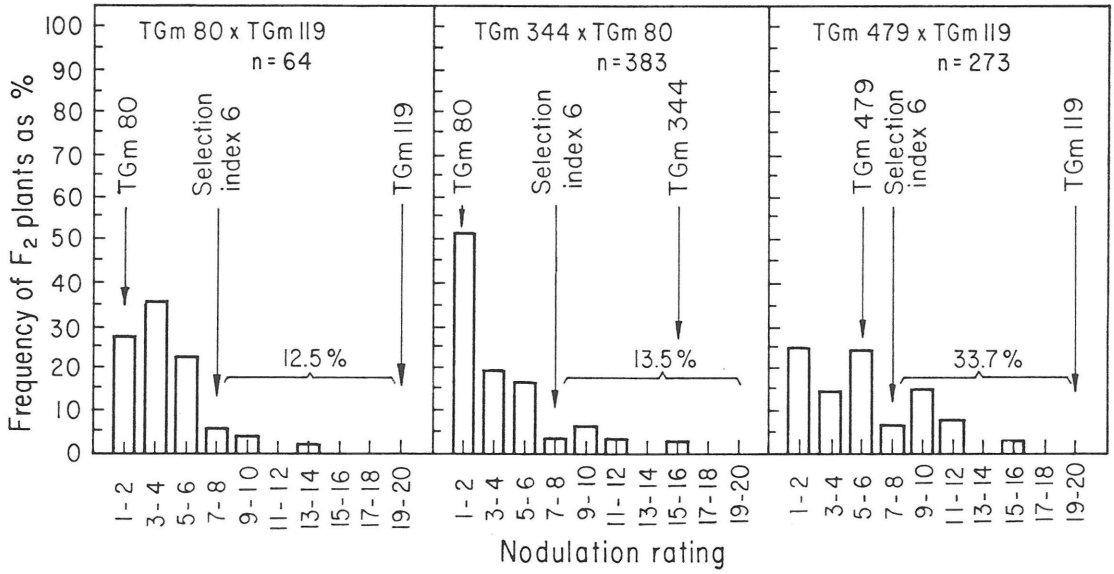


Fig. 6.
a. Frequency distribution for percent seedling emergence following accelerated ageing[z] of 33 breeding lines selected for seed longevity; b. frequency distribution for percent seedling emergence following accelerated ageing[z] of 69 F_6 breeding lines compared with cultivar Bossier.

[z] Seeds were stored for 6 weeks at 40°C and 75% RH



Note: Nodulation rating is the product of rating for nodule number (1-5) and rating for nodule size (1-5). A nodulation rating of 7 or greater indicates a nodule mass similar to an inoculated cultivar.

Fig. 7. Distribution of F_2 plants from three crosses of promiscuous and non-promiscuous soybean lines evaluated for nodulation in the field with indigenous rhizobia, Mokwa, Nigeria, 1979.
Source: IITA (1979)

Table 1. Effect of grafting a high yielding cultivar (Bossier) onto the root of a promiscuous cultivar.

Shoot	Root	Inoculum of *R. japonicum*	Shoot N Content[z] (mg/plant)	Shoot Dry Wt[z] (g/plant)	Seed Yield (g/plant)
Bossier	Bossier	-	259	8.9	15.8
		+	608	18.1	23.7
Bossier	TGm 918	-	607	18.3	24.5
		+	730	19.7	21.0
		SE	±42	±0.99	±1.27

[z] Shoot nitrogen content and dry weight 50 days after grafting

Table. 2. Yield and nodulation performance of three promising IITA soybean breeding lines grown in an advanced yield trial, 1982.

Cultivar	Mokwa yield (t/ha)/nodulation[z]	Ilorin yield (t/ha)/nodulation
TGx 326-034D	2.5/2.7	1.6/3.0
TGx 330-054D	2.0/3.9	2.3/3.3
TGx 454-060C	2.3/2.5	1.9/2.9
Bossier (check)	0.9/1.6	1.1/2.2
LSD 0.05	0.89/0.6	0.12/0.1

[z] Nodulation scores: 1 = poor, 2 = fair, 3 = good, 4 = excellent
Total entries = 29 with 3 replications

Table 3. Yield and nodulation performance of two promising IITA breeding lines in a preliminary yield trial, 1982.

Cultivar	Mokwa yield (t/ha)/ nodulation[z]	Ilorin yield (t/ha)/ nodulation	Ibadan yield (t/ha)/ nodulation
789-02D	1.6/1.8	1.9/2.7	1.6/2.6
726-01D	1.8/2.7	1.7/3.4	0.6/3.5
Jupiter (check)	1.0/1.3	1.3/1.7	1.4/1.5
LSD 0.05	0.52/0.8	0.47/0.8	0.40/0.9

Entries = 70 with 3 replications
[z]Nodulation scores: 1 = poor, 2 = fair, 3 = good, 4 = excellent

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Soybean Breeding for the Brazilian Tropics

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Introduction

Soybean (Glycine max) was first grown in the southern part of Brazil, an area that is called the "traditional region". More recently, production has spread to a six-state area known as the "expansion region" (Table 1) (also see Fig. 1. Spehar et al.- eds). In 1982-83, soybean production in the expansion region was about 50% higher than Brazil's total production in 1970. The increase was principally due to the development of improved cultivars: UFV-1, IAC-2, IAC-6, IAC-7, IAC-8, Cristalina, Doko, and Numbaira. Adapted cultivars have also been developed for equatorial zones: Tropical, Timbira, Teresina (BR-10), and Carajas (BR-11).

General Breeding Objectives

EMBRAPA's objective in developing cultivar's for latitudes below 15°L was to produce determinate, agronomically acceptable soybeans that flower 45 to 55 days after emergence and that mature in 110 to 140 days.

Breeders introduced genes for late flowering (long juvenile period) under short-day conditions from cultivar PI 240664, an introduction from the Philippines. PI 240664 was subsequently crossed with cv. "Hill". Late-flowering F_3 lines were then backcrossed (modified) with good agronomic-type cultivars. The resulting crosses were bulked or advanced as pedigrees. The origin of these cultivars and the breeding method used to develop them are shown in Table 2.

The yield figures for the low latitude cultivars, based on two locations, are shown in Table 3. Each has determinate growth habits and is resistant to bacterial pustule. Height characteristics (Table 4) are suitable for mechanical harvesting. Timbira, a short-statured cultivar, can be used in areas where cultivar Tropical lodges or produces excess vegetative growth. Cultivars Teresina and Carajas, which mature somewhat later than Tropical and Timbira, can be used in areas with long rainy seasons; they are also well adapted to mechanical planting and harvesting.

Future Breeding Objectives

The objective of EMBRAPA's original breeding program was to develop high yielding lines. This was achieved by breeding determinate cultivars that flower in 40 to 52 days, mature in 107 to 120 days, and that range in plant height from 78 to 109 cm. In the future, efforts will be made to breed for seed quality, tolerance to acidic soils, and disease and insect resistance. Attention will also be given to developing extremely early and late maturing cultivars adapted to specific areas.

Table 1. Soybean production in Brazil according to regions, 1970-82.

Year	Traditional Region[z] (RS, SC, PR, and SP)			Expansion Region (MS, MT, GO, DF, MG, BA, and MA)[y]			Total		
	area (million ha)	production (million t)	productivity (t/ha)	area (ha)x1000))	production (t)x1000))	productivity (t/ha)	area (ha)x1000))	production[x]	productivity (t/ha)
1970	1.3	1.4	1.1	15	20	1.3	1.3	1.5	1.1
1972	2.1	3.1	1.4	68	86	1.2	2.1	3.2	1.4
1974	4.8	7.4	1.5	333	463	1.3	5.1	7.8	1.5
1976	6.1	10.7	1.7	304	502	1.6	6.4	11.2	1.7
1978	7.0	8.8	1.2	708	716	1.0	7.7	9.5	1.2
1980	7.4	12.9	1.7	1,262	2,005	1.5	8.7	14.9	1.7
1982	6.6	9.9	1.5	1,601	2,887	1.8	8.2	12.8	1.5

[z] Rio Grande do Sul (RS), Santa Catarina (SC), Parana (PR), and Sao Paulo (SP)
[y] Mato Grosso do Sul (MS), Mato Grosso (MT), Goias (GO), Distrito Federal (DF), Minas Gerais (MG), Bahia (BA), and Maranhao (MA)
Source: IBGE

Table 2. Origin and breeding method of low latitude cultivars in Brazil.

Cultivar	Origin	Breeding Method
Tropical	Hampton x E 70-51[z]	Pedigree
Timbira	RB 72-1[y]	Bulk
BR-10 (Teresina)	UFV-1 x IAC 73-2736-10[x]	Pedigree
BR-11 (Carajas)	UFV-1 x IAC 73-2736-10	Pedigree
BR 79-63	IAC 73-2736-10 x Bragg	Pedigree
BR 79-1094	IAC 73-2736-10 x Bragg	Pedigree
BR 79-1759	RB 72-1	Bulk
BR 79-1776	RB 72-1	Bulk
Paranagoiana	"Parana" mutation	-

[z] E 70-51 = Hill x PI 240664
[y] RB 72-1 is a bulk of three F_3 lines from Hill x PI 240664 crossed with Hill, Vicoja, Pickett, Davis, and F 65-1376
[x] IAC 73-2736-10 (mutation of Hardee)

Table 3. Yields in two trials, Maranhao, Brazil, 1983.

Cultivar	Imperatriz (t/ha)	Brejo (t/ha)	Mean (t/ha)
BR-10 (Teresina)	3.4	3.8	3.6
BR 79-1098	3.4	3.5	3.4
Timbira	3.0	3.1	3.1
BR 79-1094	2.9	3.0	3.0
BR 79-63	3.1	2.7	2.9
BR-11 (Carajas)	2.5	3.0	2.8
Tropical	2.7	2.9	2.8
BR 79-1776	2.7	2.5	2.6
Paranagoiana	2.8	2.3	2.5
BR 79-1759	2.6	2.4	2.5

Source: EMBRAPA/CNPSo and EMAPA

Table 4. Days from emergence to flowering, days from emergence to maturity, and height of low latitude soybean lines, Imperatriz, Maranhao.

Cultivar	Flowering (days)	Maturity (days)	Height (cm)
BR-10 (Teresina)	52	120	109
BR 79-1098	52	120	92
Timbira	42	107	38
BR 79-1094	40	107	74
BR 79-63	47	120	97
BR-11 (Carajas)	52	120	102
Tropical	44	107	94
BR 79-1776	44	107	88
Paranagoiana	44	107	84
BR 79-1759	40	107	78

Source: EMBRAPA/CNPSo

Soybean in the Brazilian Tropics

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Introduction

Soybean (Glycine max) was introduced to the southern part of Brazil at the end of the 19th century (Medina 1981). Significant increases in production did not occur, however, until the 1970s when world demand led to significant price increases.

The Agricultural Institute of Campinas has conducted research aimed at adapting soybean to lower latitudes. Crosses with introduced materials led to the development of improved cultivars IAC-2, Santa Rosa, and Industrial.

The hybridization of American-developed cultivars was carried out in other parts of the country (Feres et al. 1977, Swearing and Sediyama 1969). A breeding program at the Federal University of Vicosa, for example, was responsible for the release of cultivars Vicoja, Mineira, and UFV-1.

Research conducted at the Cerrados National Research Center (Empresa Brasileira de Pesquisa Agropecuaria 1976, 1979, 1980) has made it possible to modify the cropping systems used in Brazil's central savannah zone (Cerrados). Crops such as soybean can now be grown when soils are adequately reclaimed with lime, phosphorus, potassium, and micronutrients.

Because of increasing demand for soybean worldwide, the lower latitudes of the Cerrados are also being used for soybean cultivation. Cultivars Santa Rosa, UFV-1, and IAC-2 are commonly grown in this environment.

Duque et al. 1973 studied the performance of soybean genotypes in the Federal District (15°S) and concluded that IAC-2 and IAC 70-25 had potential in central Brazil. The latter cultivar has since been released as IAC-5.

The soybean research program for central Brazil expanded with the creation, in 1975, of the Minas Gerais Organization for Agricultural Development, the Goias Organization for Agricultural Development, and the Cerrados National Research Center. A network of variety trials was subsequently established to test the performance of new genetic material. In 1976 nearly 1,500 lines were selected in the Federal District by the Cerrados National Research Center. As a result, cultivars IAC-6 and IAC-7 were released for use in the lower latitudes of the savannah zone (Empresa Brasileira de Pesquisa Agropecuaria 1980; Empresa Goiana de Pesquisa Agropecuaria 1979, Empresa de Pesquisa Agropecuaria de Minas Gerais, 1979). More recent releases include: Doko, Numbaira, IAC-8, Cristalina and EMGOPA 301.

The objective of this paper is to demonstrate the adaptability of soybean in the lower latitudes of central Brazil. The results of varietal trials conducted in Mato Grass State and in the Federal District are discussed.

Material and Methods

The Federal District trials (15°S) were conducted on a red-yellow latosol (1,168 m above sea level) and on a dark-red latosol (998 m above sea level). The experiments in Mato Grosso State were carried out on dark-red latosols at two locations: Rondonopolis (16°S; 300 m above sea level) and Diamantino (14°S; 450 m above sea level) (Figure 1). The physical and chemical characteristics of the two soils in the Federal District are shown in Table 1.

All experiments were repeated over two cropping seasons (1978-79 and 1979-80). The experimental design consisted of complete randomized blocks with four replications per treatment (cultivar). Each experimental plot consisted of four equally spaced rows (0.5 or 0.6 m). The sowing rate was 25 to 30 seeds/m.

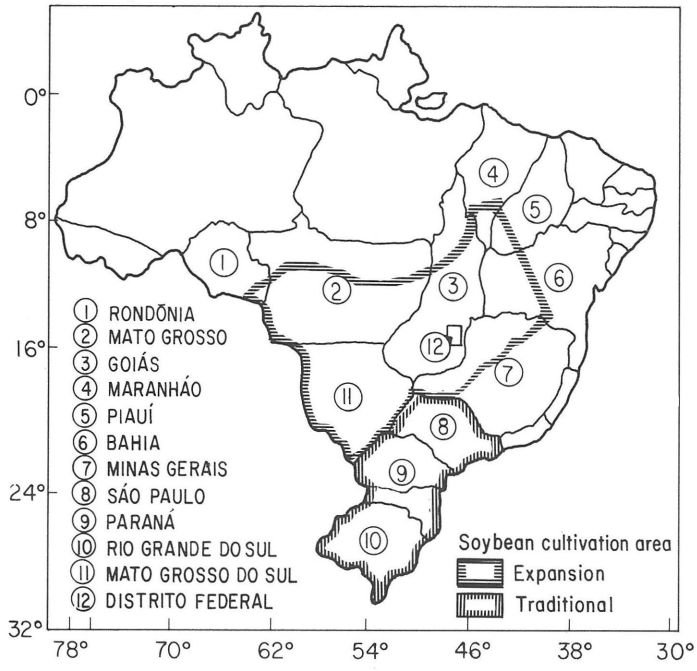

Fig. 1. "Traditional" and "expansion" soybean production areas in Brazil.

Table 1. Chemical and physical characteristics of red-yellow (RY) and dark-red (DR) latosols (oxisols) in the Federal District, Brazil.

Soil Type	Altitude (m)	Texture (%)			pH	Al	Ca+Mg	P	K
		sand	silt	clay	H_2O 1:1	meg/100 ml		ppm	
Virgin RY	1,168	60	9	31	5.00	0.5	0.05	0.5	12
Reclaimed RY[z] (1978)					5.45	0.0	3.14	2.8	26
Virgin DR	998	34	19	46	4.80	0.9	0.4	0.9	16
Reclaimed DR[z] (1976)					5.50	0.0	4.27	5.5	44

[z] Soil analysis after final cultivation, 1979-80

Trial plots were fertilized with 3 to 4 t/ha of lime, 240 to 400 kg/ha P_2O_5 (single superphosphate), 100 kg/ha K_2O (potassium chloride), and 40 kg/ha of trace elements (micronutrients). Seeds were inoculated prior to planting with

Rhizobium japonicum (Empresa Brasileira de Pesquisa Agropecuaria 1979). Data were collected on plant and first pod heights and the number of days to flowering and maturity. Yield data were taken from the two central rows.

Results and Discussion

The performance of sixteen cultivars grown on dark-red latosol soil in the Federal District is shown in Table 2. The highest yields were obtained from Santa Rosa and IAC-2, which are usually grown at 20°S. Jupiter and IAC-2 were the only cultivars that grew taller than 60 cm. All other entries adapted to latitude 30°S had lower yields, reduced plant heights, and shorter maturation periods (Table 3). These results illustrate the response of soybean to changes in photoperiod, and, consequently, the limitations of its potential in tropical areas. Interestingly, both UFV-1 and Santa Rosa had plant heights in excess of 60 cm when grown at latitudes of 15°S, depending upon location and season (Empresa Brasileira de Pesquisa Agropecuaria 1980). This response may be related to differences in soil fertility and rainfall distribution. Jupiter's plant height is counterbalanced by its low yield and high susceptibility to Cercospora sojina.

Table 2. Yield and other characteristics of sixteen soybean cultivars grown on a dark-red latosol (oxisol) in the Federal District, Brazil, 1976-80.[z]

Cultivar	Grain Yield (t/ha)	Height (cm)		Days to (after emergence)	
		plant	1st pod	flowering	maturity
Santa Rosa	2.3 a	56	12	42	109
IAC-2	2.2 ab	90	17	47	117
IAC-4	2.2 abc	53	13	43	114
UFV-1	2.1 abcd	57	17	46	118
Florida	1.9 bcde	49	9	44	98
Davis	1.9 bcdef	47	9	36	101
Hardee	1.9 bcdef	48	10	39	104
Parana	1.9 cdef	55	13	37	95
Vicoja	1.9 cdef	39	9	34	102
Pampeira	1.8 defg	36	7	34	96
Bienville	1.8 defg	32	6	28	93
Planalto	1.7 efgh	35	8	37	97
Bragg	1.6 fghi	42	9	29	92
IAS-4	1.5 ghi	31	6	29	95
Forest	1.4 hi	48	9	31	99
Jupiter	1.4 i	85	26	66	134
CV %	16.0	11.5	-	-	-

[z] Four cultivations following soil reclamation with lime, 240 kg/ha P_2O_5, 100 kg/ha K_2O, and 40 kg/ha trace elements
Numbers followed by the same letter are not statistically different at the 5% level according to Duncan's Multiple Range Test

In a comparison of cultivar IAC-2 with six genotypes developed for the farming system practiced in Central Brazil, IAC-2 was outyielded by all other test cultivars (Table 4). It may therefore be possible to develop cultivars superior to IAC-2, the standard cultivar in the savannah region. Test cultivars matured 10 days earlier (average) on both red-yellow latosols, a phenomenon which can be partially explained by variations in air temperatures.

The same tendency was observed when soybean lines and cultivars were compared to IAC-2 in Mato Grosso State. The data collected in Rondonopolis and Diamantino show that IAC-2 was outyielded in almost all treatments. Standard

cultivars UFV-1 and Santa Rosa were inferior either in terms of yield or plant height (Tables 5 and 6). Similar results have been obtained by researchers in Central Brazil (Empresa Goiana de Pesquisa Agropecuaria 1979, Empresa de Pesquisa Agropecuaria de Minas Gerais 1979) (Table 3).

Table 3. Grain yield and other characteristics of sixteen soybean cultivars tested at Londrina, PR, Brazil, 1979-80.

Cultivar	Grain Yield (t/ha)	Plant Height (cm)	Days to (after emergence) flowering	maturity
Numbaira	3.2	80	71	160
LO 75-1112	2.8	72	44	119
Perola	2.8	39	39	118
Lancer	2.8	50	41	116
BR 78-10513	2.7	86	58	153
Sant'Ana	2.6	40	40	118
IAS-4	2.6	43	35	121
Mineira	2.6	70	54	141
Bossier	2.5	56	44	130
Davis	2.5	42	41	119
Bragg	2.5	50	34	121
Planalto	2.4	38	40	118
Pampeira	2.4	41	38	119
IAC-4	2.2	70	56	146
Parana	2.1	60	39	107
Santa Rosa	2.1	74	55	142

Source: EMBRAPA-Centro Nacional de Pesquisa de Soja-CNPS. Resultados de Pesquisa de Soja 1980/81, Londrina, PR, July 1981

Table 4. Grain yield and other characteristics of seven soybean cultivars grown on red-yellow and dark-red latosols (oxisols) in the Federal District, Brazil, 1978-80.

Cultivar	Grain Yield (t/ha)	Height (cm) plant	1st pod	Days to (days after emergence) flowering	maturity
Red-yellow latosol[z]					
Cristalina	3.3 a	90	13	61	151
Numbaira	3.0 b	88	21	65	140
UFV Araguaia	2.9 b	79	14	51	148
Doko	2.8 bc	93	33	68	145
IAC-8	2.7 c	97	25	52	140
LO 75-2867	2.4 d	90	14	63	143
IAC-2	2.1 e	94	16	48	136
CV %	8.1	8.6	20.2	-	1.7
Dark-red latosol[y]					
UFV Araguaia	3.1 a	79	14	48	135
Cristalina	2.9 ab	92	14	56	136
Numbaira	2.8 abc	93	21	56	130
Doko	2.8 bc	104	29	61	135
IAC-8	2.6 bc	101	24	50	125
LO 75-2867	2.6 c	91	19	54	126
IAC-2	2.5 c	99	17	44	124
CV %	12.0	9.2	15.8	-	1.3

[z] Second and third cultivation following soil reclamation with lime, 400 kg/ha P_2O_5, 100 kg/ha K_2O, and 40 kg/ha trace elements

[y] Fourth and fifth cultivation following soil reclamation with lime, 240 kg/ha P_2O_5, 100 kg/ha K_2O, and 40 kg/ha trace elements

Numbers followed by the same letter are not statistically different at the 5% level according to Duncan's Multiple Range Test

Trial results indicated little variation in maturity among the test cultivars. Experience in Brazil has shown that inputs and machinery are best utilized when the intervals between planting and harvesting can be maximized. Similarly, farmers who double-crop need early maturing cultivars to take advantage of available rainfall. This suggests that cultivars with different rates of maturity are required. It is also evident that cultivars are needed that grow taller than Parana (the standard short-cycle cultivar) which has limited plant height (Table 2).

Table 5. Grain yield and other characteristics of thirteen soybean cultivars grown on a dark-red latosol (oxisol) at Rondonopolis, MT, Brazil, 1978-80[z].

Cultivar	Grain Yield (t/ha)	Height (cm)		Days to (after emergence)	
		plant	1st pod	flowering	maturity
Cristalina	3.8 a	74	14	48	126
UFV Araguaia	3.6 b	67	13	42	126
Numbaira	3.6 b	78	16	50	122
UFV-1	3.6 b	63	12	40	118
LO 75-2867	3.6 b	73	16	48	118
IAC-7	3.5 bc	80	16	48	120
LO 75-2868	3.5 bc	87	16	57	119
Santa Rosa	3.4 bcd	53	9	39	115
IAC 73-5208	3.3 cd	66	16	51	127
Doko	3.2 d	85	21	54	122
IAC-5	3.0 e	99	16	41	115
IAC-2	2.8 e	111	19	39	118
IAC-6	2.8 e	98	21	54	120
CV %	6.2	5.2	10.0	-	-

[z] Second and third cultivation following soil reclamation with lime, 240 kg/ha P_2O_5, 100 kg/ha K_2O, and 40 kg/ha trace elements
Numbers followed by the same letter are not statistically different at the 5% level according to Duncan's Multiple Range Test

Table 6. Grain yield and other characteristics of thirteen soybean cultivars grown on a dark-red latosol (oxisol) at Diamantino, MT, Brazil, 1978-80[z].

Cultivar	Grain Yield (t/ha)	Height (cm)		Days to (after emergence)	
		plant	1st pod	flowering	maturity
Cristalina	3.6 a	78	16	43	122
LO 75-2867	3.4 ab	82	14	42	115
Numbaira	3.4 ab	90	18	46	120
IAC-7	3.2 bc	90	17	42	118
LO 75-2868	3.1 bc	94	15	42	118
UFV-1	3.0 c	60	13	37	115
Santa Rosa	3.0 c	59	12	34	110
UFV Araguaia	3.0 c	70	14	38	120
Doko	3.0 c	89	21	47	120
IAC-5	2.7 d	88	14	38	111
IAC 73-5208	2.7 d	74	16	42	118
IAC-2	2.5 d	109	16	40	115
IAC-6	2.5 d	106	18	48	120
CV %	8.6	5.1	13.2	-	-

[z] Second and third cultivation following soil reclamation with lime, 240 kg/ha P_2P_5, 100 kg/ha K_2O, and 40 kg/ha trace elements
Numbers followed by the same letter are not statistically different at the 5% level according to Duncan's Multiple Range Test

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Breeding for Soybean Virus Resistance

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Introduction

Soybean (Glycine max) mosaic virus (SMV), soybean stunt virus (SSV), and soybean dwarf virus (SDV) are important causal agents of soybean diseases.

SMV is found in many major soybean growing areas in Japan. To date, five strains of the disease have been identified (Shivanathan 1977, Benigno 1977, Dunleavy 1973, Nakano et al. 1982, Takahashi et al. 1980, Tsuchizaki et al. 1982).

SSV occurs throughout the country, with the exception of Hokkaido; at least four strains have been identified (Takahashi et al. 1980). SSV is also found in Indonesia (Iwaki 1979, Iwaki et al. 1980).

Three strains of SDV can be found in Hokkaido and at the northern tip of Honshu (Tamada 1975, Yanagida et al. 1978). SDV's mode of transmission is different from that of SMV and SSV. The latter are either seed-borne or are transmitted by aphids (Aphis glycines, Aulacorthum solani, and Myzus persicae [non-persistent]). SDV is transmitted only by foxglove aphid (A. solani [persistent]) (Tamada 1975). SMV and SSV, unlike SDV, can also be transmitted by mechanical sap inoculation from infected plants. The symptoms and mode of transmission of Indonesian SDV are similar to those of the yellow strain of SDV; however, vector species tests, host range, and serological and cross protection provide little evidence of any relationship between the two viruses (Iwaki 1979, Iwaki et al. 1980).

The Soybean Breeding Laboratory of the Hokkaido Central Agricultural Experiment Station has been working with SDV since 1966. To date, some 20 cultivars have been identified that contain some field resistance (Tanimura et al. 1982). Although cultivars with high levels of resistance have yet to be developed, the breeding program is well underway, and is making use of cultivars such as Adams, Bavender Special 7, and Ouhouju (Matsukawa et al. 1977, Tanimura and Tamada 1976).

Cultivar Dewamusume

Significant differences have been observed in the occurrence of soybean viral diseases in the northern part of Honshu (Ishikawa 1955). Koshimizu and Iizuka (1963) reported that the major viral diseases in Japan are SMV and SSV. Isolates of the two diseases recovered from infected leaves and mottled seeds have been classified into strains on the basis of plant symptoms and pathogenicity to differential cultivars: SMV-A,-B,-C,-D,-E and SSV-A,-B,-C,-D. The reactions of different soybean cultivars to SMV and SSV were examined by Takahashi et al.(1980) (Table 1).

Cultivars with resistance to each SMV and SSV strain have been identified, but only small-seeded, black soybeans are completely resistant to all known strains. Most Japanese cultivars are susceptible to SSV-C, and no known cultivar is resistant to both SMV-C or -D (Takahashi et al. 1965 and 1980).

Breeding for virus resistance began in 1965 (Nagasawa and Iizuka 1977). A cross between cultivars Nemashirazu and Harosoy was found to be a good source of multiple resistance to four strains of SMV and four strains of SSV (Table 2). After screening for cyst nematode resistance in the F_2 and F_3 generations, selected entries were bulked and screened for virus resistance in an infected field. Plants showing virus-like symptoms and/or seed mottling were eliminated up to the F_5 bulk population. Selection was carried out in the field until the F_9. The percentage of plants with virus infection decreased as the generations advanced, and in the F_{11} all plants were found to be disease-free. The SMV and SSV resistance of selected families in the F_8 and subsequent generations was confirmed by the pathologists on the basis of artificial inoculation (Table 3).

Selection for agronomic characteristics was carried out after F_7. All five lines selected for regional tests had the desirable agronomic characters of Nemashirazu, and each showed multiple resistance to SMV and SSV. The first resistant cultivar, Dewamusume, was released in 1977 (Ishikawa et al. 1979). Unlike other recommended cultivars, Dewamusume has not shown any evidence of infection in the Tohoku area since it was first released.

Table 1. Reaction of soybean to strains of soybean mosaic virus (SMV) and soybean stunt virus (SSV).

	SMV					SSV			
	A	B	C	D	E	A	B	C	D
No. cv. tested	508	516	522	231	178	518	275	511	153
Without (w/o) infection (%)	28.3	17.5	10.3	6.9	0.6	41.3	48.0	21.7	41.8
Majority w/o infection (%)	7.7	8.1	3.3	3.0	2.8	8.7	14.5	8.6	17.6
Total (%)	36.0	25.6	13.6	9.9	3.4	50.0	62.5	30.3	59.4
All infected (%)	60.6	71.7	84.3	86.6	94.9	44.6	32.0	62.1	22.9
Majority infected (%)	3.4	2.7	2.1	3.5	1.7	5.4	5.5	7.6	17.6
Total (%)	64.0	74.4	86.4	90.1	96.6	50.0	37.5	69.7	40.5

Source: Takahashi et al. 1980

Table 2. Reaction of parents and progeny to soybean mosaic virus (SMV) and soybean stunt virus (SSV).

	SMV				SSV			
	A	B	C	D	A	B	C	D
Nemashirazu	R	R	S	S	R	R	S	(S)
Harosoy	R	S	R	R	R	R	R	(S)
Progeny	R	R	R	R	R	R	R	R

R = resistant; S = susceptible; (S) = doubtful reaction.

Table 3. Number of families derived from Nemashirazu x Harosoy with resistance to soybean mosaic virus (SMV) and soybean stunt virus (SSV)[z]

	Number of Families Tested	SMV				SSV			
		A	B	C	D	A	B	C	D
F_8	40	40	30	39	38	39	39	39	12
F_9	18	18	18	18	18	17	18	18	11

[z]Artificial inoculation at Tohoku National Agricultural Experimental Station.

Virus Occurrence

Differences in virus symptoms and seed mottling in the differential cultivars grown at the Soybean Breeding Laboratory at Kariwano and the Yamagata Agricultural Experimental Station are shown in Table 4. Virus symptoms and seed mottling were observed in cultivars susceptible to SMV-A and/or -B, both at Kariwano and Yamagata. Two cultivars that are resistant to SMV-A and -B, but susceptible to -C and -D, showed differences in their individual reactions at Akita and Yamagata; seed mottling scores were 0 at Akita and 1.0 and 1.9 at Yamagata. Dewamusume did not exhibit symptoms at either location.

Seed mottling scores in regional tests differed among cultivars depending on the SMV strains present at a particular location (Table 5 and Fig. 1). The SSSS group, which is susceptible to four strains, produced mottled seeds more frequently than the RRSS group at locations 1, 4, and 5 (Fig. 1). The RRSS group seldom produces mottled seeds in Japan's northern prefectures, but produces mottling at some locations in the south. The RRRR group has lower disease scores than the RRSS group.

Table 4. Symptom scores associated with virus infection and seed mottling of differential cultivars at two locations.

	Reaction								Symptoms		Seed Mottling	
	SMV				SSV							
	A	B	C	D	A	B	C	D	Akita	Yamagata	Akita	Yamagata
Dewamusume	R	R	R	R	R	R	R	R	0.0	0.0	0.0	0.0
Toushiken	R	R	S	S	R	R	S	R	1.2	1.7	0.0	1.0
Ou 13	R	R	S	S	S	S	S	S	1.2	1.5	0.0	1.9
Harosoy	R	S	R	R	R	R	R	S	2.8	1.3	1.0	2.1
Tokachinagaha	S	S	S	S	R	R	R	R	4.1	2.8	4.0	2.6
Kariha Takiya 28	S	S	S	S	S	R	S	R	3.8	1.7	3.7	2.1
Norin 4	S	S	S	S	S	S	S	S	3.5	2.0	1.8	1.6

R = resistant; S = susceptible
Score: Symptoms associated with virus infection; 0 = none, 1 = mild, 2-4 = severe
Seed mottling: 0 = none, 0.5% = trace, 1 = 0.5-5%, 2 = 6-15%, 3 = 16-30%, 4 = 31-50% (average 1977-80)

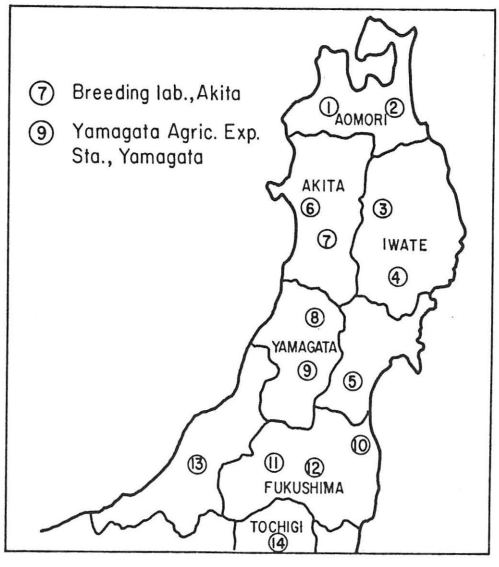


Fig. 1.
Locations of agricultural experimental test sites.

Table 5. Seed mottling scores of cultivars tested in regional trials.

Location	Reaction to SMV: RRRR[z] score	RRRR[z] no. cv. tested	RRSS score	RRSS no. cv. tested	SSSS score	SSSS no. cv. tested
Aomori	0.8	2	0.4	10	2.8	20
	0.6	13	0.5	25	0.8	38
Iwate	0.3	12	0.3	20	0.9	32
	0.0	9	0.4	25	1.8	14
Miyagi	0.9	23	1.0	32	-	0
Akita	0.0	14	0.2	29	-	0
(Breed. lab.)	0.0	23	0.0	48	2.2	5
Yamagata	0.0	21	0.0	22	-	0
	0.2	24	3.3	20	-	0
Fukushima	0.6	7	2.3	23	-	0
	1.2	13	3.6	25	-	0
	0.7	20	2.3	34	-	0
Niigata	0.0	12	0.6	18	-	0
Tochigi	0.8	16	1.9	17	-	0

Mottling score: 0 = none; 0.5% = trace, 1 = 0.5-5%, 2 = 6-15%, 3 = 16-30%, 4 = 31-50% (average for three years)
[z]Reaction to SMV: R = Resistant, S = Susceptible
[z]A to D strain from left to right
No. cv. tested: total 1979 to 1981

Screening for Virus Strains

It is difficult to select for resistance to SMV-C and -D under natural conditions in Akita (Tables 4 and 5). Therefore, attempts were made to develop an efficient artificial inoculation method. The use of an inoculum made up of an SMV-C and -D mixture was evaluated in the field in Yamagata and Akita.

The percentage of diseased plants and the distribution of lines classified into four groups on the basis of the percentage of disease in each line are shown in Figs. 2, 3, and 4. The percentage of disease decreased through repeated screening until all plants were disease-free.

To confirm the accuracy of artificial inoculation, breeding materials were divided into two groups. Half were tested using artificial inoculation with SMV-C and -D, and the others were planted in a virus-infected field (Figs. 3 and 4). The percentage of disease in plants infected by artificial inoculation is shown in Fig. 3; it was found to be similar to the trend shown in Fig. 2. The results obtained by screening with artificial inoculation showed that disease percentage decreased as the selection process advanced (Fig. 4).

A comparison of disease percentages between artificial inoculation and natural infection in each cross from F_3 to F_8 is shown in Fig. 5. A significant correlation was observed, suggesting that artificial inoculation with SMV and screening in virus-infected fields are equally effective. However, two F_6 combinations showed high disease percentages under natural infection and 0% when artificially inoculated. This suggests that viruses other than the major SMV strains occur upon occasion.

Selection for resistance to major SMV strains can be achieved by using artificial inoculation in the early generations, followed by selection in virus-infected fields.

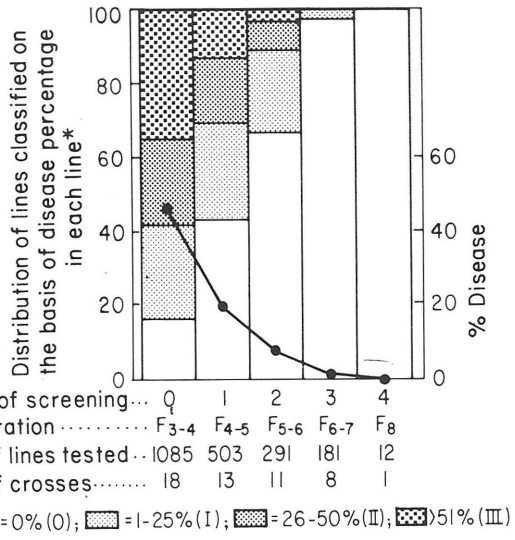


Fig. 2.
Percentage of disease associated with frequency of screening using artificial inoculation of an SMV-C and -D mixture -1 (Akita 1973-78).

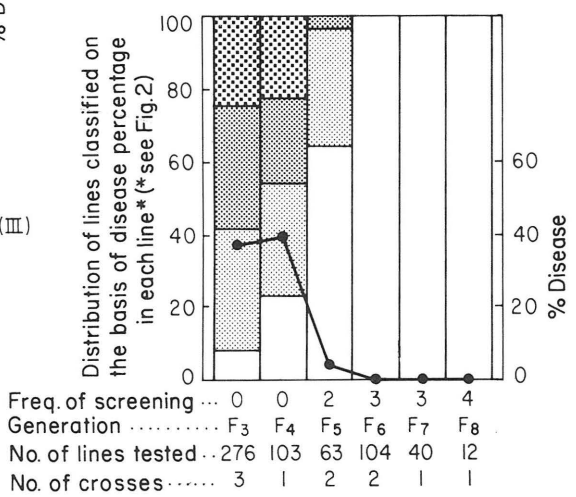


Fig. 3.
Percentage of disease associated with the frequency of screening using artificial inoculation of SMV-C and -D mixture - 2 , Akita, 1978 (see Fig. 2 for line distribution classifications).

Fig. 4.
Percentage of disease associated with the frequency of screening using artificial inoculation of SMV-C and -D mixture -3 (natural field infection, Yamagata, 1978) (see Fig. 2 for line distribution classifications).

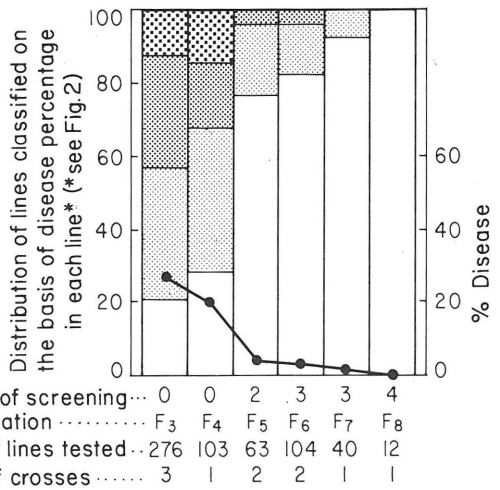
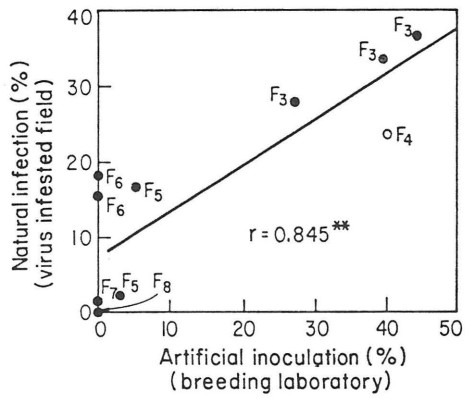


Fig. 5.
Comparison of the percentage of disease between artificial inoculation of SMV-C and -D mixture and natural infection in the field (F_3 to F_8 crosses).



Cultivar Suzuyutaka

Suzuyutaka was selected from a cross between Karikei 52 and Tohoku 35. Its female parent, Karikei 52, is a sister line of Dewamusume. Suzuyutaka was screened for resistance to SMV-C and -D using artificial inoculation (F_3 to F_7), and was evaluated in virus-infected fields from F_8 to F_{11} (Nagasawa et al. 1982).

There was a 40% disease incidence following initial inoculation and only 0.3% by the F_7 generation. Selected F_8 to F_{11} lines proved resistant to field infection. In addition to its SMV (-A,-B,-C,-D) and SSV-C resistance, Suzuyutaka is an excellent yielder and has a number of desirable agronomic characteristics.

Simplification of Artificial Inoculation Screening

One consideration involved in breeding for virus resistance is to prevent the spread of diseases. For this reason, breeding lines were screened in a greenhouse and/or framehouse covered with cheese cloth. The seedlings were transplanted in the field after discarding the infected plants, a process which took more than three weeks. Labor and a lack of facilities were the major constraints involved in accomplishing the task. In addition, evaluation of quantitative characters was complicated by the fact that the seedlings tended to elongate, which, in turn, affected growth after transplanting.

Direct sowing proved to be a better method. Using this technique, an isolated field was set up, and the breeding materials were directly sown after the application of a systemic insecticide. It was thus possible, to expand the scale of screening for virus resistance, and, at the same time, save labor.

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Breeding for Nematode and Insect Resistance

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Introduction

The distribution of insect and nematode species that infest soybean (Glycine max) varies according to location. For example, soybean pod borer (Leguminivora glycinivorella) and soybean cyst nematode (Heterodera glycines) are significant problems in northern Japan, while the predominant insects in the south are soybean pod gall midge (Asphondylia spp.), lima-bean pod borer (Etiella zinckenella), tobacco cutworm (Spodoptera litura), and root-knot nematode (Meloidogyne spp.).

Japan's soybean production season coincides with the rainy season, a fact which complicates the application of insecticides. In the case of nematodes, the situation is even more complicated. Complete control requires soil fumigation, which under most circumstances is impractical.

Insect and Nematode Resistance

Short-statured soybean cultivars have been reported to escape beetles attack (Scarabaeidae) (Kobayashi and Tamura 1939). Matsumoto (1962) found resistance to soybean pod borer in cultivars with glabrous pods. Resistance to soybean pod gall midge is due to glabrous pods or pods with long, crowded, and erect pubescence (Tamura 1941). Breeding for resistance to pod borer, beetles (Scarabaeidae), and cyst nematode has also been reported (Anon. 1954, Horiuchi 1960, 1964, and Ishikawa and Miyahara 1958). Cultivar Nemashirazu was selected in 1961 from a cyst nematode resistant cultivar, Gedenshirazu (Anon. 1967). Since then, 15 cyst nematode resistant cultivars were developed and released (Anon. 1967).

Breeding for Cyst Nematode Resistance

At least three physiological races of soybean cyst nematode have been identified in Japan (Sasaki and Sunada 1977). Cultivars Peking, PI 84751, and PI 90763 were described as highly resistant; cultivar Gedenshirazu had low levels of resistance to two races.

When breeding for cyst nematode resistance, F_2 populations are planted in a nematode-infested field; pedigree selection is based on the least damage to above-ground plant parts. Selections from the F_3 population are then planted in nematode infested-fields; subsequent selection is based on the number of cysts found on the roots. Yield and other agronomic characteristics of lines with "resistant" pedigrees are compared in normal and cyst-infested fields. The F_3 screening procedure is repeated until final selection.

Cyst nematode density can be determined by the double-row method (Ross and Brim 1957), or by counting the number of cyst nematodes that parasitize the roots of young seedlings (Matsumoto 1975). The half-root technique developed by Sakai

et al. (1975) can be used to determine the number of cyst nematodes that infest adult plants in the field.

The crossing of cultivars PI 84751 and Koganè-jiro led to the development of Suzu-hime, a cultivar with high levels of cyst nematode resistance (Sunada et al. 1981). Cultivars with low levels of cyst resistance have been developed with gamma-ray irradiation (Anon. 1970).

Insect Resistance

Several resistance sources for pod-attacking insects have been identified and used for breeding purposes (Hara and Ohba 1981, Igita et al. 1980).

Because insect populations vary according to season, a study was conducted in which potentially resistant cultivars were planted at five different dates from June to early August. Pods from ten plants were examined for damage 30 to 35 day after flowering. A highly susceptible cultivar, Enrei, served as the check. Regression analysis was used to determine percent damaged pods at flowering. The difference between the percent damage estimated for each cultivar at flowering and the observed damage was used as a measure of resistance.

Distinct genotypic differences were observed for the damage caused by Pentatomidae pests. Extremely late maturing cultivars, i.e. Sodendaizu (PI 229358), Himeshirazu, Kosamame, Menotake, Hondo, Chasengoku No. 3, and Asomasari, had high levels of resistance compared with early and medium maturing cultivars (Fig. 1).

Sodendaizu, Menotake, Himeshirazu, SJ 4, and Hondo were found to be resistant to lima-bean pod borer, and, in some cases, to Pentatomidae (Figs. 1 and 2). There was a highly significant correlation between the resistant lima-bean pod borer and the Pentatmidae pests (Fig. 3). The fact that some cultivars were more resistant than their parents suggests that future improvements could be made.

In another study, cultivar Sodendaizu was found to have resistance to tobacco cutworm and Epicauta gorhami. Himeshirazu was found to be resistant to the latter pest and Anomala rufocuprea (Horiuchi 1964). Sodendaizu was reported to have resistance to the Mexican bean beetle (Epilachna varivestis) (Kogan 1972, Van Duyn et al. 1971) and Papillia japonica.

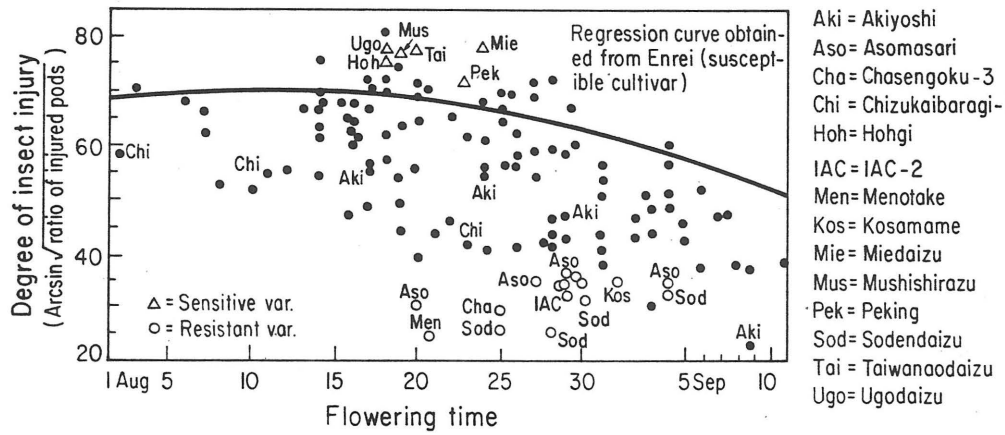

Fig. 1. Varietal differences for resistance to Pentatomidae.

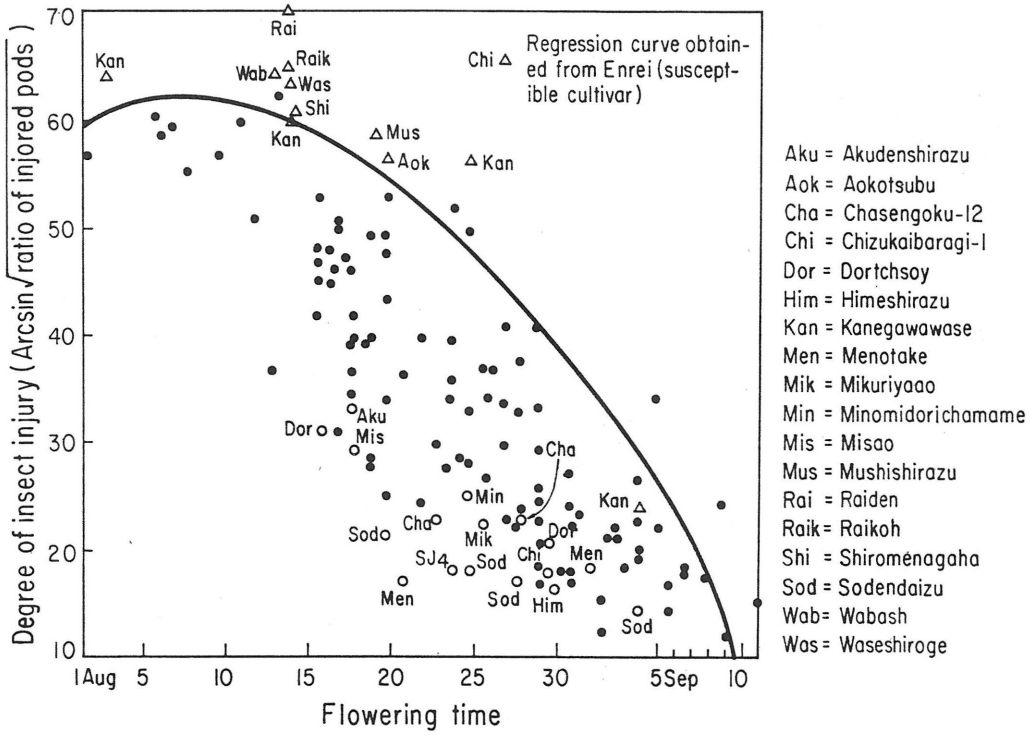

Fig. 2. Varietal differences for resistance to lima-bean pod borer (Etiella zinckenella).

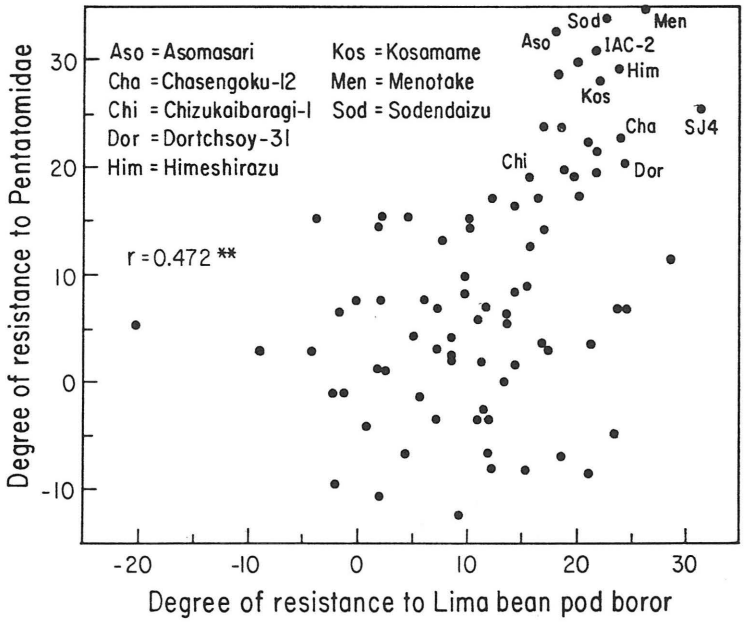

Fig. 3. Correlation between resistance to Pentatomidae and resistance to Etiella zinckenella.

Evaluation of Resistance

The non-preference of Nezara antennata for the pods of cultivars Himeshirazu and Sodendaizu, compared with susceptible cultivar Akisengoku, and the antibiosis of the resistant cultivars was studied in the laboratory.

Preference was examined by placing fresh pods from the three cultivars in a petri dish and allowing the insects to feed. The number of sucking insects on the pods was examined in the morning and in the afternoon; the percentage of sucking insects was determined according to the ratio of the mean number of insects on a specific cultivar's pod to the total number of insects that survived (Fig. 4).

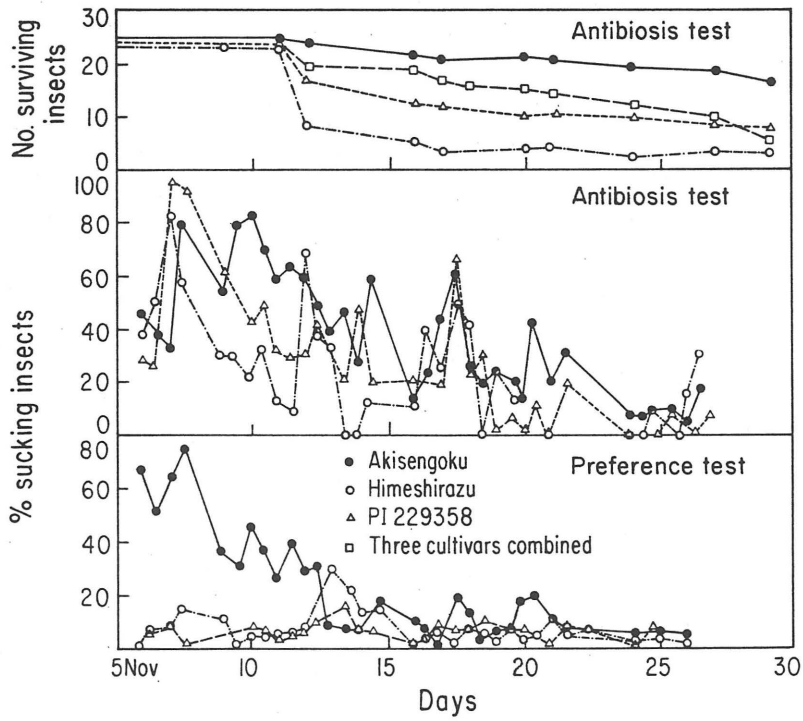

Fig. 4. Test for preference and antibiosis of three soybean cultivars.

Antibiosis was assessed by providing the pods of each cultivar separately. When the pods of the three cultivars were provided together, the insect fed only on the susceptible line. This indicates that laboratory screening might be as effective as field screening. In the antibiosis test, using four replicates of six fourth instar larvae, the number of surviving insects on the 30th day of the experiment was 16 for Akisengoku, 3 for Himeshirazu, and 7 for Sodendaizu. This suggests a clear difference between cultivars (Fig. 4). Most of the dead insects found in the resistant cultivars were dehydrated. The surviving larvae in the Himeshirazu treatment showed no signs of retarded growth. In the preference test, when the three cultivars were examined together, the survival period of the insect was compared with Akisengoku alone. This may indicate that the two highly resistant cultivars have antibiosis.

Cultivars Himeshirazu and Sodendaizu are both late maturing, have stems and pods with thick hairs, and grow vigorously. Their seed size is small; the hilum

is black or brown. Resistance may be due to: 1) low amounts of soluble sugars (Horiuchi 1960, 1964); 2) the lack of feeding-stimulants; 3) a physical feeding barrier (hairs and rigidity); or 4) unbalanced nutrition (Kogan 1972). Tester (1977) reported that the nitrogen content of cultivars Sodendaizu and PI 227687 was lower than that of the susceptible cultivars and that their sterols and carbohydrate content is high. In an analysis of leaf composition during the mid-ripening stage, Sodendaizu tended to have smaller amounts of nitrogen, free amino acids, and sugars than the susceptible cultivars.

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T-DNA Transfer in Soybean

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Introduction

Recent plant genetic engineering efforts have used Ti-plasmids as vectors (Braun and Wood 1976, Fox 1981, Academia Sinica 1978). Ti-plasmids enter the plant genomes in most dicotyledonous plants after infection by Agrobacterium tumefaciens or after the induction of tumors. Opine groups (octopine and nopaline) form in these types of tumors. In an auxin-free medium, tumor-tissue grows and forms calluses (Van Larebeke et al. 1974). After the integration of the T-DNA of Ti-plasmids into plant DNA, the metabolism of plant cells changes to produce endogenous auxin.

This phenomenon provides a convenient technique for screening transformed plants. Nopaline, a product of nopaline gene activity in the T-DNA of Ti-plasmids, can be identified by paper electrophoresis (Otten and Schilperoort 1978). Kerns et al. (1982) succeeded in transferring genes using isolated Ti-plasmids for transforming tobacco protoplasts and obtaining regenerated, transformed plants. Work is currently being carried out with the objective of inserting genes into Ti-plasmids and on the transformation of tobacco plants (Kerns et al. 1982).

DeCleene and Deley (1976) reported tumor-formations in a wild Glycine species. Lopatin (1936) failed to use Agrobacterium tumefaciens for tumor-induction. A short communication about tumor-formation in wild, semi-wild, and cultivated soybean provides screening results on tumor formation and data on nopaline gene transfer (Anon. 1982)

The aim of the present project was to apply plant genetic engineering techniques to soybean (Glycine max) improvement. The first step was to select cultivars that can produce tumors after infection with A. tumefaciens, and then study the fate of the foreign gene after it is integrated with a soybean genome.

Materials and Methods

A. tumefaciens strains included pTi 214, M3/73, C58, G1/73, B3/73, 542, A208, A4, 223, D9/73, K27, B1/73 (supplied by E. W. Nester, Washington University, USA) and T37, B6, and ACH5 (supplied by Research Group 303, Institute of Genetics, Academia Sinica). A total of 984 G. max cultivars, 129 lines of G. gracilis, and 440 lines of G. soja were used as recipients. The plants were grown both in the field and in the 20 cm pots (five plants per pot, 4 to 8 pots per cultivar). Plant growth was normal in all treatments.

A YEB medium was used for culturing A. tumefaciens. After sterilization, the bacteria were inoculated in the YEB medium and cultivated on a shaker (80 rpm/28°C). After 2 or 3 days of culturing, the bacteria was injected with a syringe into young plant stems.

Calluses were induced on an auxin-free MS medium from tumor-tissues. Paper electrophoresis was used for quantifying callus nopaline (Olten and Schilperoort 1978). T-DNA cell lines were obtained from calluses in a liquid MS medium (5mg IAA, 0.3mg 2.4-D, 0.5 mg KT).

Reaction to *A. tumefaciens*

Data on tumor formation are presented in Tables 1 and 2. Tumors were induced in 1.5% of the test population, the highest proportion of which occurred with G. gracilis.

Tumor-Tissue Culture and Determination of Gene Transfer

Tumor tissues were inoculated in the MS medium to induce bacteria-free calluses. Twenty- and 30-day-old tumor-tissue pieces (1 to 2 mm) were inoculated on an auxin-free MS medium. Bacteria-free tumor-tissues were obtained by transferring 40-day-old tumor tissues; 20-day-old tumor tissues were heavily contaminated with bacteria. Normal soybean tissues could not be grown or forced to form calluses in the auxin-free MS medium, but tumor-tissues could be induced. Calluses from tumor tissues of G. gracilis and G. soja, but not G. max, were obtained on the auxin-free MS medium. This indicates the presence of T-DNA in these types of calluses, but further studies are needed to determine if nopaline content is a product of the nopaline gene in T-DNA.

The presence of nopaline or octopine in plant tissues can serve as a marker-gene for T-DNA transfer (Thomashow et al. 1980). In our experiments nopaline and octopine determinations were made for calluses taken from tumor tissues. Paper electrophoresis verified the presence of nopaline in all calluses, thus confirming the integration and expression of nopaline genes in soybean genomes.

T-DNA Cell Lines

T-DNA soybean cell lines were obtained from T-DNA calluses in a liquid medium. These lines grew rapidly and had to be transferred to new media every 5 to 7 days. To date, line transfers have been made 29 times. Paper electrophoresis has verified that some cell lines contained nopaline, indicating that T-DNA soybean cell lines were obtained.

Discussion

The major problems encountered were low regeneration rates and the lack of suitable vectors. Correlations between regeneration ability and teratome-formation were observed. Ninety-four cultivars or forms of wild, semi-wild, and cultivated soybean formed tumors. Some tumors were flat surfaced, and can thus be considered as potential teratomes.

The data presented here verify that Ti-plasmids can be used as a vector for cultivated, semi-wild, and wild soybean. T-DNA was introduced in a stable form to soybean genomes through vegetative propagation. Nopaline gene transfer in genomes was also successful.

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Table 1. Tumor-inducing effects of strains T37 and C58 of Agrobacterium tumefaciens in soybean.

	T37			C58		
	plants treated	plants with tumors	percentage	plants treated	plants with tumors	percentage
G. max	1035	7	0.68	1035	33	3.19
G. gracilis	820	16	1.95	820	70	8.54
G. soja	1820	7	0.38	1820	19	1.04

Table 2. Reaction of different forms of soybean to tumor-induction by Agrobacterium tumefaciens

	Experimental Site	Cultivars or Forms of Soybean Treated	Cultivars or Forms with Tumors	Percentage	Plants Treated	Plants with Tumors	Percentage
G. max	Field	870	4	0.45	11,760	4	0.03
	Greenhouse	114	21	18.42	2,070	84	4.05
	Total	984	25	2.54	13,830	88	0.63
G. gracilis	Field	47	0	0	282	0	0
	Greenhouse	82	35	42.68	1,640	150	9.14
	Total	129	35	27.13	1,922	150	7.80
G. soja	Field	258	3	1.16	1,548	3	0.19
	Greenhouse	182	31	17.03	3,640	86	2.36
	Total	440	34	7.72	5,188	89	1.71
Total		1,553	94	6.05	20,940	327	1.56

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Discussion Section II

Question: For a multiple intensive cropping system, what is the ideal plant type?

Sumarno: In upland areas where mixed cropping is practiced, a semi-determinate, non-lodging type with disease resistance should be good. A semi-determinate type with early maturity is desirable for lowland cropping.

Question: What do you mean by "combine the small seeds with earliness?" Did you mean that the smaller seeds have a shorter lifespan or shorter blooming to maturity period?

Sumarno: I mean early maturity, 78-82 days, with small seed size, 10 g/100 seeds. It is possible to combine small seed size and early maturity simultaneously.

Nassib: This season (1983) we got some "promiscuous" varieties from INTSOY, but they did not nodulate under Egyptian conditions.

Frederick: This emphasizes the point that native rhizobia vary greatly from place to place. Also, keep in mind that all inoculants are not equally good.

Rennie: The fact that indigenous Rhizobium japonicum do not exist in the soil is an advantage rather than a problem. Proper inoculation is made easier. Each year microbiologists provide superior N_2-fixing strains. Soil rhizobia, even highly competitive ones, are often poor N_2-fixers. Breeding soybeans for promiscuous nodulation ability is, in fact, selection for mediocrity.

Dashiell: We are in full support of the use of inoculants. However, where they are not available to producers, the promiscuous lines can be very useful.

Question: Seed quality is difficult to define and it means different things to different people. What do seed and seedling attributes contribute to good stand establishment soon after harvest and after various periods of storage? Should we consider inherent traits - germination or non-germination, radicle emergence, radicle elongation, as well as others such as the effects of hot, arid, crusted soil, and give a genotype profile for quality/longevity characters?

Dashiell: Studies at IITA have indicated that the major factor causing poor soybean stands in the tropics is that the seed has a low germination percentage rate. Weak seed may germinate but never emerge. Therefore, we evaluated genotypes for percent emergence using the modified accelerated aging technique. We are selecting genotypes that have a high percentage of vigorous seed after eight months ambient storage in tropical conditions. Lines having this characteristic are said to have good seed longevity. The use of the term "good seed quality" can mean many things, and thus should not be used unless defined.

Question: In what type of cropping system is soybean used in tropical Brazil?

Kiihl: Sorghum after soybean and wheat after soybean are the major systems. Upland rice for 3 years and soybean is also practiced.

Question: Are the SMV strains mentioned in your presentation local ones?

Hashimoto: SMV is widespread in Japan; CMV is limited to southern Japan.

Question: Are the strains similar to the ones found in the USA?

Hashimoto: We did not check that.

Question: What are the advantages of using your T-DNA technique compared with conventional breeding methods?

Wang: We can transfer genes from perennial Glycine.

Question: What is the objective of the induction of Agrobacterium tumefaciens to soybean, and are there any practical applications in transferring genes from bacteria to soybean?

Wang: We are still testing the methodology.

Section III
Management

Saturated Soil Culture — An Innovative Water Management Option for Soybean in the Tropics and Subtropics

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Introduction

Temporary waterlogging is a common feature of tropical and subtropical cropping systems, because of 1) extended periods of wet weather, 2) rainfall immediately after irrigation, or 3) irrigation at appropriate levels during periods of high evaporative demand, especially on soils with low infiltration rates. Attempts to avoid waterlogging under conditions of high evaporative demand may result in irrigation levels below those required for maximum yield. In recent Australian studies, soybean (Glycine max) yields responded to the shortest irrigation intervals tested: 3 to 4 days (Garside et al. 1979) and 10 to 14 days during pod and seed development (Constable and Hearn 1980).

The detrimental effects of waterlogging may result from an oxygen supply that is not sufficient to sustain root respiration, from the production of microbial toxins, and/or from the loss of soluble N compounds (Russell 1977). In legumes, excessive soil water may be detrimental to both root growth and nodule function (Sprent 1969, Huck 1970, Bergersen 1971, Gibson 1976). Field observations (Pendleton 1976, Lawn and Byth 1979) and laboratory studies (Pankhurst and Sprent 1975, Stanley et al. 1980) suggest that soybean, compared with other legumes, is relatively tolerant to temporary waterlogging, and, in the absence of disease, recovers quickly after waterlogging ceases.

Recent studies have provided a new insight into irrigation management and the waterlogging of soybean. The detrimental effects of waterlogging on soybean growth do not persist if waterlogging is maintained and water tables are constant. Rather, soybean will acclimate to the saturated soil environment and re-establish normal growth and development. The growth rate and yield of continually waterlogged soybean usually exceed those of well-watered plants. This paper describes the development of this concept and summarizes present knowledge relating to its physiological basis and its potential applications in tropical and subtropical cropping systems.

Developmental Research

Acclimation of soybean to saturated soil was first reported by Hunter et al. (1980). Twenty-four soybean lines were grown for 36 days in a glasshouse. Soil beds were saturated starting 14 days after sowing by a constant water table, either 3 or 15 cm below the soil surface. All lines responded similarly.

After 22 days in soil saturated by a 15 cm water table, mean total dry weight was 37% greater than that of the control plants (spray irrigated). Plants grown in soil saturated by a 3 cm water table soon became extremely chlontic - a characteristic of severe nitrogen stress. However, green leaf color was regained, and growth resumed so that after 22 days, mean total dry weight was only 18% less than that of the control.

In a follow-up study, also in glasshouse soil beds (Nathanson et al. 1984), high growth rates of a short-season soybean line in saturated soil were sustained to maturity; seed yields were 65 and 71% greater with 3 and 15 cm water tables, respectively, than with conventional irrigation. Higher seed yields were mainly due to greater numbers of pods per plant, and also to increased seed size.

Substantial yield increases were also found in field studies in northern Australia. Plants were grown on raised beds and furrow-irrigated, either by continuous low-volume water flow (resulting in permanently saturated soil) or after 60 mm of cumulative open-pan evaporation (i.e. at 7 to 10 day intervals, the most frequent commercially feasible). The mean yield response of 14 cultivars to saturated soil culture (all of which recorded a positive response) was 22%, from 3.44 to 4.21 t/ha (Garside et al. 1980 and in press).

Physiological Characteristics of Soybean in Saturated Soil

Acclimation to Saturated Soil

Soil saturation results in a rapid increase in the proportion of photosynthates allocated to below-ground plant parts, particularly nodules, and earlier and more rapid establishment of nodule activity (acetylene-dependent ethylene production) (Table 1). However, total nitrogen uptake is reduced, mainly because of root death below the water table and the loss of root absorbing surfaces, with the result that a lighter leaf color is usually discernible during the second week of saturated soil culture. Total dry matter increment at this time may decline in relation to the control plants (cf. Table 2), possibly because of reduced leaf nitrogen levels, but mainly because of the reduced leaf area that results from a greater proportion of photosynthates being allocated to the roots and nodules. In a glasshouse experiment (Table 2), mean net assimilation rate (growth rate per unit leaf area) of plants in saturated soil culture (SSC) was initially equal to, and subsequently greater than, that of conventionally irrigated (CI) plants, despite consistently lower leaf N levels. Total growth rates were comparable eight to twelve days after SSC initiation, and were 11% higher for SSC during the following four days, despite poorer leaf N status.

Lower leaf N levels in SSC plants were found to persist until 28 to 42 days after SSC initiation, depending upon cultivar (Nathanson et al. 1984). Data from

Table 1. Total dry weight and its partitioning, nodule activity, and total N for saturated soil culture (SSC)[z] and conventionally irrigated (CI)[y] plants, 13 days after sowing (data of R. J. Troedson)[x].

	SSC	CI
Total dry weight (g/plant)	0.34	0.32
Percent in:		
tops	61.4	67.0*
roots	37.7	32.8*
nodules	0.9	0.2**
Nodule activity (μmoles C_2H_4 plant/hr)	0.55	0.07*
Total nitrogen (mg/plant)	14.4	16.4*

[z] Watertable 3 cm below the soil surface, imposed 7 days after sowing
[y] Irrigation after use of 50% available soil moisture
[x] From a glasshouse experiment in which plants were grown in beds of soil. Data are means for two cultivars, three N levels, three soil prehistories and two replications
*, **: Difference between irrigation regimes is significant, $P<0.05$, 0.01 respectively

Table 2. Net assimilation rates (NAR), total growth rates, and leaf % N for SSC[z] and CI[y] plants for the first 16 days after SSC initiation (data of R. J. Troedson)[x].

	Days After SSC Initiation				
	0-2	2-5	5-8	8-12	12-16
NAR ($mg/cm^2/day$)					
SSC	0.98	0.82	0.64	0.58	0.52
CI	1.01	0.82	0.60	0.50	0.40
Total growth rate (g/plant/day)					
SSC	0.075	0.105	0.135	0.198	0.257
CI	0.078	0.117	0.151	0.200	0.232
Leaf N[w] (%)					
SSC	6.10	4.94	5.04	4.41	4.18
CI	6.53	6.06	6.10	5.56	4.98

[z] Watertable 5 cm below the soil surface, imposed 13 days after sowing
[y] Irrigation after 50% available moisture use
[x] A subset of treatments from a glasshouse experiment in which plants were grown in soil beds (data are means for three pretreatments and three replications)
[w] At the end of the relevant period

long-term experiments (Nathanson et al. 1984, Garside et al. in prep.) suggest that total dry matter of SSC plants exceeds that of CI plants 50 to 70 days after sowing, and that growth rates remain substantially higher until maturity (Fig. 1).

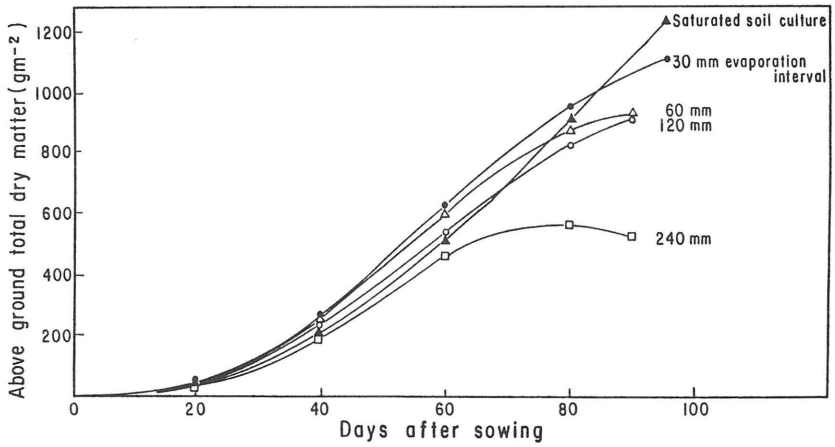

Fig. 1. Effect of irrigation interval on shoot dry weight of soybean cv. Ross (date of A. L. Garside).

Nodule mass continues to increase rapidly during acclimation to saturated soil culture. The nodules are characterized by lenticels - ridges of loosely packed aerenchyma tissue which presumably facilitate gas exchange in the saturated soil (Pankhurst and Sprent 1975). Where soil N levels are low, N fixation is a major N source for plants grown in both CI and SSC, but particularly in SSC where the soil N contribution is negligible. This is clearly illustrated by data from a field experiment in Southeast Queensland that compare nodulating and non-nodulating isolines of cultivar Clark 63 (Table 3). This cultivar is not adapted to subtropical conditions, which may explain its relatively low SSC yield response.

Table 3. Total N, nodule mass, and seed yield (g/plant) for a nodulating and a non-nodulating isoline grown with two irrigation regimes[z] (data of R. J. Troedson)[y].

	Total N	Nodule Dry Weight[x]	Seed Yield
SSC			
Nodulated	0.84	1.10	8.9
Non-nodulated	0.08	-	0.2
CI			
Nodulated	0.85	0.74	8.3
Non-nodulated	0.16	-	1.7

[z] SSC: Continuous furrow irrigation, plants grown on raised beds. CI: Irrigation after 60 mm pan evaporation

[y] A subset of treatments from a field experiment, with plant population 417,000/ha; data are means for three replications

[x] At end of flowering

Growth After Acclimation

Diurnal profiles of leaf conductance and leaf water potential presented by Nathanson et al. (1984) suggest that the higher net assimilation rates in saturated soil culture (Table 2) may be partially explained in terms of leaf water status and its effect on diffusive resistances. The data presented were taken one day prior to the irrigation of the CI treatment; leaf water potential of CI plants declined rapidly to -1.5 MPa at 11:00 hours. Leaf water potential of SSC plants declined more slowly to only -1.0 MPa at noon. Leaf conductances oscillated during the morning but, on average, were substantially higher in SSC plants than in CI plants (Nathanson et al. 1984). Minimum leaf water potentials below -1.1 MPa have been associated with the inhibition of photosynthesis (Boyer 1970, Ghorashy et al. 1971). A recent report suggests that even when decreases in minimum leaf water potential are small (0.2 to 0.3 MPa), and are confined to a few hours at midday in otherwise non-water stressed plants, yield losses can be substantial (Boyer et al. 1980).

Additional indirect evidence that higher SSC growth rate and yield are due to enhanced photosynthesis was provided by Troedson et al. (1982). In a field study, light-enhancing treatments (three or six weeks of reflective sheeting or the removal of alternate plants) or N-enhancing treatments (weekly spray with urea solution or removal of the center leaflet of the top five leaves to increase assimilate supply to the nodules via illumination of the lower leaves) were imposed on furrow-irrigated CI and SSC crops during seed development. The effects of reduced above-ground growth during acclimatization to SSC were evident at the start of seed development in the form of lower dry matter (DM) and N accumulation (Table 4). However, in control plants, subsequent DM accumulation for SSC was 46% greater than in the CI treatments, while N accumulation was 2.5 times greater. Nodule activity has been shown to decline rapidly during grain development in conventional crops (Lawn and Brun 1974), while it is sustained in SSC (Nathanson et al. 1984). Ultimately, seed yields were 24% greater in saturated soil culture (Table 4).

N enhancement had little effect on grain yield and DM accumulation and a relatively small effect on nodule activity and N accumulation in CI only. In contrast, each of these parameters was increased by light enhancement, particularly in CI plants where levels were comparable to or greater than those in SSC, possibly reflecting higher dry weight and N levels at the start of seed development with conventional irrigation. Comparisons of DM and N accumulation and

nodule activity during grain development in SSC and light-enriched CI suggest that a possible explanation for yield increases in SSC plants is that photosynthesis is enhanced (relative to CI plants) sufficient to maintain nodule activity concurrent with grain filling. Enhanced carbon input generates a matching nitrogen input that maintains C/N balance in the plants and in seed yield.

Table 4. Effect of light and nitrogen enhancement during seed development on above-ground dry weight and nitrogen accumulation, and nodule activity, for plants grown in two irrigation regimes (after Troedson et al. 1982).

	SSC[z]			CI[z]		
	control[y]	+light[x]	+N[w]	control	+light	+N
Dry weight accumulation (g/plant)						
Prior to seed development	--------11.4-------			--------14.3------		
During seed development	9.9	10.3	8.2	6.7	11.1	7.4
Seed yield	7.8	8.6	7.4	6.3	9.0	6.7
Nitrogen accumulation (g/plant)						
Prior to seed development	----------0.33-------			---------0.41------		
During seed development	0.31	0.36	0.30	0.13	0.32	0.21
Seed yield	0.51	0.56	0.50	0.41	0.59	0.44
Nodule activity[u]	17.20	51.10	19.00	8.30	25.40	13.60

[z] As for Table 3
[y] Plant population 556,000/ha
[x] Mean of three treatments (see text)
[w] Mean of two treatments (see text)
[u] Eight days after treatment initiation, µmoles C_2H_4/plant/hr

Agronomic Implications of SSC

Soil Type

Saturated soil culture is only suited to soils with low vertical percolation rates. In permeable soils large quantities of water would be required to maintain saturation, which could result in possible pollution or salinity problems. On soils with minimal percolation, water use after canopy closure should not be substantially greater than in conventional irrigation, particularly if tail-drain water can be minimized or recycled to the head-ditch or used downslope.

Studies to date have been conducted only on heavy, highly fertile clay soils (e.g. Hunter et al. 1980). Thus far there is no evidence of nutritional problems due to soil saturation. Waterlogging increases the amounts of calcium, magnesium, potassium, and manganous and ferrous ions in the soil solution, but their levels depend on many factors, including pH and organic matter content (Russell 1973). There are conflicting reports concerning the effect of waterlogging on soil copper and zinc levels (Iu et al. 1982). However, the information available on the range of soil transformations in submerged rice (Oryza sativa) soils (e.g. Ponnamperuma 1972) may not be directly applicable to saturated soil culture systems. Recent work has demonstrated that with a sub-surface water table as high as 3 cm below the soil surface, the soil above the water table remains oxidized (Troedson et al. in prep.).

There are large areas in northern Australia, and undoubtedly in other parts of the the tropics and subtropics, where cropping is limited by high seasonal

water tables and/or flooding. The potential of soybean to permit cropping on these soils is at present untested. Land-works would be required to enable the removal of excess water following heavy rain, and a method of establishing the crop on already saturated soil may be necessary.

Irrigation Methods

To date, SSC field studies have been carried out with plants grown in 4 to 6 rows on raised beds (1.5 m wide) separated by furrows. Each furrow receives a constant water supply (trickle). The raised bed provides a free-draining wet zone (5 to 15 cm) in which roots and nodules proliferate. Under Australian conditions the reduced labor requirement of permanent siphons represents a substantial cost saving. No work has been done on the application of SSC to other irrigation systems, e.g. paddy bays, but the provision of a shallow depth of soil above the water table would be important. Depending on soil type, a filled ditch around the perimeter of a bay may be sufficient to maintain saturated soil. In this case, precise leveling in the bay would be critical.

Water supply is intermittent in many irrigated tropical and subtropical areas. Once SSC is established, extended periods without irrigation are known to be detrimental, although yield will probably not drop below that of a CI crop (Table 5). However, where water supply is sufficient, 3- to 4-day irrigation cycles on heavy soils may result in plant performance similar to that found on continuously irrigated fields.

Table 5. The effect of withholding water temporarily or permanently on yield in saturated soil culture (data of R. J. Troedson)[z].

Stage of Withholding Irrigation from SSC	Duration (days)	Seed Yield (t/ha) 1980	1981
SSC[y] control	-	4.30a	4.32c
Preflowering, rewatering at flowering	11	3.02d	-
Preflowering, rewatering after flowering	17	3.61bc	-
During flowering	14	3.77ab	-
During flowering	22	3.29bcd	-
During pod development	12	3.16cd	-
During seed development	Until maturity	-	3.57d
CI[y] control	-	-	3.49d

[z] Field experiments; data are means for three (1980) or two (1981) replications; within years, treatments followed by different letters are significantly different, $P < 0.05$

[y] As for Table 3

Timing of SSC and Starter N

Recent studies (Troedson et al. 1981, and in prep.) indicated that SSC should be initiated during seedling establishment. Early commencement of SSC resulted in rapid nodule development and ensured that growth rates and leaf N levels were restored prior to flowering.

Soil saturation should be sustained long enough to ensure that high soil moisture levels are maintained in the root zone (first 15 cm of the soil) until physiological maturity. If the crop is mechanically harvested, water application must cease in time for the soil to be able to support harvesting equipment. The timing of SSC termination will depend upon soil type and the probability of rain

during the harvest. Where the crop is to be hand-harvested, SSC termination is less critical. SSC may also help facilitate multiple and relay cropping.

Application of 25 kg N/ha at sowing, either as KNO_3 or $(NH_4)_2SO_4$, reduced leaf N deficiency and increased early growth rates without seriously affecting nodule development (Table 6). The application of an N solution at the commencement of SSC was found to be equally effective. The use of starter N is likely to be particularly important for short-season cultivars.

Table 6. Effects of seeding age at SSC commencement and of starter N on above-ground dry weight and nodule activity 25 days after sowing, and mean %N in leaves between 13 and 25 days after sowing (after Troedson et al. 1981).

Seedling Age at SSC Commencement Days After Sowing	Nitrogen Application (kg/ha)	Above Ground Dry weight (g/plant)	Nodule Activity (μmoles C_2H_4/ plant/hr)	Leaf N (%)
7	0	0.93	10.3	5.04
	25, as NO_3	0.99	9.6	5.32
	25, as NH_4	1.19	11.9	5.48
13	0	0.92	10.3	5.23
	25, as NO_3	1.09	8.2	5.52
	25, as NH_4	1.06	6.8	5.53
Significant differences:[z]				
Seedling age		NS[y]	NS	NS
Nitrogen		**	NS	*

[z] *, **: P < 0.05, 0.01 respectively
[y] NS: Not significant

Rotations with Rice

There is potential for SSC soybean production in rice rotations utilizing common irrigation structures. Rice is often grown in Asia on small terraces, with peripheral ditches used either for rodent control or to allow rapid removal of excess rainfall. Puddling ensures adequate leveling within the bays, and the fact that soybean roots in SSC only proliferate in the first 5 to 10 cm of the soil eliminates the cultivation usually required to grow an upland crop after rice. The only land preparation needed would be occasional furrows contiguous with the surrounding ditch, at intervals sufficient to maintain soil saturation above a sub-surface water table (Fig. 2). In mechanized agricultural systems the possibility of using rice-soybean rotations, with both crops grown on saturated beds, may provide considerable savings in land preparation.

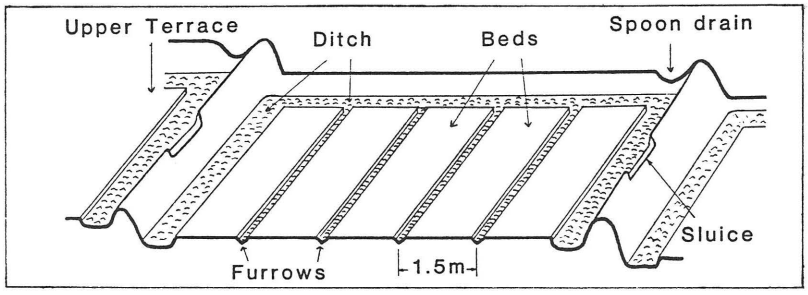

Fig. 2. Cross section of a rice bay adapted for SSC soybean.

A major proportion of the N accumulated by the symbiotic N fixation of high yielding grain legume crops is translocated to the seed. However, the decomposition of roots, nodules, and abscised leaves and petioles provides a gradual N supply to succeeding crops. From data presented by Nathanson et al. (1984), the total N from roots and nodules that remained in the soil after their experiment was 26.9 kg/ha for SSC (mean of two water table depths) compared with 9.3 kg/ha for CI. The difference was due to both higher root weight and percent N in SSC. In their experiment, data were not collected for abscised leaves and petioles, but data from field experiments (R. J. Troedson, unpublished) suggest that N inputs from this source are similar for SSC and CI.

Weeds

Saturated soil culture alters the spectrum of weed species that compete with a crop. A number of major weeds are eliminated in SSC, but a few previously insignificant species prosper, including some that inhabit irrigation ditches. The use of SSC in rotations with upland or CI crops is therefore likely to be an effective weed management option.

Insects

Few major interactions have been observed between insects and SSC, except for an ameliorating effect on the damage caused by stemborer, Zygrita diva. This insect is a major soybean pest in northern Australia, and is responsible for water stress, premature plant death, and pinched seed. Infested SSC plants appear to maintain water status better than CI plants, thus resulting in fewer pinched seeds and improved germination.

Diseases

Phytophthora stem rot may cause major plant losses when susceptible cultivars suffer temporary waterlogging after heavy rain. The interaction of this disease and SSC is currently being studied on a site where a soybean crop was previously infected by Phytophthora. In susceptible cultivars, plant losses occurred earlier in SSC, but, in cultivars with field resistance, losses were comparable to those observed in CI (Table 7). To date, differences in plant growth between SSC and CI in this experiment are consistent with those reported in the absence of disease.

Table 7. Percent disease-free plants 68 days after sowing (data of R. J. Troedson)[z].

Cultivar	SSC[y]	CI[x]
Nessen	95.3	93.8
Davis	93.4	93.8
Bragg	87.2	82.6
Dragon	86.0	82.2
Forrest	88.0	93.0
Wills	18.6	12.8
Fitzroy	18.2	22.5
Semstar	4.3	19.8

[z] Trial sown on a site with a history of severe Phytophthora infection
[y] Cultivar ranked in order of decreasing resistance to Phytophthora in laboratory inoculation studies
[x] As for Table 3

Conclusions

Saturated soil culture has a radical influence on soybean performance; it promotes higher growth rates, more prolific nodulation, greater and more prolonged N fixation, and higher seed yields than assiduous conventional irrigation. Yield enhancement by agronomic manipulation of commercial cultivars selected under conventional irrigation conditions suggests that substantial yield increases should be possible through genetic improvement. Saturated soil culture is not appropriate in all irrigated soybean areas, but clearly could substantially broaden soybean adaptation. The increase in water use should be balanced against increases in seed yield and the return from the residual water and N in the soil after the crop has been harvested.

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Soybean Genotypic Responses for Minimum and Maximum Input in Different Seasons

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Crops express their maximum genetic yield potential when grown in favorable environments and with genotype-specific management practices. High soybean (Glycine max) yields can be produced in the tropics (Shanmugasundaram, 1976), but this potential is rarely seen on farmers' fields. Gomez (1980) suggested that there are four yield levels - experimental, potential, economic, and actual (Fig. 1).

Soybean can be grown in the tropics and subtropics year-round. Significant interactions between genotypes and season have been observed for various agronomic characteristics (Hung and Shanmugasundaram 1980). This suggests a need to select genotypes for specific environments.

Soybean in Southeast Asia is generally grown in rice-based (Oryza sativa) cropping systems (Shanmugasundaram et al. 1980). Farmers cultivate their crops either with no-tillage or with minimum tillage, especially during the dry season. From the farmer's point of view, yield increases due to improved germplasm are preferable to those derived from expensive cultural practices and inputs. Therefore, cultivars are needed that can produce higher yields under a variety of inputs levels (Swaminathan 1979).

Experimental Background

Eleven Glycine selections (AGS) and three local cultivars (checks) were evaluated at two management levels: AVRDC's suggested cultural practices (maximum inputs) (Shanmuagasundarm 1980a) and minimum inputs (land preparation, planting, and harvesting only). The experiment was conducted at the AVRDC experimental farm in the spring (February), summer (July), and autumn (September) seasons of 1980 and 1982 and in the summer and autumn of 1981. The data were analyzed individually; seasons and years were pooled and analyzed together. Different seasons and years were considered as a series of the same experiment.

Variation in Environmental Variables

Spring, summer, and autumn photoperiodic conditions at AVRDC are shown in Fig. 2. Temperature increased from a yearly low to a yearly high during the spring season, remained uniformly high during the summer, and decreased from the high to the low during the autumn. Yearly temperature variations were encountered, but general trends were similar throughout the test period (Figs. 3a, 3b, 3c). Rainfall patterns and distribution, however, differed not only within a particular year, but between years. The year 1980 was characterized by low rainfall (Fig. 3a). May, July, and September of 1981 and May, June, July, and August of 1982 were high rainfall months: >200 mm/month (Fig. 3b, c). Heavy precipitation (500 to 600 mm; typhoons) was recorded in September 1981 and July 1982 (Fig. 4).

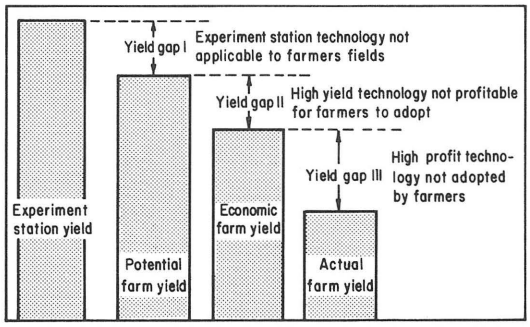

Fig. 1. Yield gap between experimental and on-farm yields (adapted from Gomez 1980).

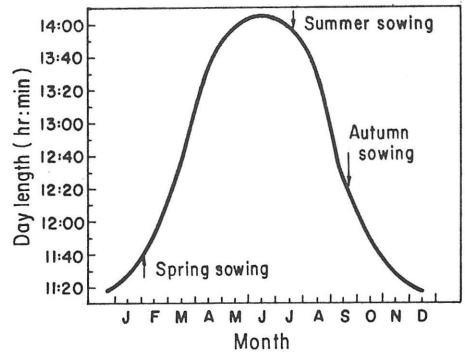

Fig. 2. Photoperiodic differences during three soybean-growing seasons at AVRDC.

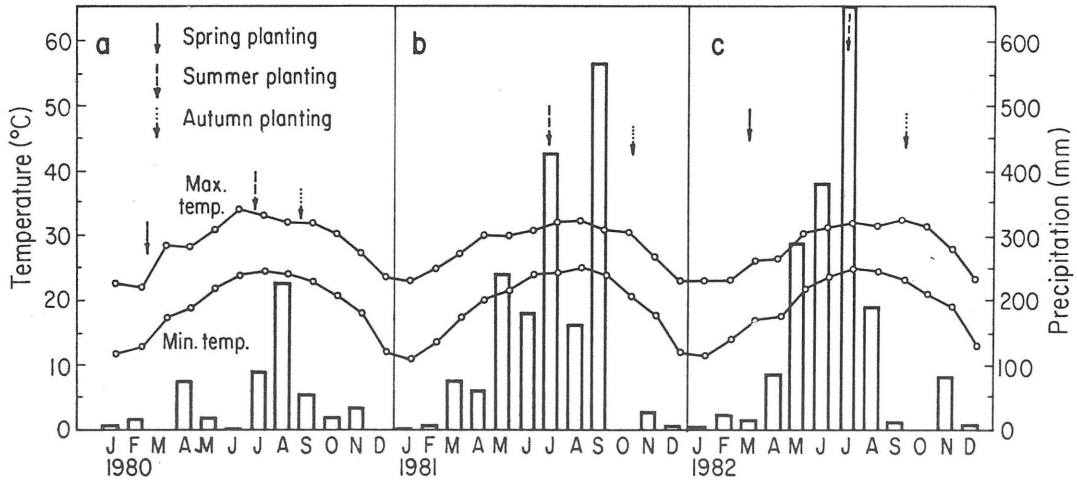

Fig. 3. Temperature and rainfall patterns, 1980-1982, AVRDC.

Fig. 4. Typhoon flooding conditions at AVRDC.

Grain Yield

Significant yield differences were observed between seasons (Table 1). Average yield in the spring season was nearly 94% and 21% higher than in the autumn and summer seasons, respectively. Summer yields were almost 61% higher than autumn yields (Table 2).

Time to flowering and maturity duration were longest in the spring and shortest in the autumn. Plant height and number of pods/plant at maturity were highest in the summer season. One hundred-seed weight was similar to the data for days to maturity and grain yield (Table 2); longer maturation periods apparently increased 100-seed weight, and thus resulted in higher yield. In the summer season, higher pod number and moderate seed weight were responsible for moderate seed yield. Shorter maturity duration - due to short days, fewer pods, and lower seed weight - was responsible for lower yields during the autumn season (Table 2).

Some reports indicate that nutrient absorption rises as temperatures increase (De Mooy et al. 1973, Gukova 1960, Paulsen and Rotimi 1960, Wallace 1957). Soybean nutrient absorption in the spring and summer seasons is apparently enhanced because of higher temperatures. Summer yields may have been lower than spring yields because of excessive rainfall and poor drainage. It is also likely that there was excessive vegetative growth and improper pod filling under high temperatures.

The 1980 yields were significantly higher (2.0 t/ha) than those recorded in 1981 (1.2 t/ha); 1982 yield (1.6 t/ha) did not differ significantly with 1980 or 1981 yields.

Maximum and Minimum Inputs

Differences in yield brought about by minimum and maximum input use is referred to as the "yield gap." Significant yield differences were found between inputs and the interaction between inputs and seasons (Table 1). Compared with the minimum inputs treatments, yields in the maximum input plots increased 107%, 98%, and 112% in 1980, 1981, and 1982, respectively (Fig. 5). The yield gap was highest in the spring season, followed by autumn and summer (3-year average) (Fig. 6).

Spring yields were highest under maximum input conditions: 3.2 t/ha compared with 2.3 and 1.6 t/ha during the summer and autumn seasons, respectively. The trend for other agronomic characteristics followed the pattern shown in Table 2 (Table 3). In contrast, grain yield in the minimum input treatment was highest in the summer (1.4 t/ha), followed by spring (1.3 t/ha) and autumn (0.7 t/ha) (Table 4).

Days to flowering and days to maturity were not affected by management inputs. As expected, there was a distinct increase in plant height, pods/plant, and 100-seed weight under maximum inputs (Tables 3 and 4). A critical evaluation of the INTSOY International Soybean Variety Experiment (ISVEX) trials indicated that management variables jointly accounted for 56% of the variability in yield among sites (adjusted for environmental effects) (Whigham 1976, Whigham et al. 1978). However, better adapted cultivars are essential for promoting management (Shanmugasundaram et al. 1980). The average yield of the 14 genotypes in the maximum input treatment was 2.3 t/ha compared with an average of 1.0 t/ha for the same lines grown under minimum input conditions.

Table 1. Analysis of variance of the individual factors and interactive effects for soybean grain yield.

Source	Degrees of Freedom	Mean Square	F
Year	2	39761689.2	336.4**
Season	2	84205016.1	712.5**
Genotypes	13	1201656.3	10.2**
Inputs	1	297689042.5	2518.9**
Inputs x genotypes	13	252024.4	2.1**
Season x genotypes	26	525234.0	4.4**
Season x inputs	2	24899231.9	210.7**
Season x inputs x genotypes	26	265924.0	2.3**

Table 2. Variation in yield and other agronomic characteristics according to seasons.

Season	Days To flowering	Days To maturity	Height at Maturity (cm)	Pods/ Plant	100-seed Wt.(g)	Yield (t/ha)
Spring	48 a	106 a	50 b	20 b	18 a	2.2 a
Summer	38 b	96 b	78 b	32 a	15 b	1.9 b
Autumn	31 c	88 c	48 c	16 c	14 c	1.2 c

Values followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test

Table 3. Mean yield of 14 cultivars grown under maximum input in three seasons.

Season	Days To flowering	Days To maturity	Height at Maturity (cm)	Pods/ Plant	100-seed Wt.(g)	Yield (t/ha)
Spring	48 a	105 a	60 b	27 b	19 a	3.2 a
Summer	38 b	97 b	79 a	37 a	16 b	2.3 b
Autumn	30 c	85 c	50 c	17 c	15 c	1.6 c

Values followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test

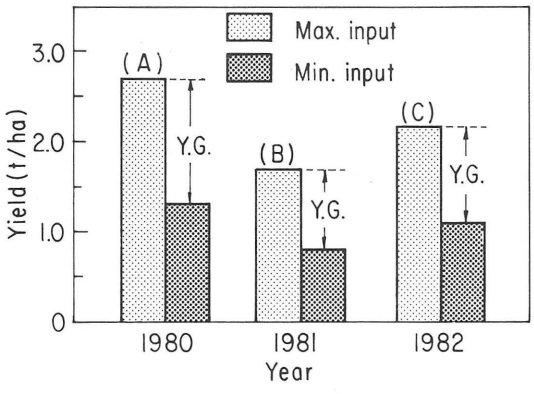

Fig. 5. Yield gap (Y.G.) between maximum and minimum inputs, 1980-81 (treatments with different letters signify significant differences).

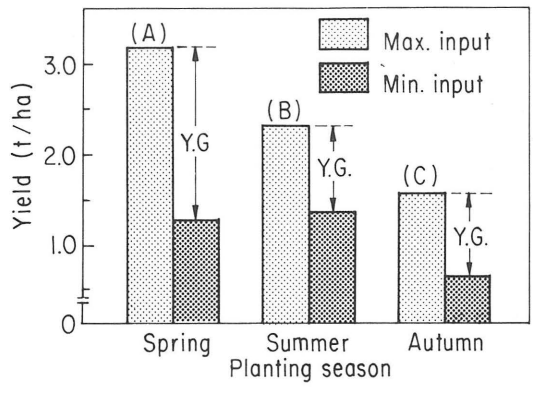

Fig. 6. Yield gap (Y.G.) between maximum and minimum inputs, 1980-82 (treatments with different letters signify significant differences).

Table 4. Mean yield of 14 cultivars grown under minimum inputs in three seasons.

Season	Days To flowering	Days To maturity	Height at Maturity (cm)	Pods/ Plant	100-seed Wt.(g)	Yield (t/ha)
Spring	48 a	106 a	41 b	13 b	16.6 c	1.3 b
Summer	38 b	95 b	76 a	24 a	13.9 b	1.4 a
Autumn	30 c	82 c	45 b	16 b	13.7 b	0.7 c

Values followed by the same letter are not significantly different at 0.05 level according to Duncan's multiple range test

Table 5. Seed yield of different genotypes as affected by minimum and maximum inputs.

Genotype	Yield (t/ha)		
	maximum inputs[z]	minimum input[y]	mean
AGS 68	2.532 a	1.200	1.866 ab
AGS 59	2.485 ab	1.349	1.917 a
AGS 144	2.476 abc	1.181	1.828 ab
AGS 71	2.464 abc	1.246	1.855 ab
AGS 143	2.295 abcd	1.116	1.706 abc
AGS 85	2.259 abcde	1.109	1.693 abc
AGS 66	2.237 abcde	1.255	1.754 abc
AGS 17	2.236 abcde	1.049	1.652 abc
AGS 74	2.222 abcde	0.973	1.608 bc
AGS 78	2.211 abcde	1.044	1.627 abc
G 38	2.167 bcde	0.935	1.592 bc
G 2043	2.158 cde	0.935	1.556 bc
AGS 62	2.054 de	1.066	1.593 bc
G 2261	1.946 e	0.992	1.469 c

[z] Values followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test
[y] Not significantly different

Yield Differences Between Genotypes

Under maximum input conditions AGS 68 produced significantly higher yields than the high yielding check, G 38. In the pooled analysis of max/min inputs, AGS 59 outyielded G 38 (Table 5). The highest average yield across seasons, inputs, and years was produced by AGS 59 (23.7% higher than G 38). Average yield in many tropical and subtropical countries is only 1.0 t/ha (Shanmugasundaram 1980b).

Genotypes, Seasons, and Inputs

All of the individual factors examined, and their first and second order interactive effects, were highly significant for yield (Table 1). Among the 14 entries evaluated, the highest yielder under maximum inputs was AGS 68 (2.53 t/ha) (not significantly different from AGS 59's 2.48 t/ha). AGS 59 also produced higher yield under minimum inputs (1.35 t/ha).

Among the genotypes evaluated, G 38, G 2043, and AGS 74 were highly responsive to inputs; AGS 66, AGS 59, and AGS 62 were not (Table 5).

Yield under maximum and minimum input conditions were correlated ($r = 0.658^{**}$ and 0.508^{**}, respectively). The test for heterogeneity showed a chi-square value of 7.783 with 7 degrees of freedom; P was 0.39. Therefore, the correlation for all seasons were combined; the corresponding r for the pooled data was 0.551^{**} suggesting that cultivars suitable for both low and high input cultivation can be selected in advanced yield trials.

Yield response due to maximum input varied with season and genotype. Compared with G 38, AGS 68, AGS 59, and AGS 144 produced significant yield responses when grown with maximum inputs. Under minimum input conditions, AGS 68 and AGS 143 outyielded the high yielding check, G 2043.

In the summer season, with maximum inputs, there was no significant difference between G 38 and other genotypes. But under minimum input conditions, AGS 62 and AGS 66 outyielded G 38. Virtually no differences were found when AGS 66 was grown in the maximum or minimum input treatments (Table 6).

In the autumn, AGS 71 yielded 21% more than the high yielding check, G 2261, under maximum inputs. AGS 59 yielded twice as much as G 2261 with minimum inputs (Table 6).

The spring season was characterized by increasing temperatures, longer photoperiods, and dry weather (Figs. 2 and 3). As a result, there was a significant response to fertilizer, weed control, irrigation, and pest control. Decreasing temperatures and photoperiodic and dry weather conditions retarded soybean growth in the autumn season. Therefore, although the difference between maximum and minimum input was as dramatic in the autumn as it was in the spring, absolute yield in the autumn was far lower. The minimum input treatment plots were not irrigated in the rainy season, but precipitation was adequate. With a genotype such as AGS 66, where the difference between the maximum and minimum input yield was negligible, irrigation is probably the most important input determinent for yield. However, AGS 68 yielded 65% more with maximum inputs than with minimum inputs (2% for AGS 66 in the summer season). Therefore, for AGS 68, water is probably only one of several inputs required for the full expression of its yield potential.

Table 6. Seed yields (t/ha)of 14 genotypes as influenced by three seasons and two inputs levels (1980).

Genotype	Spring Crop			Summer Crop			Autumn Crop		
	input		mean	input		mean	input		mean
	max	min		max	min		max	min	
AGS 62	2.9	0.7	1.8	3.1	2.6	2.8	1.9	0.8	1.3
AGS 66	3.5	1.0	2.2	3.1	3.0	3.1	1.8	0.9	1.4
AGS 74	3.1	1.0	2.0	2.6	1.7	2.1	1.8	0.6	1.2
AGS 78	3.8	1.1	2.4	2.5	1.9	2.2	2.1	0.7	1.4
AGS 85	3.3	1.4	2.3	3.0	2.4	2.7	2.0	0.6	1.3
AGS 71	3.7	1.4	2.6	2.6	2.1	2.4	2.3	0.7	1.5
AGS 68	3.8	1.6	2.7	2.7	1.6	2.1	2.1	0.6	1.4
AGS 59	4.2	1.4	2.8	2.4	1.7	2.0	2.1	1.3	1.7
AGS 143	3.5	1.7	2.6	2.3	1.4	1.8	2.0	0.6	1.3
AGS 144	4.3	1.1	2.7	3.0	2.1	2.5	2.2	0.9	1.6
AGS 17	3.3	1.2	2.3	2.4	1.5	2.0	1.9	0.6	1.3
G 38	3.5	1.1	2.3	2.9	2.1	2.5	1.7	0.5	1.1
G 2261	3.1	0.9	2.0	2.5	1.8	2.2	1.9	0.6	1.3
G 2043	3.2	1.2	2.2	2.5	1.8	2.1	1.6	0.5	1.1
Mean	3.5	1.2	2.4	2.7	2.0	2.3	2.0	0.7	1.3
LSD (0.05)	0.3	0.3	0.2	0.4	0.4	0.2	0.3	0.4	0.2
LSD (0.05) between seasons: 0.007									

Conclusions

Genotypic variation for yield potential is available in tropical soybean, and soybean production in the tropics can be augmented by varietal improvement. Response to agronomic inputs varies with genotype and season, but, in general, input-use can improve tropical soybean production. Genotypes that respond to inputs in specific seasons can be selected, and genotypes with high yield potential that are indifferent to inputs during specific seasons (AVRDC rainy season) are available. Some genotypes with high yield potential selected under maximum input conditions are also high yielding under minimum input conditions. High yielding genotypes grown with maximum inputs are not necessarily high yielding under minimum input conditions, except during the summer season when water is not a limiting factor.

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Maximum Yield and Maximum Economic Yield for Soybean

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Introduction

There are numerous factors and interactions that contribute to the potential yield of soybean (Glycine max). Because genetic potential and environmental conditions are key to determining yield potentials, the theoretical maximum yield for soybeans may vary considerably according to year and location. Johnson (1982) estimated that the theoretical maximum soybean yield in the United States was more than 11 t/ha. Average and world record yields represent only a fraction of the theoretical yield (Table 1). Potential yields in the tropics and subtropics may be even higher.

This paper discusses the development of the concepts of maximum yield research (MYR) and maximum economic yield (MEY) of soybean in North America and their potential application in the tropics.

Maximum Yields and Maximum Economic Yields

Maximum Yield Research

The concepts of MYR and MEY have been widely adopted in North America by researchers and farmers. Maximum yield research is defined as the study of one or more variables and their interactions in a multidisciplinary system that strives for the highest possible yield in a given soil and climate (Dibb 1983). Maximum yields vary according to climate, season, and soil conditions, but in a perfect growing season maximum yield should approach maximum yield potential. The objective of MYR is to regulate all controllable production factors at an optimum rate so as to take advantage of the cumulative effects of positive interactions, and, in turn, maximize crop production. Wortman and Cummings (1978) put MYR in perspective by stating:

> As a part of their agriculture research, biological scientists in each country must continuously test the limits of available technology as well as their ability to put together new technological components to achieve highest yields. Maximum yields may not be economically practical, but agricultural scientists should not, for supposed economic reasons, fail to attempt to raise the limits on productivity imposed by technology.

Therefore, the purpose of MYR is to build an integrated, multidisciplinary systems in which the components may interact freely, but without the presence of the limiting factors that prohibit maximum yield.

Initially, economics is of no concern in MYR. Once a production system is identified that consistently produces maximum yields, it can be refined and economically analyzed to determine MEY for the farmer.

Maximum Economic Yields

Maximum economic yields can be defined as the corresponding yield level where net profits are maximized in response to increasing inputs or improved production practices. While yields might increase beyond this point by adding selected inputs and management practices, net profits will not increase. Maximum economic yields vary according to location and time because of climate and soil conditions.

The relationship between net profit and yield is shown in Fig. 1. Points A, B, and C correspond to estimated average farm yields, MEY, and maximum yields for soybean, respectively. In a production function, both maximum yield and MEY are near the top of the response curve, but average farm yields represent only a fraction of that potential. Wagner (1983) stated that: "The difference between average yield and maximum economic yield is the world's greatest food reserve". It also represents the farmer's greatest potential source of economic survival.

Average farm yields and profits can be significantly increased by selecting cost-effective inputs and management practices to produce MEY where net profits per hectare are maximized. When yields are increased from MEY to maximum yields, the total yield increase will not justify the cost of additional inputs and management. Sheard (1983) stated that: "The difference between maximum yields and maximum economic yields may be only 2 to 5%, but the difference in inputs to achieve that yield increase may be 20%."

As MYR and MEY systems are developed for the tropics, it will be important to evaluate production practices on a long-term basis with regard to yield, quality, and net returns.

Developing Maximum Yield Systems for Soybean

Two researchers in the USA conducted MYR experiments in 1982 that produced soybean yields in excess of 6.7 t/ha. Flannery (1982) identified a maximum yield system that consistently produced maximum maize and soybean yields over a three-year period (Table 2). In 1980, when the project was initiated, his production goals were 6.7 t/ha of soybean and 18.9 t/ha of maize.

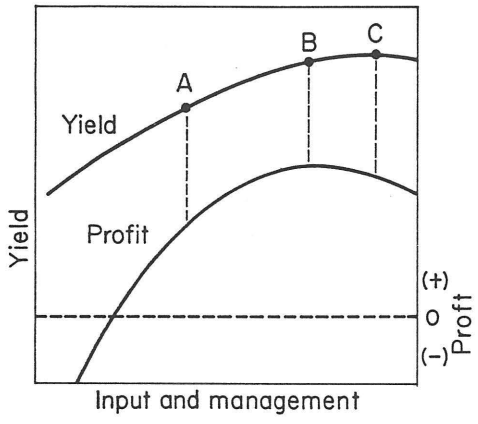

Fig. 1. The relationship of yield and profits to inputs and management (A-average farm yield, B-MEY, C-maximum yield).

Table 1. Average and world record soybean yields.

Developing Countries	Average Yield (t/ha)	
	USA	world record
1.6	1.9	7.4

Table 2. Maximum yield results from New Jersey, 1980-1982.

Year	Yield (t/ha)	
	soybean	maize
1980	6.33	19.61
1981	6.27	17.91
1982	7.34	21.24
Average	6.64	19.58

Source: Flannery (1982)

The experiment was conducted on a Freehold sandy loam (pH 6.0); P and K values were high. The following cultural practices were used:

Crop rotation	- maize (Zea mays) -soybean
Cover crop	- autumn rye (Secale cereale)
Tillage	- subsoiled in autumn, moldboard-plowed and disked before planting
Lime	- applied each year as needed
Macronutrients	- Two rates were compared with split applications during the growing season
Micronutrients	- 1.1 kg B/ha, 5.6 kg CU/ha, 28.0 kg Mn/ha, and 5.6 kg Zn/ha (preplant)
Weed control	- Treflan at 2 l/ha (preplant)
Seed treatment	- inoculum and ammonium molybdate (4 g/kg)
Insect control	- applications of Furadan, Dyfonate, and Sevin as required
Disease control	- Captan seed treatment
Irrigation	- low pressure trickle system to maintain soil moisture at 60 to 100% field capacity
Seeding rate	- Cultivar Asgrow 3127 planted at 369,000 and 553,000 plants/ha; cultivar Hobbit planted at 738,000 and 1,107,000 plants/ha
Row spacing	- 18 cm
Planting date	- May 13, 1982

Soybean yields ranged from 3.3 to 7.3 t/ha (Table 3). The highest yield was produced by Asgrow 3127 at 553,000 plant/ha with irrigation and the highest fertilizer application rate. The key factors were irrigation, higher macronutrient fertilization, high plant population density, and cultivar selection. The combination of these and other factors are common in many of the MYR experiments that produce maximum yields in North America.

Flannery's maximum yield research philosophy - "Leave nothing to chance" - has proven quite successful. He applied current technology to develop a multidisciplinary system in which multiple interactions positively influenced yield.

Cooper (1983) also reported yields in excess of 6.7 t/ha at Ohio State University. Table 4 shows the soybean yields produced between 1980 and 1982.

Table 3. Effects of cultivar, plant population, irrigation, macronutrient, and micronutrients on soybean yield, New Jersey, 1982.

Fertilizer Applied (kg/ha)			Soybean Yield (t/ha)							
			Asgrow A3127				Hobbitt			
N	P	K	369,000 plants/ha		553,000 plants/ha		738,000 plants/ha		1,107,000 plants/ha	
			N.I.[y]	I.[x]	N.I.	I.	N.I.	I.	N.I.	I.
83	48	114[w]	4.76	4.70	4.22	6.44	4.33	4.45	4.25	5.68
83	48	114[v]	4.64	5.10	4.57	6.18	4.39	4.93	4.06	6.05
138	97	228[w]	4.23	5.82	4.23	7.32	3.58	4.97	3.91	6.27
138	97	228[u]	3.38	6.98	3.33	6.92	3.71	6.50	3.40	6.73

[z] Yields standardized to 13% moisture
[y] N.I. = not irrigated
[x] I - irrigated
[w] No micronutrients applied
[v] Micronutrients applied (B-1.1 kg, Cu-5.6 kg, Mn-28 kg, Zn-5.6 kg)
Source: Flannery (1982)

Cooper's experimental site was composed of a silt loam soil (pH 5.4). Soil test levels for P and K were very high. The following cultural practices were used:

Crop rotation	- maize-soybean
Fertilizer	- broadcast in the spring and plowed down; annual application rates were 220 kg N/ha, 87 kg P/ha, and 332 kg K/ha
Disease control	- three applications of Benlate
Weed control	- Lasso pre-emergence and Basagran post-emergence
Insect control	- one application of Pounce
Irrigation	- sprinkler irrigation (7.5 cm/week with rates adjusted for rainfall
Row spacing and seeding rate	- Determinate, semi-dwarf cultivars seeded at 555,000 plants/ha in 76 cm rows and 741,000 plants/ha in 18 cm rows; indeterminate cultivars seeded at 371,000 plants/ha in 76 cm rows and 555,000 plants/ha in 18 cm rows
Planting date	- May 6, 1982

Grain yields ranged from 3.8 to 6.8 t/ha (Table 5). Average yields totaled 4.4 t/ha for the 76 cm row spacings and 6.4 t/ha for 18 cm spacings. Yields were 30% higher in narrower rows than in wider rows. The data indicate a trend for higher yields with the shorter semi-dwarf soybeans; semi-dwarfs were also somewhat resistant to lodging.

Several factors contributed to higher yields in 1982, including irrigation late in the growing season and the cumulative buildup of soil fertility (200% increase in P and K levels over the past several years). A new program to control foliar diseases may have also helped.

The requirements for maximum yield in a multiple cropping system may be different from those of a single-crop system. Sartain and Forbes (1983) studied K requirements for maximum yield in a multiple cropping system in the State of Florida (USA). The experiment was conducted on an Immokallee fine sand with tile drainage (P content was high and K content was medium-low). The cultural practices used in a soybean-cabbage (Brassica oleracea var. capitata) -sweet corn multiple cropping system are as follows:

Crop history	- vegetables for several years
Macronutrients	
Soybean	- K applied after emergence
Cabbage	- 250 kg N/ha (4 splits)
Sweet corn	- 200 kg N/ha (3 splits) and 25 kg P/ha applied prior to planting
Micronutrients	- applied prior to planting sweet corn
Weed control	- herbicide applied prior to planting
Insect control	- nematicides and pesticides applied to all crops
Seed treatment	- granular inoculant for soybean
Row spacing	- 76 cm rows
Irrigation	- as needed
Planting dates	
Cabbage	- December 1981
Sweet corn	- April 1982
Soybean	- June 1982

The effect of K fertilization on sweet corn, soybean, and cabbage are shown in Table 6. The data indicate that at lower K rates, soybean responds best to direct K application. However, at higher rates soybean responds equally well to both direct and residual K application, except when K is applied directly to sweet corn and cabbage. The highest overall production for all three crops occurred when the highest K rates were split between soybean and cabbage; a single application seemed to reduce yield.

Table 4. Maximum yield research results in Ohio, 1980-1982.

Year	Soybean Yield (t/ha)
1980	3.37
1981	4.72
1982	6.89

Source: Cooper (1983)

Table 5. Effects of cultivar and row spacing on soybean yields, Ohio, 1982.

Cultivar	Yield (t/ha) 76cm	Yield (t/ha) 18cm	Height (cm)	Lodging Score[z]
Beeson 80	3.80	5.05	104	5.0
Williams 79	4.29	6.58	117	5.0
Hobbit	4.45	6.27	61	2.0
Sprite	4.72	6.54	64	2.2
Pixie	4.57	6.66	61	2.2
Exp. 1[y]	4.58	6.76	61	1.5
Exp. 2[y]	4.47	6.85	64	2.0
Exp. 3[y]	4.49	6.89	76	3.0
L.S.D.[x]	.60	.98		

[z] Higher number indicates more lodging
[y] Experimental determinate semidwarf lines
[x] Least significant difference
Source: Cooper (1983)

Table 6. Effects of K fertilization sequence on yields of sweet corn, soybean, and cabbage in a one-year multiple cropping system.

Sequence of K Fertilization (kg/ha)			Yields (t/ha)		
sweet corn	soybean	cabbage	sweet corn	soybean	cabbage
0	0	0	12.03	3.43	60.10
112	112	0	14.18	4.02	63.99
0	0	224	14.28	3.61	65.71
0	112	224	14.37	4.27	69.59
112	0	224	14.18	3.81	63.86
0	0	336	14.57	4.37	59.74

Source: Sartain and Forbes (1983)

Developing Maximum Economic Soybean Yields

Production of maximum yields by the researcher, or MEY by the farmer, requires a multi-disciplinary approach that combines production practices. Many inputs cost little or nothing but effectively increase yields. To develop an MEY system, researchers and the farmer must select cost-effective inputs that interact to produce the highest yields and maximize profits under existing climatic

and soil conditions. This does not mean that each input must be cost-effective when used in isolation, but that it must be cost-effective in an integrated, multi-disciplinary system where interactions from several inputs provide maximum profit.

Cooke (1975) stated: "In a highly developed agriculture, large increases in yield potential will mostly come from interaction effects. Researchers and farmers must be ready to test all new advances that may raise the yield potentials of their crops and be prepared to try combinations of two or more practices." The number of interactions that might occur in a production system is almost unlimited. Developing MEY systems will largely depend on creating production systems where interactions can occur. Changes in fertility and cultural practices will play an important part in developing these systems.

Interactions

Wagner (1979) describes interactions as the modification of responses to one or a series of factors by one or more other factors. Positive interactions occur when the response from a combination of two or more inputs is greater than the sum of the individual responses. Often, interactions may be absent or suppressed under poor or even average management because of one or more limiting factors. The yield potential of a crop can be increased by changes in management practices that increase the chances of a single or multiple interaction. Failure to adopt improved production practices are also associated with reduced fertilizer efficiency and effectiveness. The relationship between management practices and fertilizer response was illustrated by Pretty and Sanders (1981) (Fig. 2). A, B, C, and D represent improved practices that are progressively introduced. With the implementation of improved practices, management improves, yields increase, and larger quantities of nutrients can be used more effectively and economically.

Herbek and Murdock (1982) showed that P and K interact to increase soybean yields (Table 7). Applications of P and K on narrow rows increased yields by 1.14 t/ha, but only by 0.97 t/ha on wider rows (narrower rows also increased yields - 0.57 t/ha). These data illustrate how improved practices can be associated with soybean yield increases and greater P and K efficiency.

Table 8 illustrates a fertility-placement interaction. P broadcast on high pH soils (pH 7.5) is much less effective than P which is side-banded or drilled below the seed (Bailey 1977). Yields increased by as much as 65% when P was drilled below the seed. However, drilling higher P rates with the seed appears to be detrimental. Again, nutrient-use efficiency can be associated with improved practices, and is thus instrumental in developing MEY systems.

Soybean cultivars respond differently to increased fertility. Fig. 3 shows a fertility-cultivar interaction whereby the soybean cultivar Dare responded more to increasing rates of K than did Bragg (Terman 1977). At 149 kg/ha, Dare outyielded Bragg by more than 40%.

Interactions also occur between fertility levels and stress conditions. Weather is a key yield determinant. However, Table 9 shows how higher K rates and soil test values can modify the effects of dry weather (Johnson and Wallingford 1983). Increasing K rates up to 93 kg/ha resulted in increases in yields and profits in both stress and non-stress years; the largest response occurred in the stress year.

Numerous interactions occur between crop production practices. To achieve MEY, the farmer must use as many improved production practices as possible, e.g. proper amounts and combinations of nutrients, superior cultivars, narrower row spacings, and improved pest control measures.

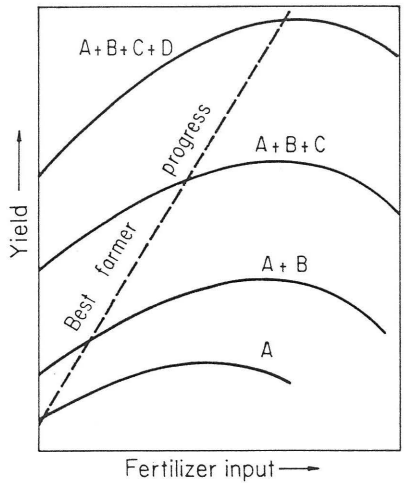

Fig. 2.
The relationship between adoption of management practices, response to applied fertilizer, and crop yield.

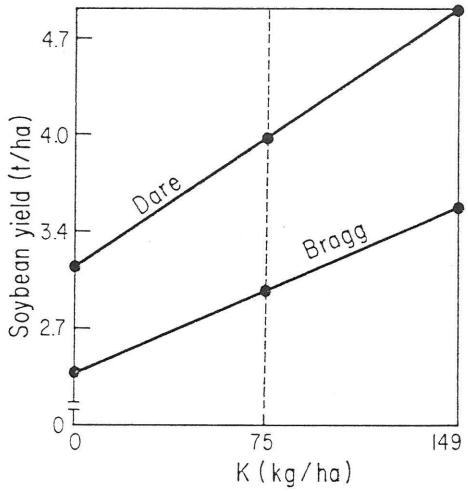

Fig. 3.
Soybean varietal response to applied K.

Table 7. Effect of row spacing and applications of P and K on soybean yields.

Annual Application (kg/ha) P	K	Row Width (cm) 24	27
0	0	2.97	2.51
0	183	3.38	2.78
67	0	3.44	2.85
67	183	4.11	3.48

Source: Herbeck and Murdok (1982)

Table 8. The effects of P rate and placement on soybean yields.

P (kg/ha)	Broadcast	Drilled with Seed	Side Banded Below Seed	Drilled Below Seed
	t/ha			
0	2.35	2.35	2.35	2.35
13	2.35	3.83	3.83	3.90
26	2.62	0.87	3.96	4.23
52	2.69	0.34	4.10	4.30

Source: Bailey (1977)

Table 9. Effect of K on soybean yields and profits in a good rainfall year and in a dry year.

K^z (kg/ha)	Soybean Yield (t/ha) good year 1980	stress year 1981	Soil Test Fall 1980 (kg K/ha)
0	3.77	2.02	144
46	3.98	2.83	170
93	4.04	3.23	220
186	3.91	3.23	264
LSD 0.05	0.27	.13	13
Response to K^y	0.27 t/ha	1.21 t/ha	
Profit from K	$ 44/ha	$ 257/ha	

[z] K rates applied every other year
[y] 93 kg K/ha
Source: Johnson and Wallingford (1983)

Building Soil Fertility for MEY

Nutrient Uptake: Table 10 illustrates how total nutrient uptake is influenced by soybean yield (Anon. 1979). Nitrogen requirements are usually furnished by N-fixing bacteria. However, many maximum yield researchers are applying N fertilizer to produce higher yields. Estimates show that N fixation from nodulation provides enough N to produce 4.0 t/ha (Jones et al. 1977). Soybean also removes large amounts of other elements, especially K.

Soybean Response to P and K: Soybean plants must absorb about 0.6 kg P and 1.9 kg K to produce 100 kg of soybean. Table 11 shows how P and K interact to boost yields (Jones et al. 1977). In this case, when P and K were applied individually, yield increases totaled 0.10 and 1.37 t/ha, respectively. When P and K were applied together, yields increased by 1.83 t/ha - a positive interaction. Increasing P and K also had a positive effect on nodule number and nodule weight. Increased nodulation is particularly important when soybean is grown in soils with low available N.

The effect of increased K on soybean yield is shown in Table 12. When maize was fertilized with four rates of K for four years, soil test levels increased correspondingly. Soybean was grown in the fifth year without additional K. Yields increased by 1.3 t/ha due to the residual K.

pH and Micronutrients: Typical soybean micro-nutrient deficiencies include Fe, Mn, Zn, and Mo. Many of these deficiencies are pH-related. At high pH levels soybean may show signs of Fe, Mn or Zn deficiencies; low levels can produce Al, Fe, or Mn toxicity. Mo may also be unavailable at low pH levels. Table 13 shows that supplemental Mo increased soybean yields when the crop was grown in low pH soils; however, there was no response at higher values (Thompson 1981). Under North American conditions, the most desirable pH for soybean ranges from 6.0 to 6.6.

Cultural Practices for MEY

Superior Cultivars: The selection of management-responsive cultivars is an essential component of higher yields. Table 14 shows that cultivars may respond differently to changes in management. When planted on 76 cm rows, cultivar B recorded the highest yield, but cultivar C was the highest yielder on 18 cm rows (PPI 1982). The data also show that narrower rows increased the yield of each cultivar, but that there were inter-varietal differences.

Row Spacing and Plant Population: Table 15 demonstrates that soybean yield increased as row spacing decreased, in this case from 100 cm to 25 cm (Parks 1983). However, the number of plants/m/row had little effect on yield, except to reduce it at the lowest spacing.

Parks indicated that narrow rows have several advantages, most of which are related to early canopy closure. These include: Increased radiation, a reduction in moisture evaporation, a decrease in the use of herbicides, equalized root density throughout the planting area, lower levels of soil erosion, and pod positioning suitable for mechanical harvesting. He also lists several disadvantages, i.e. weed control problems, lodging, and increased water usage.

Plant populations for MEY vary. In the midwestern United States, seeding rates are calculated according to planting date, seedbed condition, cultivar, and row spacing. The following guidelines were developed for 18 cm rows (BASF): 430,000 viable seeds/ha; add 10% for very early or late planting, add 10% if planting a short, non-branching cultivar or 30 to 40% for a determinate semi-dwarf; add 10% if planting in a poor seedbed; subtract 10% if planting a tall

Table 10. Nutrient reduction as a function of soybean yield increases.

Nutrient	Soybean Yields 2.7 t/ha	4.0 t/ha	5.4 t/ha	6.7 t/ha
N[z]	242	363	484	605
P	21	31	41	52
K	88	132	176	219
Ca	20	30	40	50
Mg	29	28	37	46

[z] Partially air-derived
Source: Anon. (1979)

Table 11. Effect of applied P and K on nodule number and weight and soybean yield (two-year average).

Fertilizer Applied		Nodules		Yield
p (kg/ha)	K (kg/ha)	per plant	dry weight (mg)	(t/ha)
0	0	35	4.4	1.74
60	0	59	5.6	1.84
0	112	79	7.4	3.11
60	112	114	7.9	3.57

Source: Jones et al. (1977)

Table 12. Results of four years of K application (to corn) on K soil test results and soybean yields.

Annual K Rate (kg/ha)	Soil Test (kg k/ha)	Yield (t/ha)
0	304	3.37
112	321	3.84
224	344	4.25
448	502	4.72

Source: Welch (1974)

Table 13. Soybean response to Mo at low pH (Tennessee).

pH	Yield (t/ha) Mo	No Mo
5.6	2.76	2.16
5.7	2.90	2.29
6.0	2.70	2.49
6.2	2.83	2.70
6.4	2.76	2.83

Table 14. Effect of cultivar selection and row spacing on soybean yields.

Soybean Cultivar	Row Width (t/ha) 76 cm	18 cm
A	3.91	4.58
B	4.45	5.32
C	4.25	5.59

Source: PPI (1982)

Table 15. Effect of row spacing and plant population on soybean yield.

Plants/m	Yields (t/ha; 3-year average) row spacing (cm) 102	76	51	25	mean
40	3.71	4.04	4.04	4.65	4.11
33	3.77	3.91	4.31	5.19	4.31
26	3.44	4.04	4.31	5.39	4.31
26	3.64	3.84	3.98	5.12	4.20
13	3.50	3.64	3.98	5.19	4.11
6	2.76	3.23	3.44	4.85	3.57
Mean	3.50	3.77	4.04	5.05	

Source: Parks (1983)

branching cultivar; subtract 10% if planting in deep, fertile soil where lodging is a problem; and subtract 10% if planting under ideal conditions, i.e. optimum planting date, seedbed condition, soil, moisture, and temperature.

Planting Date: Early planting may be one of the most cost-effective ways of increasing soybean yields in North America. Since it costs no more than planting

late, yields can be significantly increased without increasing the cost of production. Optimum planting dates vary from north to south, but growers in the midwestern USA can expect to lose 9 to 14 kg/day by planting later than the optimum date. Table 16 shows the reduction in yields that occur due to late planting (PPI 1982). Planting soybean one month later than the optimum date decreased yields by 1 t/ha.

Ohio State University (1983) data show that combining narrower rows and earlier planting dates produces a favorable interaction. Fig. 4 shows that with three row spacings (18, 38, and 76 cm) yields decreased as planting date was delayed; yield losses were higher in the wider spacings.

Tillage: Soybean yields and profits can be dramatically effected by tillage. Touchton (1983) showed the estimated cost of different tillage systems and the resulting effects on soybean yields in Alabama (USA) (Table 17). The no-tillage system produced the highest recorded yield with the lowest cost. Soybean often responds to no-tillage in areas where weed control and soil fertility are minor problems.

Pest Management: Pest management is an integral part of MEY. As yields increase, denser canopies develop, plants grow at a rapid rate, and humidity in the canopy increases. These conditions may call for the use of insect and disease management practices. When soybean was grown under a high rate of disease incidence, both K and fungicides effectively increased yields (Fig. 5). The combination of K + fungicide produced the highest yields.

Nematodes are a major problem in some areas. In an integrated program, adequate fertility may help to reduce the damage. Fig. 6 shows that the yields of nematode-affected plants were increased by K fertilization, but that nematicide was the best treatment (PPI 1982). While K is not a cure for nematodes, the merits of combining adequate fertility with a nematicide are quite obvious. These types of interactions are often overlooked, even though they form the basis of an MEY system where maximum profits can be derived from a series of interacting factors.

Table 16. Effect of planting date on soybean yield.

Planting Date	Soybean Yield (t/ha)	Yield Loss After May 10 (t/ha)
May 10	3.30	-
May 25	2.90	0.40
June 10	2.29	1.01

Source: PPI (1982)

Table 17. Estimated cost of tillage practices and their effect on soybean yield.

Primary Tillage	Estimated Cost ($/ha)	Yield (t/ha)
No tillage	0	3.64
Disk	9.88	3.50
Chisel	14.82	3.44
Turn	17.29	3.57
Chisel-disk	27.17	3.57
Turn-disk	29.64	3.50

Source: Touchton (1983)

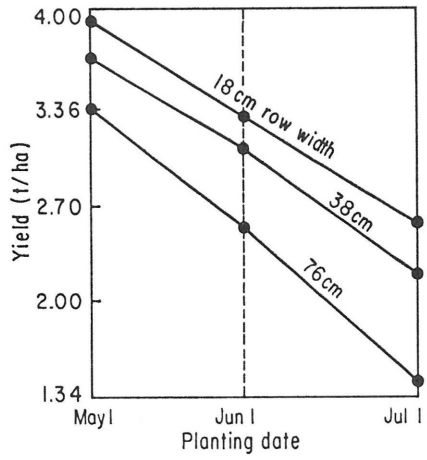

Fig. 4. The relationship between planting date and row width and its effect on soybean yield response.

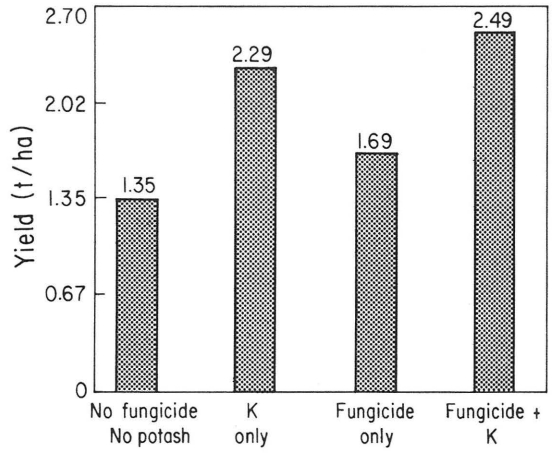

Fig. 5. Soybean response to K and foliar fungicides.

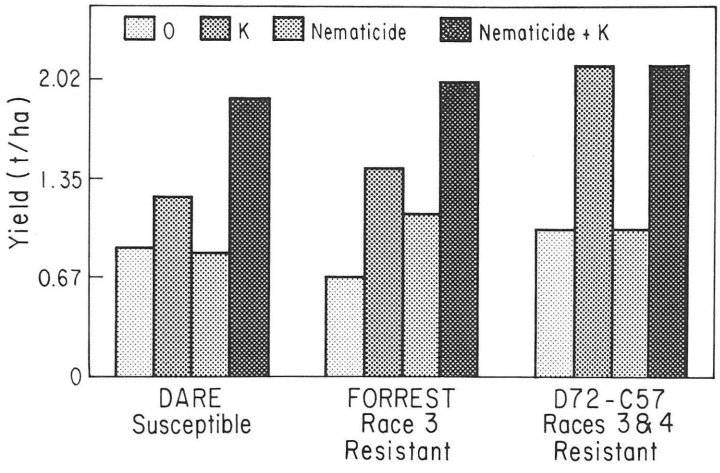

Fig. 6. Soybean response to K and nematicides.

Conclusions

The development of MYR and MEY systems can help to stabilize world food supplies and provide an economic stimulus for farmers. There are many factors which researchers and farmers must use to develop these integrated multidisciplinary systems. Maximum yields or MEY of soybean can only be achieved through the integrated management or control of the following factors: 1) optimum soil fertility, 2) proper inoculation, 3) higher plant populations, 4) superior cultivar selection, 5) proper row spacing, 6) optimum planting date, 7) proper tillage, 8) good drainage, 9) supplemental irrigation, 10) pest control, 11) crop rotation, 12) multiple cropping, and 13) good harvesting techniques.

Selection of the proper amounts and combinations of inputs will critically influence soybean yields, a fact which emphasizes the need for MYR. Once maximum yield systems are developed, yield limiting factors and interactions can be economically assessed to formulate an MEY soybean plan.

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Agronomic Requirements for Wet and Dry Season Soybean

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Introduction

Rainfall is one of the major factors that influence seasonal variations in the tropics. Farmers usually plant a rainfed crop during the wet season, and irrigate in the dry season. Crops grown between the two major seasons are also irrigated (Fig 1).

In Sri Lanka's high rainfall season, temperatures usually drop and relative humidity rises (Table 1). The dry season is characterized by longer photoperiods and an increase in solar radiation (Table 1 and Fig. 2).

This paper describes the soybean (Glycine max) cropping practices used in Sri Lanka with regard to seasonal climatic patterns.

Wet and Dry Season Soybean

Climatic Requirements

Rainfall: Seedbed preparation in the tropics usually coincides with the first rainfall of the season. Moisture availability is critical to germination, initial stand establishment, flowering, and pod-filling (Hinson and Hartwig 1982). Soybean cropping is possible in the dry season if farmers irrigate (Fig. 1 and Table 2).

Germination, emergence, and stand establishment are comparatively poor during the dry season, especially when rainfall at sowing is inadequate or irrigation is not available. Mulching helps to conserve soil moisture.

Temperature: Delouche (1952) found that 30°C was the optimum temperature for soybean germination. White et al. (1972) observed that emergence occurs at 40°C with cultivar Amsoy.

Diseases: Seed-borne microorganisms can adversely affect soybean germination and initial growth. Several fungi and bacteria are responsible for poor germination at higher temperatures (Dhingra et al. 1973, Ellis et al. 1974, and Schiller et al. 1977).

Photoperiod: In Sri Lanka (8°N), photoperiods vary approximately 45 minutes per year. The wet and dry seasons average 6.8 hr and 8.0 hr of effective sunshine per day, respectively. Solar radiation is higher during the dry season: 397.0 cal/cm^2/day compared with 353.5 cal/cm^2/day in the wet season.

Water Management

Water availability significantly affects germination, vegetative growth, and pod-filling. Natural rainfall satisfies most water requirements during the wet season, but irrigation may be necessary in the dry season, especially during the pod-filling stage (Figs. 1 and 3).

The planting of a wet season soybean crop should be adjusted to fit prevailing rainfall patterns. In Sri Lanka, wet season planting is usually carried out around mid-October 20 (appearance of the first rains). This practice allows the crop to receive optimum water during the vegetative and pod-filling stages, and helps to ensure that it matures in the post-rainfall dry period.

Conversely, too much rain may limit germination, emergence, or stand establishment. This can be caused by physical shifting of the seed, soil displacement and subsequent crusting, restricted oxygen movement, increased pathogenic activity, anaerobic conditions caused by waterlogging and poor drainage, or lodging and physical damage to emerging seedlings.

Shanmugasundaram (1980) reported a 28% reduction in soybean plant establishment due to flooding that occurred immediately after sowing. Grable and Danielson (1965) found that pathogens developed rapidly on germinating seeds and roots under saturated soil conditions (see Troedson et al., eds.). Thus, well-drained, light soils are important for good stand establishment during the early wet season. This fact also indicates the difficulty of growing soybean in rice fields (Oryza sativa) because of their poor drainage characteristics. Soybean, however, can withstand short periods of waterlogging (Singh and Saxena 1969).

Poor drainage and high water tables can also result in poor or shallow root development, which in turn may lead to water stress if the crop is subjected to subsequent dry spells. In Sri Lanka, soybean planted during the late wet season on heavy, poorly drained soils is particularly susceptible to this problem. Timely sowing and proper site selection is therefore essential.

Water management and irrigation practices are equally important for dry season soybean (Fig. 3). Water stress during the pod-filling stage may result in higher yield reductions than stress during flowering (Runge and Odell 1960). Table 3 shows that 31% of the crop's total water requirement (266 mm) is used for vegetative growth, and that 43% (362 mm) is used during pod-filling. When comparing water requirements with actual rainfall during the dry season (Fig. 1), deficits totaled 166 mm during the vegetative and flowering stages and about 340 mm during pod-setting.

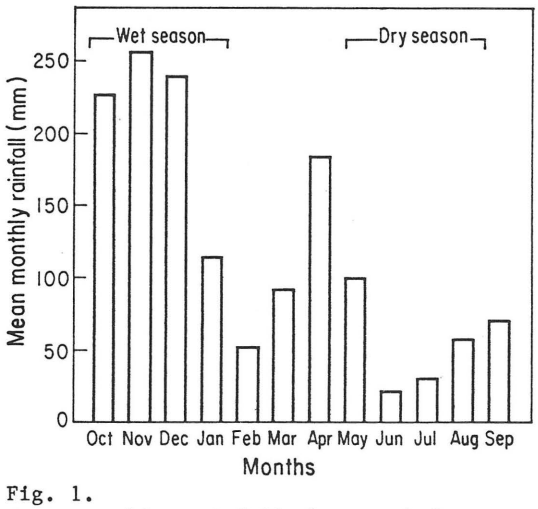

Fig. 1.
Mean monthly rainfall (wet and dry seasons) in the soybean growing regions of Sri Lanka. Source: Department of Agriculture, Sri Lanka.

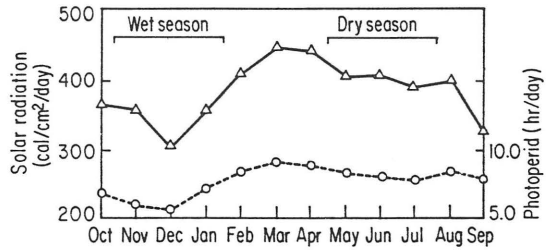

Fig. 2.
Mean solar radiation and photoperiod (hr/day) (wet and dry seasons) in the soybean growing regions of Sri Lanka. Source: Department of Agriculture, Sri Lanka.

Table 1. Average climatic data for the wet and dry seasons in Sri Lanka's soybean growing areas.

	Wet Season	Dry Season
Total rainfall (mm)	744.0	268.7
Mean/photoperiod duration (hr/day)	6.8	8.0
Solar radiation (cal/cm^2/day)	353.5	397.0
Relative humidity (%)	78.9	76.6
Maximum temperature (°C)	30.7	33.2
Minimum temperature (°C)	21.2	24.6

Table 2. Agronomic data for wet and dry season soybean in Sri Lanka.

Plant Characteristic	Wet Season	Dry Season
Mean yield (t/ha)	2.0	2.4
Mean days to flowering (days)	31.4	28.7
Mean days to maturity (days)	82.5	99.6
Mean plant height (cm)	44.2	50.4
Mean 100-seed weight (g)	15.8	16.1

Table 3. Average water use by cultivar Bragg during three growing seasons in southern Brazil. Adapted from Hinson and Hartwig (1982).

Growth Stage	Daily (mm)	Total (mm)	% of Total
Planting to emergence	2.2	16	1.9
Emergence to flowering	5.1	266	31.7
Flowering to pod set	7.4	160	19.0
Pod set to 50% yellow leaves	6.6	362	43.1
50% yellow leaves to maturity	3.7	36	4.3
Total	25.0	840	100.0

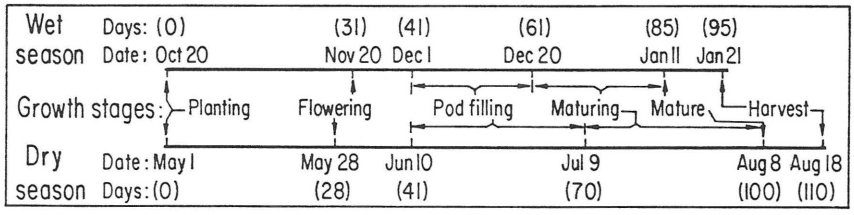

Fig. 3. Main growth stages and development of wet and dry season soybean in Sri Lanka. Source: Department of Agriculture, Sri Lanka.

Agronomic Practices

Planting Date and Cultivar: The selection of a suitable planting date and cultivar must be closely linked with prevailing rainfall patterns. Sri Lanka's heavy rainfall period lasts about three months, usually from October to December. If planting is carried out in conjunction with the first rains in mid-October, there should be enough moisture for the critical growth and development periods (Figs. 1 and 3).

Cultivar requirements for the rainy season are as follows:

1. Growth periods that coincide with prevailing rainfall;
2. Relative insensitivity to short photoperiods and low solar radiation levels;
3. Waterlogging or flooding tolerance; and
4. Resistance or tolerance to diseases associated with heavy rainfall, wet soils, and cloudy weather.

In Sri Lanka, dry season planting is carried out with the objective of making maximum use of available rainfall. Farmers try to plant their crops to coincide with the April rains (Figs. 1 and 3). Emergence, stand establishment, flowering, and pod set are adversely affected during this period by high temperatures and dry winds. The requirements for dry season cultivars are as follows:

1. Early maturity (to save irrigation water and to avoid oncoming dry weather);
2. Tolerance to high temperatures; and
3. Adaptation to physiological drought stress.

Land Preparation, Sowing, and Plant Spacing: Ridging and furrowing can help to prevent waterlogging. Heavy soils should be prepared in a way that improves infiltration capacity and reduces the effects of runoff.

In lowland areas, and where soybean is planted after rice, land preparation for the dry season should take into account soil moisture conservation and irrigation requirements.

Minimum tillage can be used to conserve soil moisture. Shanmugasundaram (1976) reported that soybean roots followed the root channels of decomposing rice roots, thus accelerating root development and enhancing the absorption of residual moisture.

Minumium tillage is usually practiced on flat, irrigated rice fields. When the land is fairly uneven, ridging can help to facilitate irrigation. However, deep ploughing, excessive weeding, and exposure of the soil should be avoided.

Plant spacing is a function of cultivar and environment. Studies in Sri Lanka show that the best spacing pattern, regardless of season, is 40 x 5 cm (500,000 plants/ha).

Inoculation and Fertilization: A soybean crop that produces 2.5 t/ha requires about 0.2 t N/ha. The amount of N that rhizobia can fix is highly variable. Soil temperature, light intensity, soil organic matter, and soil moisture are all involved in nitrogen fixation and fertilization. Kno and Boersma (1971) found that N fixation increased up to a point of 27°C, but decreased at higher temperatures. This shows that high soil temperatures in the dry season may reduce nodulation. In contrast, better lighting conditions may enhance N fixation. When soybean is shaded, as it often is when intercropped with corn (Zea mays) nodule number and the rate of fixation usually fall (Lawn and Brun 1974).

Sprent (1971) showed an 80% reduction in N fixation due to a 20% decrease in nodule moisture content. During the dry season, between irrigations, the upper layers of the soil may dry out, thereby retarding nodulation on the upper part of the root system.

Moisture saturation and waterlogging may also limit N fixation. Since dry season soybean is often grown in puddled rice fields that are kept anaerobic during rice production, more information on rhizobium survival in these types of soils would be useful.

Sri Lankan rice farmers usually apply large amounts of phosphorus and potash to their rice crops. Hence, the following soybean crop may have access to residual phosphorus and potassium. Aerobic soil conditions during the dry season also support the release of fixed P and K. However, additional P and K may be needed for a wet season (highland) crop.

Crop Protection: Insect, disease, and weed infestations are directly affected by climate. Heavy rainfall and low temperatures during the wet season reduce the activity of pests such as leaf-eating caterpillars. Insect damage in Sri Lanka generally increases as rainfall declines.

The opposite is true of diseases. Pathogenic disease activity is enhanced by moist, cloudy weather and saturated soils (Grable and Danielson 1965).

Weeds actively compete with soybean in the wet season. Hinson and Hartwig (1982) observed that in high rainfall areas several types of weeding can be combined to provide effective control. High rainfall reduces the efficiency of soil-applied herbicides and often prevents hand weeding or mechanical control.

A combination of the following measures may prove useful:

1. Adequate land preparation before the onset of the heavy rains;
2. The use of pre-emergence herbicides;
3. The adjustment of row spacings to provide 100% ground cover by the crop canopy; and
4. Mechanical or hand weeding until the canopy is established.

Seed quality is largely governed by environmental conditions. Hunter Andrews (1982) noted that low precipitation, absence of early morning fog or dew, and low humidity before and during the harvest are some of the factors that determine seed quality. He also observed that high temperatures, coupled with high rainfall, exert severe stress on developing seeds. Nicholson and Sinclair (1973) found that seeds harvested after India's monsoon rains were of better quality, and had a lower incidence of seed-borne fungi, than seeds harvested during the monsoon. Alternate wetting and drying, which can occur at the end of the monsoon season, is detrimental to soybean seed.

Most research indicates that wet season soybean has poor seed quality. This problem could be offset by adjusting planting dates so that pod maturation occurs after the monsoon.

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Soybean Weed Control

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Introduction

Effective weed control in the tropics can be achieved by mechanical means, crop rotations, crop competition, biological and chemical control, or by burning (Klingman 1961). Asian farmers usually weed soybean (Glycine max) by hand, but herbicide use is increasing, mainly because of labor costs. The purpose of this paper is to review weed population shifts in soybean crop rotations, weed control measures in no-tilled soybean, and to report on general weed control research at AVRDC.

Weed Shifts and Crop Rotations

Crop rotations can reduce and shift the balance of weed flora (Dowler et al. 1974, Harwood and Bantilan 1974). Burnside (1978) reported that by rotating sorghum (Sorghum vulgare) and soybean, infestation from green foxtail (Setaria viridis), tall waterhemp (Amaranthus tuberculatos), and large crabgrass (Digitaria sanguinalis) decreased, whereas velvet leaf (Abutilon theophrasti), sunflower (Helianthus annuus), and Pennsylvania smartweed (Polygonum pensylvanicum) increased.

Shifts in weed flora in Nigeria have also been observed (Moody 1982) (Table 1). An experiment was conducted on land cleared from a 15-year-old secondary forest. At the end of the first season, weed weight was reduced an average of 59% because of crop competition. The majority of the weeds were broadleafs (85% by weight); grasses were in the majority in the second crop (81.5%). When maize (Zea mays) and cowpea (Vigna unguiculata) were planted as the second crop, irrespective of the previous crop, grasses represented 73 to 79% of the total weed population. There was an even greater shift to grasses when soybean was planted (5.9 to 7.7% broadleaf weeds). Weed weight was significantly higher when legumes followed legumes, rather than when legumes followed maize. Compared with maize-maize, weed weight was also higher when maize followed soybean. Grassy weed predominated in the third crop. Continuous soybean cultivation led to a significant increase in weed weight over the fallow plot (Moody 1982).

Weed Control in No-Till Soybean

Most temperate no-tilled soybean is double-cropped (soybean-grain) (Jeffery et al. 1980, Sanford 1982, Touchton and Johnson 1982). Weeds are controlled by applying either 1.4 kg/ha of linuron (3-[3,4-dichlorophenyl]-1-methoxy-1-methyl-urea) (Sanford 1982) or 0.43 kg/ha of metribuzin (4-amino-6-tert-butyl-3-[methylthio]-as-triazin-5[4H]-one) and 0.56 kg/ha of paraquat (1, 1'-dimethyl-4, 4'-bipyridinum ion) (Touchton and Johnson 1982). A mixture of either metolachlor (2-chloro-N-[2-ethyl-6-methylphenyl]-N-[2-methoxy-1-methylethyl] acetamide) (2.0 kg/ha) + linuron (0.75 kg/ha) + paraquat (0.5 kg/ha) or metolachlor (2.0 kg/ha) + metribuzin (0.5 kg/ha) + paraquat (0.5 kg/ha) is also recommended (Jeffery et al. 1980).

Table 1. Weed population development under different cropping systems.

Cropping Pattern	Grass Weight crop (%)		Broadleaf Wt. crop (%)		Weed Weight[z] crop (t/ha)	
	1st	2nd	1st	2nd	1st	2nd
Fallow-fallow-fallow	29.0	70.4	70.8	28.6	6.32a	3.56a
Maize-maize-maize	14.9	73.2	83.4	26.1	2.45b	2.26c
Maize-cowpea-maize	14.9	77.0	83.4	21.8	2.45b	2.31c
Maize-soybean-maize	14.9	91.3	83.4	7.7	2.45b	2.73c
Cowpea-maize-cowpea	13.8	79.4	86.1	20.6	2.85b	2.58bc
Cowpea-cowpea-cowpea	13.8	77.9	86.1	21.2	2.85b	3.69a
Soybean-maize-soybean	13.2	77.5	86.6	22.5	2.54b	3.38ab
Soybean-soybean-soybean	13.2	94.0	86.6	5.9	2.54b	3.83a

[z]Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test
Source: Moody (1982)

In Brazil, weeds are controlled by minimizing soil movement (decreasing the number of weed seeds brought to the surface) by mulching with crop residues and by spraying with appropriate doses of both contact and preemergence herbicides. Mixtures of paraquat and metribuzin are the most common. Where vigorous annual grasses are a problem, specific grass-killers such as oryzalin (3,5-dinitro-N^4, N^4-dipropylsulfanilamide) or metolachlor are often included in the mixture (Hayward et al. 1980).

In southern Taiwan, no-till soybean is planted after the second rice crop. Soybean seeds are dibbled near the rice stubble, usually in September or October. Weeds are controlled by a combination of mulching with rice straw and the application of herbicides. The most popular herbicides are paraquat (0.6 kg/ha), alachlor (2-chloro-2', 6'-diethyl-N-[methoxymethyl acetanilide) (1.5 kg/ha), or pendimethalin (N-[1-ethylpropyl]-3,4 dimethyl-2, 6 dinitrobenzenamine) (0.6 kg/ha).

Weed Control Research at AVRDC

Two approaches are used at AVRDC to identify effective soybean weed control practices. The first is aimed at defining the time when weeds critically affect crop yield (critical period); the second is to identify effective chemical controls.

Weed Competition Study

Previous studies on the critical weed competition period emphasized the timing of manual weeding to avoid yield losses with the least labor input. These experiments were based on the premise that if weeds are controlled during the critical weed competition period, the crop can compete without significant yield reductions. Two trials were conducted (spring 1982 and 1983) using a randomized complete block design with four replications. Hand weeding treatments included weed infestation for 0, 15, 30, 45, 60, and 75 DAP (days after planting) and plots kept weed-free continuously for 0, 15, 30, 45, 60, and 75 DAP. Individual plots were 2 x 6 m, and consisted of eight rows of soybean spaced 10 cm apart within rows and 25 cm between rows.

The results of the spring 1982 trial showed that soybean kept weed-free for 30 DAP yielded 2.61 t/ha, a figure similar to the weed-free check's 2.29 t/ha (Fig. 1). Controlling weeds for longer periods failed to increase yield. Yield

was reduced 18% when the crop was kept weed-free for only 15 DAP. Yields were significantly affected by weed interference. The longer weeds were left unchecked, the higher the yield loss. The trial also showed that soybean tolerated weed interference up to 30 DAP (Fig. 1). When weed competition lasted more than 30 days, yield was significantly reduced. Yield was reduced 47% when weeds were left unchecked throughout the season. Yield variations were due to differences in pod and branch no/plant and seed size (Table 2).

The response in 1983 indicated that soybean tolerated weed competition up to 75 DAP without significant yield losses (Table 3). Continuous interference throughout the season reduced yield by 22%. In the weed-free treatments significant yield losses occurred in plots kept weed-free for 15 DAP.

These data reveal the amount of time that weeds can be left to compete with soybean. In 1982, significant yield losses were recorded when weeds competed with the crop for more than 30 DAP, whereas in 1983 weeds could be left unchecked for as long as 75 DAP. This phenomenon was due to the level of weed infestation; in 1982 infestation was more than twice as great as in 1983 (weed fresh weight 75 DAP was 15.5 and 6.5 t/ha in 1982 and 1983, respectively).

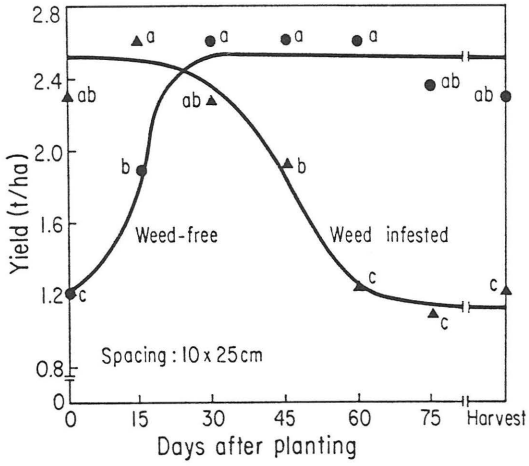

Fig. 1. The relationship between the duration of weed interference and soybean yield, spring, 1982.

Table 2. Yield components of soybean as affected by duration of weed interference, spring, 1982.[z]

Duration of Weed Interference (DAP)	Yield (t/ha)	100-Seed Wt. (gm)	Pod (no./plant)	Branch (no./plant)
Weed-free				
15	1.88b	15.4abc	16.4cd	1.25bc
30	2.61a	15.4abc	24.1ab	1.88ab
45	2.60a	15.2bc	24.1ab	2.02a
60	2.60a	15.1bc	23.7ab	2.00a
75	2.37ab	15.4abc	20.0bc	2.20a
to harvest	2.29ab	14.5c	21.8ab	1.78abc
Weed-infested				
15	2.60a	14.7c	25.4a	2.15a
30	2.26ab	14.8c	22.5ab	2.02a
45	1.90b	15.4abc	19.4bc	1.15c
60	1.24c	16.7ab	11.0e	0.18d
75	1.09c	17.0a	13.1de	0.23d
to harvest	1.20c	16.2abc	12.4de	0.15d

[z] Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test

Table 3. Effect of weed duration-interference on soybean yield, spring, 1983.[z]

Weed Duration-Interference (DAP)	Yield (t/ha)	
	Weed-free	Weed-infested
15	2.00b	2.97a
30	2.98a	3.14a
45	3.04a	3.13a
60	3.22a	2.99a
75	2.83a	2.65ab
To harvest	2.94a	2.29bc

[z] Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test

Chemical Control

Chemical control studies seek to establish the most effective compounds for controlling weeds without damaging the crop. Three trials were conducted to test the effectiveness of the following herbicides: Alachlor, oxyfluorfen (2-chloro-1-[3-ethoxy-4-nitrophenoxy]-4-[trifluoromethyl] benzene), metolachlor, Galex 500 (mixture of metolachlor and metobromuron [3-(4-bromophenyl)-1-methoxy-1-methyl-urea]), and pendimethalin. Individual trials were conducted in the spring and summer of 1982 and the spring of 1983. The experimental design was a randomized complete block with four replications. Plot size was 2 x 6 m consisting of 8 rows of soybean spaced 25 cm apart between rows and 10 cm within rows. All herbicides were applied preemergence.

Results of the 1982 trials are presented in Table 4. In the spring trial, the major broadleaf weeds were spiny amaranth (Amaranthus spinosus) and lambs quarter (Chenopodium album). The presence of grassy weeds was minimal. Statistically, broadleaf weeds were controlled by all herbicides. Yields from all herbicide treatments, except alachlor and metolachlor, were as good as the weed-free check. Jungle rice (Echinochloa colonum) and goosegrass (Eleusine indica) were the major weeds in the summer season. Both were effectively controlled by metolachlor and Galex 500, but not by oxyfluorfen. Alachlor and pendimethalin provided moderate control. Broadleaf infestation was low. Yields from the metolachlor and Galex 500 plots were as high as the weed-free check. Although yields from the pendimethalin treatments were higher than the weedy check, they were significantly lower than the weed-free check, except the 1.5 kg a.i./ha treatment.

Weed infestation during the 1983 season was comparatively low (Table 5). Weed fresh weight from all herbicide-treated plots was lower than the weedy check. Although weed infestation was lower than in the previous year, soybean yield was significantly reduced when weed growth was left unchecked throughout the season. Only yields in the oxyfluorfen-treated plots (0.23 kg a.i./ha) were significantly reduced compared with the weed-free check. This was due to phytotoxicity during the early growth stages. Oxyfluorfen at 0.12 kg a.i./ha was not phytotoxic.

These results indicate that oxyfluorfen is not an effective herbicide for grassy weeds and that it is phytotoxic to soybean when applied at 0.23 kg a.i./ha. Alachlor and pendimethalin provide moderate control of grasses. Metolachlor effectively control grasses and broadleaf weeds. Galex 500, pendimethalin, and metolachlor + oxyfluorfen (0.12 kg a.i./ha) provide adequate

control during the spring season in Taiwan, when the infestation from grassy weed is relatively low. Metolachlor and Galex 500 perform best in the summer season.

Table 4. Soybean yields and herbicide effectiveness, 1982.[z]

Herbicide Rate	Spring (t/ha)			Summer (t/ha)		
(kg a.i./ha)	yield[y]	grass	broadleaf	yield[y]	grass	broadleaf
Weedy check	1.52e	1.12a	12.05a	1.24f	5.52a	0.05bc
Weed-free check	3.12a	0.00b	0.00b	3.37a	0.00d	0.00c
Alachlor						
2.0	2.41bc	0.05b	1.57b	2.28cd	2.76bc	0.01b
Oxyfluorfen						
0.12	3.18a	1.15a	0.87b	1.45ef	5.62a	0.02bc
0.23	3.19a	0.45ab	0.00b	1.67ef	3.65ab	0.00c
Ala. + Oxy.[x]						
2.0 + 0.12	3.30a	0.00b	0.00b	2.78abc	2.78bc	0.01bc
2.0 + 0.23	3.46a	0.00b	0.00b	1.96de	5.47a	0.01bc
Metolachlor						
1.0	1.69de	0.12b	2.62b	3.12ab	1.66bcd	0.03bc
1.5	1.79de	0.00b	2.72b	3.27ab	0.30d	0.21a
2.0	1.90cde	0.00b	3.08b	3.38a	0.32d	0.02bc
2.5	2.20cd	0.00b	2.52b	2.99ab	0.26d	0.04bc
Galex 500						
1.5	3.00a	0.12b	0.00b	3.25ab	0.95cd	0.15ab
2.0	2.92ab	0.00b	0.00b	3.08ab	0.88cd	0.02bc
2.5	2.91ab	0.00b	0.00b	3.15ab	0.34d	0.04bc
3.0	3.33a	0.00b	0.00b	3.17ab	0.15d	0.01bc
Pendimethalin						
1.0	3.06a	0.38ab	0.00b	2.66bc	2.07bcd	0.08abc
1.5	3.22a	0.00b	0.00b	2.88ab	1.62bcd	0.01bc
2.0	3.22a	0.18b	0.00b	2.25cd	2.12bcd	0.00c

[z] Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test
[y] Soybean yield
[x] Alachlor + Oxyfluorfen

Table 5. Herbicide effectiveness and soybean yield, spring, 1983.

Treatment	Rate (kg a.i./ha)	Yield[y] (t/ha)	Weed Fresh Wt.[y] grass (t/ha)	broadleaf (t/ha)
Weedy check	-	2.32c	1.74a	0.21a
Weed-free check	-	3.20a	0.00c	0.00b
Ala. + Oxy.[z]	2.0 + 0.12	3.17a	0.21c	0.00b
Ala. + Oxy.	2.0 + 0.23	2.86b	0.44cb	0.01b
Metolachlor	1.5	3.21a	0.01c	0.03b
Metolachlor	2.0	3.16a	0.04c	0.02b
Metolachlor+Oxy.	1.5 + 0.12	3.18a	0.00c	0.00b
Metolachlor+Oxy.	1.5 + 0.23	2.42c	0.94b	0.00b
Metolachlor+Oxy.	2.0 + 0.12	3.23a	0.00c	0.00b
Metolachlor+Oxy.	2.0 + 0.23	2.79b	0.11c	0.00b
Pendimethalin	1.0	3.19a	0.20c	0.01b
Pendimethalin	1.5	2.92ab	0.35cb	0.07b

[z] Alachlor + Oxyfluorfen
[y] Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test

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The Influence of Planting Method and Mulching on Soybean Seed Yield

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Introduction

In Indonesia, soybean (Glycine max) is usually grown during the dry season after lowland rice (Oryza sativa), especially if the water requirements for a second rice crop cannot be met. Most farmers grow soybean without fertilizer or pesticides, and they rarely till before planting (Suhartatik et al. 1982). The major factors that limit soybean production in rainfed areas are water availability and the physical properties of wetland rice soils (Fagi and De Datta 1983).

In East Java, soybean seed is usually broadcast - a practice which often results in poor germination, inadequate plant stands, and high levels of weed infestation. Broadcasting, combined with the adverse effects of pests and diseases, can lead to poor seed quality and low yields (0.5 to 0.8 t/ha).

Field experiments were conducted to determine if improved planting practices and rice straw mulching might improve plant stands, increase soil aeration, and reduce weed infestation.

Materials and Methods

The experiments were conducted following lowland rice in the dry season at the Mojosari Substation (18 m above sea level; mean max/min temperature 32/29°C; 1,624 mm rainfall/year; Tropohumid soil type). Cultivar Orba (see Sumarno and Hidayat, eds.) was grown from July to October 1980 and from April to July 1981 in rice stubble without fertilizer. A split plot design with four replications was used. Treatments were as follows: Main plots - no mulch or rice straw mulch (5 t/ha); subplots - seed dibbled into holes made in the center of the rice stubble, 5 cm from the stubble, midway between stubble rows (20 cm), or broadcast on the soil surface. Subplot size was 4 x 5 m; plant spacing was 20 x 20 cm with 2 plants/hill. Seed in the broadcast treatments was scattered at a density equivalent to three times the population of the other treatments. All plants were sprayed every ten days with Azodrin 24 WSC (Dimethyl phosphate + 3-Hydroxy-N-methyl-cis-crotonamide) (2 l/ha total) and Dithane M45 (Ethylenebis dithiocarbamate 62% + Manganese^{++} 16% + Zinc^{++} 2%). (1 kg/ha). Yield components were calculated from 20 plants sampled at harvest; seed yield was derived from 2 x 2 m strips.

Results and Discussion

Planting Method

Soybean grown in or 5 cm from the rice stubble produced higher yields than plants that were broadcast or grown between the stubble (Table 1). This may have been due to improvements in the soil moisture regime and aeration caused by the decomposition of the rice roots (see Dharmasena, eds.).

Similar results were also obtained for the number of filled pods/plant (Table 2), but no significant differences were observed for plant height, empty pods/plant or 100-seed weight.

Planting methods did not influence weed infestation as measured by weed fresh weight/m^2 (Table 3).

Mulching

Mulching with dry rice straw (5 t/ha) increased seed yield by approximately 0.3 t/ha compared with the non-mulched treatment (Table 4). Mulching may have increased soil moisture content and reduced fluctuations in soil temperature. Similar observations were made by Syarifuddin (1979) who found that mulched plots had significantly higher soil moisture contents than non-mulched plots.

Table 1. Effect of planting method on seed yield.

Planting Method	1980 (t/ha)	1981 (t/ha)	Mean (t/ha)
In rice stubble	1.15	1.21	1.17
Five cm from rice stubble	1.14	1.17	1.15
Between rice stubble	1.06	1.03	1.05
Broadcast	1.06	1.00	1.03
LSD (P = 0.05)	0.07	0.13	

Table 2. Effect of planting method on number of filled pods/plant.

Planting Method	1980	1981	Mean
In rice stubble	39.95	33.40	36.68
Five cm from rice stubble	41.50	31.50	36.50
Between rice stubble	35.70	27.70	31.70
Broadcast	32.80	27.30	30.05
LSD (P=0.05)	6.70	3.36	

Table 3. Effect of planting method on weed infestation 30 days after sowing.

Planting Method	Weed Fresh Weight	
	1980	1981
	-------(g/m^2)------	
In rice stubble	342	144
Five cm from rice stubble	312	168
Between rice stubble	320	172
Broadcast	330	174
LSD (P=0.05)	NS[z]	NS

[z]Not significant

Table 4. Effect of mulching on seed yield.

Treatment	1980	1981	Mean
	---------(t/ha)----------		
No-mulch	0.92	0.98	0.95
Rice straw mulch	1.28	1.22	1.25
LSD (P = 0.05)	0.21	0.05	

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The Development and Testing of a Manual Soybean Seeder

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Introduction

Dry season soybean (Glycine max) is planted in Thailand in December-January, mainly in rice-stubble without tillage. Traditional planting methods vary, but most farmers allow their fields to dry after the rice crop (Oryza sativa), and then irrigate before planting. Some farmers plant soybean in dry fields, irrigate, and then drain the fields.

The number of seeds planted varies from 3 to 7/hill. If the field is irrigated after planting, more seeds are sown to compensate for seed spoilage.

The traditional planting tool is a pointed wooden stick. On occasion, bamboo or wooden sticks are joined together to make two holes at a time. This tool, however, causes fatigue and has no real advantage over the single-stick implement.

Depositing seeds (3 to 5) in the holes is the most time-consuming part of planting, and requires the farmer to bend or squat. After a time fatigue reduces productivity.

Development of A No-Tillage Seeder

The Asian Institute of Technology (AIT) developed two prototype seeders to reduce the labor requirements involved in soybean planting (Figs. 1 and 2) (Thunyaprasart 1977 and Singh et al. 1980).

The prototype II seeder was tested in December 1980 and 1981 in Chiang Mai (Rahman 1981). This device combined seed hole preparation and seed deposit in one operation, and could be used from a standing position. However, the soil opener was prone to clogging. To resolve this problem a third prototype (Fig. 3) was developed with the following features:

1. The end of the soil opener was made wider by replacing the flat plate with a semi-circular one.

2. An extra support was added to the outer pipe to stabilize the apparatus.

3. A 1.59 cm (diameter), slightly bent pipe was fixed at the lower end of the outer pipe for easy seed discharge. The pipe remains on the soil surface when the seeder is pushed downwards. Since the seed passage remains above the soil surface, there is little chance of soil clogging. If clogging does occur, the device can be easily cleaned.

Seed Breakage and Cut-Off Plate Damage

The cut-off plate of the prototype II seeder consisted of a thin steel plate and a rubber strip that was affixed to the end of the plate. The cut-off plate was quite sensitive. It allowed the seed to pass through the seed cell on the metering roller and sweep excess seeds over the roller surface.

Seed jamming frequently occurred between the metering roller and the cut-off plate, which often damaged both the seed and the cut-off plate. When the gap between the metering roller and the cut-off plate was increased, extra seed was discharged. Furthermore, the rubber strip cracked after a few hours of use.

The steel cut-off plate was replaced in the prototype III seeder with a leaf spring (1 mm thick, 14 mm wide). The advantage of this device is that when the seeds exert excess pressure on the spring, the pressure is deflected and the spring returns to its original position after seed discharge. The leaf spring has proven durable and leaves the seed undamaged.

The metering roller was also made thinner in the third prototype, and was placed inside the seeder so that the seed slot could accommodate three or four seeds at a time. The number of seeds discharged can be regulated by changing the slot size. Thinner, lighter materials were used in prototype III, thus reducing the weight of the seeder from 3.2 kg to 1.5 kg.

A soft soil seeder (prototype IV) was also developed using the third prototype as a model (Fig. 4). In this case, the higher the soil moisture content, the easier the seeder is to use. With a sharpened soil opener, prototype IV can also be used for upland rice.

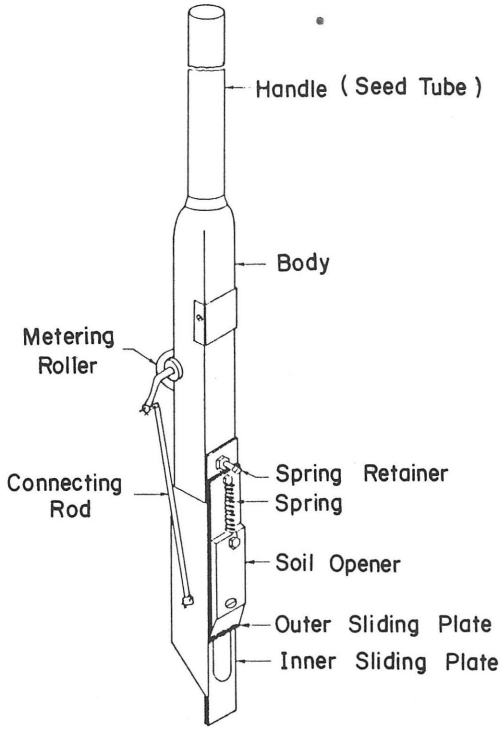

Fig. 1. Prototype I manual soybean seeder.

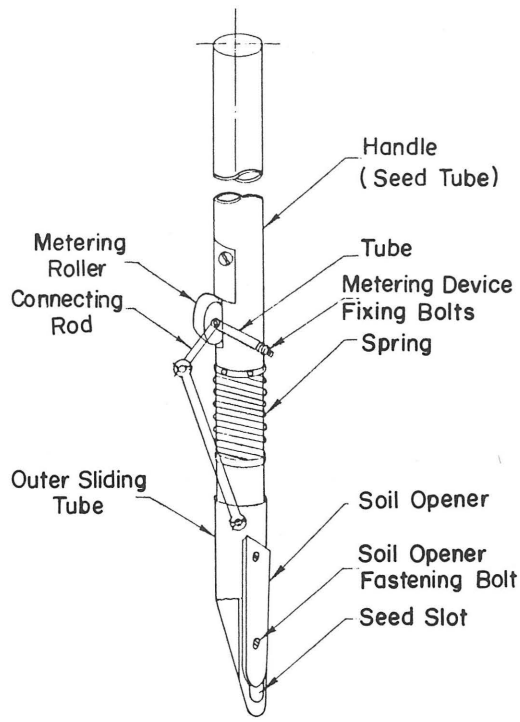

Fig. 2. Prototype II.

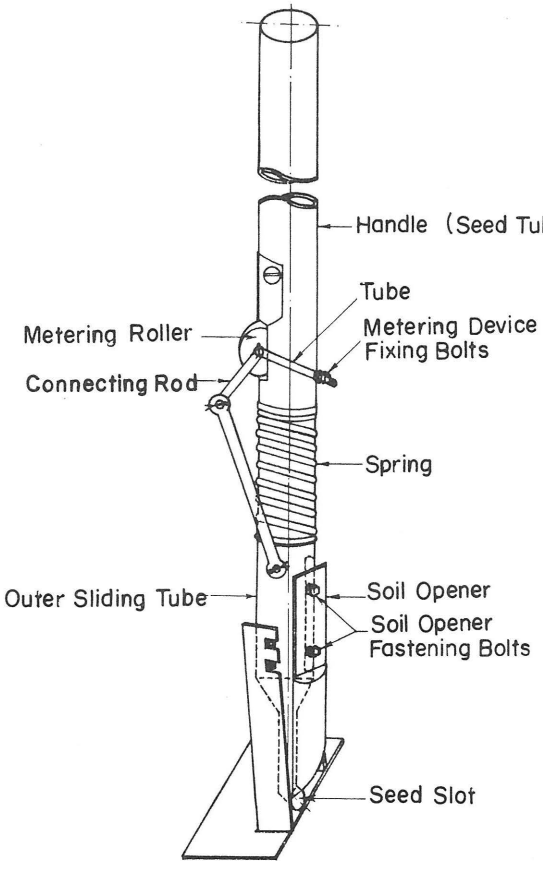

Fig. 3. Prototype III.

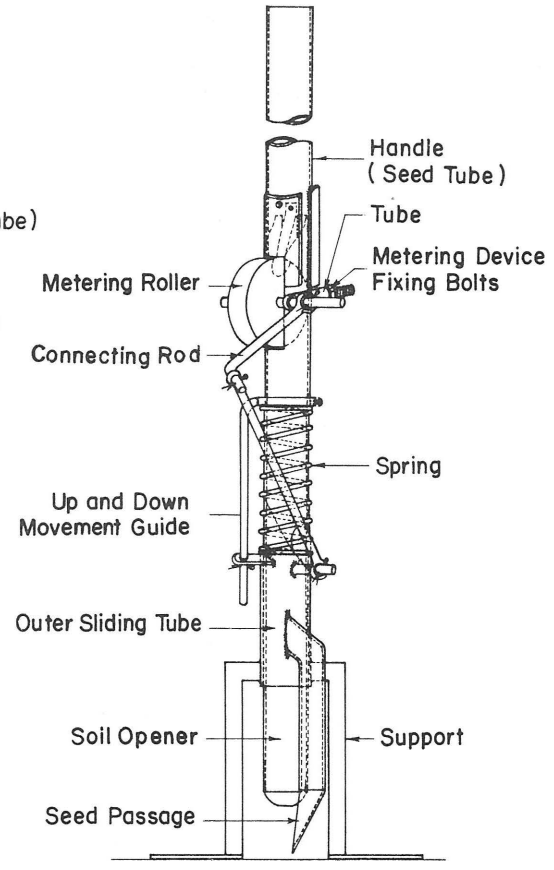

Fig. 4. Prototype IV (soft soil seeder).

Testing

No seed breakage or seeder damage was observed for prototype III when tested with three popular cultivars (SJ 2, SJ 4, and SJ 5) (Table 1).

Field testing was carried out at seven locations in the Mae-Rim and Hangdong districts of Chiang Mai Province. The capacity of the seeder at various locations is shown in Table 2. Labor requirements are approximately 22 workdays/ha (6 hr = 1 workday) compared with 45 workdays/ha for traditional planting.

Table 1. Seed discharge from the prototype III seeder.

Cultivar	Number of Seeds/Hill 0	1	2	3	4	5	6	Number of Hills	Average Discharge/Hill (no. of seeds)	Missing Hills (%)	Remarks
SJ 2 first run	0	16	136	211	94	41	13	511	3.1	0.0	No seed
SJ 2 second run	0	19	146	215	99	30	8	517	3.0	0.0	breakage
SJ 4 first run	6	24	311	226	83	21	15	582	2.85	1.0	No seed
SJ 4 second run	2	34	203	234	97	40	12	622	2.9	0.3	breakage
SJ 5 first run	7	41	228	203	69	9	7	564	2.6	1.2	No seed
SJ 5 second run	9	28	124	214	94	19	2	490	2.85	1.8	breakage

Table 2. Field capacity of the seeder compared with the traditional planting method.

Location		Area Planted (m^2)	Number of Laborers	Time Requirement (hr)	Field Capacity (worker hr/ha)
----------Manual Seeder----------					
Mae-Rim	1	540	2	2.75	100
	2	1,200	3	4.00	100
	3	1,170	3	4.75	120
	4	1,550	4	6.00	155
Hangdong	1	830	3	4.25	155
	2	1,000	3	4.50	135
	3	760	4	2.50	130
----------Traditional Method----------					
Mae-Rim		1,400	8	4.75	272
Hangdong		4,900	20	6.50	266

Cost

The cost of the seeder is approximately US $10.00 (materials $3.70, labor $4.50; profit $1.80). The prevailing wage in the Chiang Mai area is US $2/day. Thus, the labor cost for traditional planting is US $90/ha, whereas the cost of planting with four seeders is approximately US $84 (US $10 x 4 + US $ 2 x 22). By planting only 1 ha, a farmer can recover the cost of the seeders after just six days of use.

Acknowledgements

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Wheat-Soybean Double-Crop Management in Missouri

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Introduction

Missouri is located in the central part of the United States (36 to 41° N latitude). The state's crop production season varies from 160 days in the north to 220 days in the south, mostly as a function of temperature. Although the production season is shorter than in the tropics, multiple cropping is an important part of the state's agriculture.

Multiple cropping includes any system that permits the harvesting of more than one crop from a single parcel of land in a given year. It includes both intercropping and sequential cropping. With a few exceptions, soybean [Glycine max) is not intercropped in the Americas. It is, however, a major component of sequential cropping schemes, the most important of which is wheat (Triticum aestivum) followed by soybean.

The wheat-soybean cropping systems practiced in Argentina, Brazil, and the United States are quite similar: Each uses the winter period for wheat. Late harvesting of the wheat crop usually results in late soybean planting. This in turn reduces potential soybean yields to a level lower than that of a full season crop. In Missouri, both wheat and soybean production are fully mechanized. There is a growing tendency to practice reduced-tillage with double-cropped soybean. Although this practice may prevent soil erosion and reduce energy costs, its most important benefits in a multi-cropping system are savings in time between the harvest of the first crop and the planting of the second, as well as reductions in soil moisture loss.

Insect and weed control for Missouri soybean are largely chemical-dependent; however, disease control relies mainly on genetic mechanisms.

This paper discusses wheat-soybean double-cropping in Missouri. Other potentially useful systems are also highlighted.

Double-Crop Wheat Management

Successful double-cropping begins with proper winter wheat management. A good, full tillered, properly fertilized wheat stand usually suppresses weeds until harvest. Savings in both time and soil moisture can be realized when wheat stubble is sufficiently weed-free to permit the planting of no-till soybean. Where weeds are a problem, several herbicides are available for broadleaf and grass control (McHarry and Kapusta 1979).

Cultivars

The ideal wheat cultivar in a double-crop system is one that will produce consistently good yields of high quality grain, yet matures early enough to permit timely establishment of the soybean crop. In Missouri, high yield and quality are usually associated with early maturity. Very early cultivars should be avoided because of the danger of frost damage during flowering.

Fertilization

Fertilizer for the soybean can be applied at the same time as fertilizer for the winter wheat. This system saves time and is more practical than trying to apply additional fertilizer after the wheat harvest. Furthermore, if no-till is used for the soybean crop, fertilizer is already present in the soil. The high fertility levels that result from this practice may also benefit the wheat, and, in the event that the soybean double-crop cannot be planted, the extra P and K will remain in the soil for the benefit of a future crop.

Fertilizer application rates should be based on soil fertility status and the yield expectations of both crops. Soil fertility can be determined with a reliable soil test; yield expectations should be based on past experience. Most Missouri soils need P and K to produce both a wheat and a soybean crop. Current recommendations for P and K are shown in Table 1. N fertilizer is not recommended for soybean, but should be applied for the benefit of the wheat crop.

Planting Date

Wheat can grow at temperatures as low as 3°C, but optimum temperatures range from 21 to 25°C. Wheat can be planted from early September to mid-November, but should preferably be planted in late September or early October in northern Missouri and by mid-October in the southern part of the state. If a cultivar is susceptible to the Hessian fly (Mayetiola destructor), planting should be delayed until after the "fly-free date" (Reitz 1976).

Seeding Rates

A seeding rate of 100 kg wheat/ha is usually adequate if planting is completed by the recommended date. Seeding rates can be adjusted up or down, depending upon seeding date and seed size.

Harvest

The yield of full-season soybean cultivars decreases approximately 65 kg/ha/week as planting is delayed from early to late June. In July, yields decrease from 200 kg/ha/week in the southern part of the state to as much as 335 kg/ha/week in the north (Helsel and Scott 1982). Therefore, it is important to harvest the wheat and plant the soybean crop as early as possible, especially in more northerly areas.

In addition to permitting earlier planting of the double-crop, early harvesting reduces yield losses due to shattering and lodging. The economical relationships that support this practice are illustrated in Table 2 (Hoeft et al. 1975). Windrowing also permits early soybean planting. Wheat can be windrowed at up to 40% moisture content. Unless wet conditions prevail, drying will occur more rapidly than it does in standing wheat.

Straw Management

There are two basic methods for establishing soybean in wheat stubble: Planting into prepared seedbeds or planting without tillage.

Seedbed preparation delays planting and can lead to soil moisture loss. Yellowing of young plants and growth reductions have been associated with the incorporation of wheat straw (Sanford 1982). Yields can also be adversely affected by this practice in drier years, and so it is not uncommon for farmers to burn the wheat straw before preparing the land for double-crop soybean.

Table 1. Fertilizer application rates for double-cropped wheat-soybean as a function of crop yield and soil test values.

Double-Crop Yield (t/ha)		Fertilizer Recommended (kg/ha)					
		P			K		
		soil test level[z]			soil test level[y]		
wheat	soybean	low	med	high	low	med	high
2.0	1.0	38	23	5	38	23	5
	2.0	45	29	7	49	34	8
	3.0	51	35	9	59	44	12
4.0	1.0	47	32	8	43	27	6
	2.0	54	38	10	54	38	10
	3.0	59	44	12	67	48	13
6.0	1.0	56	40	11	47	32	8
	2.0	62	47	13	58	42	11
	3.0	68	53	15	68	53	15

[z]Low, medium, and high Bray I P soil test levels are 10, 30, and 60 kg P/ha, respectively

[y]Low, medium, and high K soil test levels are 150, 250, and 400 kg K/ha, respectively, for a soil with a cation exchange capacity (CEC) of 12 meq./100g of soil

Table 2. Net returns/ha for drying high moisture wheat ahead of double-crop soybean (Hoeft et al. 1975).

Additional Costs		Additional Returns	
item	US $/ha	item	US $/ha
Wheat dry costs (6.59 t x 7 percentage points x $0.1875)	8.65	Reduced wheat harvesting losses (2% x 6.59 t x $37.48)	4.94
Extra hauling, handling, and shrinkage (6.59 t x $0.45)	2.97	Increased soybean yield[z] (0.2 mt x $ 185.30)	37.06
	11.62		42.00
Net advantage of harvesting high-moisture wheat			30.38

[z]Soybeans planted six days earlier with a yield increase of 33 kg/day

No-till limits disturbance of the soil to all portions of the seedbed except the slots in which the seeds are planted. Wheat straw, unless burned, remains on the surface and acts as a mulch that impedes run-off and reduces surface crusting. No-till practices are valuable in situations where the moisture available for germination is limited, as is normally the case during the wheat harvest in Missouri - especially when planting is delayed. Residues, however, complicate seed placement, seed coverage, weed control, and light penetration. These problems can be overcome with proper equipment and straw management.

In a no-till system, small grain stubble should not be bunched or windrowed unless it will be baled and removed. Planters cannot penetrate thick residues and still place seeds at the proper depth. Furthermore, some types of furrow-openers tend to press the straw into the soil during planting, and thus prevent good seed-to-soil contact. A simple way to manage wheat straw in a no-till

system is to cut the small grain at a height of approximately 20 cm (Hovermale et al. 1979), shred it with a combine shredder attachment, and distribute it evenly across the field. Shade provided by standing stubble stimulates elongation of soybean stems and causes a higher first pod height. This simplifies the harvest of the soybean and reduces harvest losses. While 20 cm stubble height seems optimal, taller stubble heights can produce spindly, lodging-susceptible soybean plants without increasing yields.

Burning the straw is another option. This practice seldom produces higher yields than those achieved with chopping and spreading the straw. However, Sanford (1982) found that burning the straw, followed by no-till planting and cultivation, lowered costs and increased the profits in five double-crop systems (Table 3).

Double-Crop Soybean Management

The advisability of planting double-cropped soybean can only be decided after the wheat harvest, and only then on a case-by-case basis. Farmers must decide if there is enough moisture to germinate the soybean crop, if there is enough time to grow a crop before the first frost, and if pests can be controlled.

Deciding to Plant

Rapid germination and emergence of a uniform soybean stand may determine the success of double-cropping. In Missouri, soil moisture is the environmental factor that determines whether or not a good stand will be achieved. Soybean can germinate only in a soil with a moisture tension of not less than -6.6 bars (Hunter and Erickson 1952). If the soil is too dry for prompt emergence, the seeds may die or emergence may be so late that the remainder of the season is too short for the crop to complete its growth cycle. Thus, if the top two inches of the soil are dry, and the soybean cannot germinate and emerge without additional water, then planting should be postponed. If sufficient rainfall for stand establishment is not received by the latest "safe date," double-cropping should be abandoned for that year. The low probability of rainfall in Missouri during late June and July (Table 4) means that soybean will not be double-cropped in some years, particularly in the central and northern parts of the state. The need to conserve moisture through practices such as no-till is obvious. This recommendation also means that the major source of double-crop failures are eliminated before most of the variable costs associated with soybean are incurred.

If moisture is available 5 cm below the soil, furrow-openers or similar mechanical devices can be used to exchange the dry top soil for the moist soil found at lower depths. Planting directly into deep, moist soils is not reliable.

The last safe date to plant soybean is a function of the length of the remaining growing season at a given location. At least 90 frost-free days are needed so that double-cropped soybean can reach physiological maturity. Subtracting 90 days from the average date of the first killing frost can be used to calculate the last safe date.

Average dates of killing frosts in Missouri range from October 22 in the north to November 10 in the extreme south. Minus 2.2°C is considered to be a "killing" temperature, although the effect of low temperatures on soybean yield, seed viability, and composition are clearly growth stage-dependent. From 74 to 81% yield reductions occur (Saliba et al. 1982) when soybean is frozen at the R5 growth stage, but essentially no loss occurs after physiological maturity (R7).

While seed moisture content is still 55 to 60% at physiological maturity, the seed is drying and becoming increasingly resistant to freezing. Approximately 8 hours of exposure to 7°C produces a significant reduction in standard germination at this growth stage (Judd et al. 1982). Soybean frozen before R6 has a lower oil content (Saliba et al. 1982).

Pod color is a useful indicator of physiological maturity; when the pods lose their normal green color and turn yellow, the seeds are physiologically mature (Crookston and Hill 1978) and safe from freezing injury.

Table 3. Soybean yield, cost of production, and returns for five soybean-wheat cropping systems and a soybean monocrop system (Sanford 1982).

Straw Management	Seedbed Preparation	Weed Control Method	Soybean Yield (t/ha)	Total[z] Cost ($/ha)	Gross[y] Income ($/ha)	Net Returns ($/ha)
Double-crop						
Burned	prepared	cultivated	1.24 ab[x]	594	820	226
Burned	none	cultivated	1.37 a	523	853	330
Incorporated	prepared	cultivated	1.00 c	608	761	153
Left standing	none	chemical	1.09 bc	582	782	200
Shredded	none	cultivated	1.25 ab	536	822	286
Monocrop						
No straw	prepared	cultivated	1.93	316	496	180

[z]Production costs include all direct and fixed costs for both wheat and soybean. Gross income and returns are also based on wheat and soybean yields where applicable.
[y]Commodity prices used to compute gross income were US $257.25/t for soybean and US $148.84/t for wheat
[x]Means in columns followed by the same letter are not significantly different at p = 0.05 by Duncan's New Multiple Range Test (monocrop soybean yields were not included in the analysis of variance)

Table 4. Probability of rainfall during one-week periods in June and July in Missouri (Barger et al. 1959).

Location	Rainfall (cm)	Week Ending (% probability)				
		June		July		Aug
		7	21	5	19	2
Southeast	1.5	53.8	48.5	32.0	42.4	37.3
	2.5	41.8	30.1	18.6	24.5	25.8
	3.0	36.8	23.3	14.3	18.3	21.6
Southwest	1.5	58.6	53.5	41.1	39.0	44.2
	2.5	42.1	39.6	28.4	26.9	30.6
	3.0	35.4	34.1	23.7	22.5	25.7
Central	1.5	53.6	43.6	36.5	36.4	46.0
	2.5	37.1	26.6	25.8	23.8	31.5
	3.0	30.8	20.8	21.9	19.4	26.2
Northern	1.5	61.2	57.9	45.8	21.4	50.3
	2.5	46.6	42.9	31.6	09.9	36.1
	3.0	40.8	37.0	26.4	06.8	30.7

Cultivars

Maturity is a primary consideration in choosing soybean cultivars for double-cropping. In general, they should be medium and medium-late season cultivars for the normal full-season planting time in a given area (Lewis 1976). They should also produce a closed canopy to shade out weeds. Cultivars that mature too early are generally lower yielding and produce pods that grow close to the soil surface, and are thus more difficult to harvest. On the other hand, long-season cultivars have favorable growth habits, but may still be immature at the onset of a killing frost. Similarly, the new determinate, semi-dwarf and semi-determinate cultivars should not be used for double-cropping in Missouri because of their short stature and early flowering.

Research has shown that the following US maturity groups are suitable for wheat-soybean double-cropping in different parts of the state: North-Late Group II; Central-Late Group III; Southwest-Group IV; and Southeast-Group V.

It is usually possible to double-crop soybean after winter wheat in southern Missouri, however, in much of the state farmers can only grow three crops in a two-year period because of short growing seasons. Soybean requires about two weeks of "drydown" after reaching physiological maturity. For this reason, the wheat that follows double-cropped soybean will not have time to establish itself for the coming winter season. Sanford (1979) found that over-seeded wheat consistently outyielded a conventionally seeded crop, provided that it was over-seeded when the soybean canopy was completely closed (Table 5). Lewis and Phillips (1976) found that over-seeding was unsuccessful on sandy, quick-drying soils.

Row Spacing

When soybean is planted late in the normal growing season, the time available for vegetative growth is reduced. This results in less branching in double-cropped soybean, which in turn reduces the soybean canopy's ability to fill the spaces between wide rows. Drilled or narrow rows (50 cm) have resulted in 15 to 20% yield increases over wider rows in Missouri. Recent results from neighboring states (Beaver and Johnson 1981 and Beatty et al. 1982) show similar tendencies (Table 6). The advantage of narrow rows, especially in late plantings, is most often attributed to increased light interception. Typically, wheat is harvested in late June or early July so that the longest days of the growing season are lost to crop production. Narrow row spacings speed the formation of a full soybean canopy, and increase the crop's yield potential where light interception is a limiting factor.

Doubling-back with a row planter to split the middle part of 76 cm rows is a useful technique for producing narrower rows. Uniform row spacing is not critical in no-till because cultivation is not generally practiced.

Seeding Rates

Plant populations can vary without affecting soybean yields. However, higher seeding rates are recommended for double-cropped soybean because of unfavorable seedbed conditions. In addition, when soybean is planted in no-till, it is difficult to control the depth of planting or produce good slot closures. A rate of 23 to 26 seeds/m is suggested for 50 cm rows (60 to 80 kg seed/ha).

Weed Control

Herbicides are generally used to control weeds in double-cropped soybean. In no-till double-cropping, contact herbicides with a broad control spectrum can

be used to kill existing vegetation after harvest. Triplett (1978) attributed at least half of the yield increase in a 3-year study to the use of either paraquat (1, 1'-dimethyl-4, 4'-bipyridinium ion) or glyphosate (N - [phosphonomethyl] glycine).

Pre-emergence grass and broadleaf herbicides with residual activity are usually needed to control weeds that emerge after planting in either conventional or no-till seedbeds. The relative effectiveness of several chemical compounds are shown in Table 7.

When there is doubt about the success of establishing a soybean stand, or where residues are heavy and there are few weeds, it is possible to defer herbicide application and rely instead on post-emergence compounds. If a poor stand results, or only certain weeds are a problem, then resources will not have been spent on unnecessary herbicides. Total reliance on post-emergence herbicides, however, involves several problems, including cost, ineffectiveness on larger weeds, and the fact that treated weeds continue to compete with the crop until death occurs.

Irregardless of the type of weed control used, it is necessary to analyze the weed problem and the conditions under which it exists, and then select herbicides and application methods accordingly.

Insects and Diseases

Double-crop soybean often escapes the pests that cause problems on full-season soybean. However, in some instances pest damage can be more injurious to double-crop than to full-season soybean because plant foliage is minimal and all available leaf areas are needed for production. What may be considered as only minor insect damage on large, full-season soybean may be serious in a soybean double-crop, and thus requires earlier treatment. Because expected double-crop yields are lower than full-crop yields, consideration should be given to the potential productivity and economics of double-crop soybean before expensive pest control treatments are initiated.

Multiple Alternatives

The northern border of Missouri (41°N) coincides with the northern limit of wheat-soybean double-cropping. At that latitude, timeliness in planting is crucial to reducing losses due to late planting and fall frost. One promising tactic is to relay-intercrop soybean with wheat. In areas where the season is too short for soybean after wheat, this system may increase productivity per unit area.

In relay-intercropping systems, soybean is planted into wheat in early May and thus occupies the land for as long as a soybean monocrop. At the time of interseeding, the level of wheat development should be somewhere between the mid-boot and early heading stages (Brown 1982). Some wheat yield losses will occur during interseeding, but these can be minimized by leaving skip rows in the wheat for the tractor and soybean planter tracts. Jeffers and Triplett (1979) suggested that wheat yield reductions of 25% are about average. Approximately 40% of the loss results from skips in the wheat; the remainder is a function of mechanical damage. Sowing soybean from the air has been attempted, but is unreliable.

Soybean growth should not interfere with the wheat harvest. However, the soybean should be capable of vegetative development so that it can exploit the environment when the wheat is removed. In the midwestern part of the USA, late

maturing, indeterminate cultivars fit these requirements better than early maturing cultivars or those with determinate growth habits.

On average, soybean grown as a relay-intercrop produces approximately 60% as much as soybean grown in comparable monocultures (Table 8). While near normal yields have been reported under favorable conditions (Brown 1982), crop failures are possible under conditions of extreme drought or poor weed control.

Table. 5. Yield of wheat over-seeded in soybean at two levels of canopy closure (Sanford 1979).

Soybean Canopy (%)	Wheat Yield (t/ha)	Soybean Yield (t/ha)
76	2.72 b[z]	2.16 b
100	3.15	2.41 a

[z]Column means not followed by a common letter differ at the 0.05 probability level according to Duncan's Multiple Range Test

Table 6. Row spacing effects on soybean yield.

Location	Row Spacing (cm)	Yield (t/ha)
Brownstown, IL[z]	20	1.75
	50	1.84
	80	1.80
LSD (0.1)		0.06
Keiser, AR[y]	18	1.90 a[x]
	Broadcast	1.69 b
	48	1.89 a
	96	1.65 b

[z]Beaver and Johnson (1981)
[y]Beatty et al. (1982)
[x]Means not followed by the same letter are satistically different at the 5% level of probability according to Duncan's Multiple Range Test

Table 7. Yield of double-crop soybeans following wheat (Triplett 1978).

Herbicide	Rate	Contact Herbicide and Rate					
		None		Paraquat 0.28 (kg/ha)		Glyphosate 0.56 (kg/ha)	
		1973	1975	1973	1975	1973	1975
	t/ha						
No herbicide		0.2	0.1	0.9	0.8	1.1	0.6
Linuron[z]	1.12	1.0	1.1	1.4	1.3	1.5	1.3
Metribuzin[y]	0.56	1.0	0.7	1.4	1.0	1.5	1.0
Alachlor[x]	2.24	0.7	0.2	1.3	0.8	1.5	0.6
Linuron + Alachlor	0.56 + 0.24	1.1	1.0	1.4	1.4	1.4	1.2
Metribuzin + Alachlor	0.56[w] + 2.24	0.9	0.7	1.3	1.2	1.3	1.1
LSD 0.05		0.1	0.5	0.1	0.5	0.1	0.5

[z]Linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea]
[y]Metribuzin [4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4H)-one]
[x]Alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide]
[w]Rated reduced to 0.28 kg/ha in 1975

Table 8. Mean yield of seven cultivars grown as intercrops and monocultures based on three experiments (McBroom et al. 1981).

Cultivar	Intercropping (t/ha)	Monoculture (t/ha)
Harcor	7.24	3.63
Cumberland	2.01	3.46
Corsoy	1.99	3.30
Beeson	1.99	3.44
Wells	1.77	3.31
Oakland	1.72	3.34
Hark	1.83	2.90
LSD (0.05)[z]	305	

[z]LSD (0.05) for within column comparisons only

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Discussion Section III

Question: What is the fertilizer recommendation for wet soil culture?

Troedson: Recommendations are the same for both wet culture and dry culture.

Sundar: The Sorjan's method of cultivation in Indonesia is similar to saturated soil culture. Therefore, wet soil culture is actually a modification of an old method. Furthermore, the rice bund soybean production practiced in Nepal, Korea, Japan, and other countries have similarities to wet soil culture.

Question: What is the source of your cultivars and what was the range of varietal tolerance to waterlogging? Are any breeding programs aimed at these types of stress environments?

Troedson: The variability for tolerance to waterlogging was 2% to 61% in the 40 cultivars that we studied. No breeding work was done.

Question: Did you saturate the soil from planting to harvesting or only during certain growth stages? What is the water requirement for soybean per hectare? Is it the same amount as for flooded rice?

Troedson: We have applied water from soon after emergence until physiological maturity. The water requirement depends on the soil type and plant and environmental conditions. We have not made any water requirement measurements.

Question: At what stage of crop development is recovery observed in the saturated soil culture? Were the yield advantages reported observed in both long-season and short-season soybeans?

Troedson: Recovery was observed between one and three weeks after saturating the soil, depending on the depth of the water table, the soil nitrogen level, and the use of starter nitrogen. However, growth continues during the yellowing period and rapid growth resumes prior to the recovery of full green leaf color. Depending on the rapidity of recovery, the yield advantage may be reduced or eliminated in very early cultivars.

Question: What is the moisture content of this soil at field capacity? Did you measure the moisture content of the soil surface in the wet treatment?

Troedson: The gravimetric moisture content at the field capacity of the soils we have been working with is between 30% and 50%. The gravimetric moisture content in the saturated treatment was 5% to 10% higher than at field capacity.

Question: Are Australian rice farmers using the system that you mentioned?

Troedson: Research has been carried out on this system in the field for the past five years, but has recently concentrated on a physiological understanding of the system. There has been no extension program to encourage farmers to grow soybean in saturated soil, but some farmers are doing so anyway.

Question: Could you describe the distribution of roots and root nodules under saturated soil culture in more detail?

Troedson: In our work, with a saturated soil zone resulting from a water table 10-15 cm below the surface, root and nodule development occurs only above the water table. Once the surface is shaded, roots and nodules appear on the surface. However, root and nodule dry weight are substantially greater than in conventionally irrigated plants where roots have a much greater soil volume to explore.

Question: Have you observed any increase in the incidence of disease or fungus under saturated soil conditions for soybean?

Troedson: Under our conditions, and with our cultivars, we have not noticed any increase in disease incidence.

Question: Would you describe high input and low input, and what are the principal contributing factors to high input?

Sundar: From this experiment we cannot single out a specific factor that contributes to high yield. However, for some genotypes there is no difference in yield between maximum input and minimum input during the summer rainy season. So for those genotypes irrigation is the key to increasing yield. But probably there are other factors which can increase the yield as well because by including other factors yield increases in those genotypes. But irrigation alone can do the magic. From other experiments that we are now conducting, we know that in certain seasons if we apply only insecticide, yield increases. There is no need to apply fungicide because diseases are not so serious during the summer season. But during the other seasons you need to use only fungicide for disease control. At that point yields increase. I should caution here, if you are going to do it in Indonesia, the situation may be quite different. Insects may predominate or weeds may predominate, and you may end up finding that these two need to be controlled in order to increase yield.

Question: How many irrigations or at what plant growth stage did you find that you get the maximum return or minimum return from irrigation?

Sundar: Our crop management specialist has done experiments in this regard, and he has found that, at least under our conditions during the spring and autumn seasons, irrigation 30 days after planting and 60 days after planting - at the flowering stage and at the beginning of seed filling - is sufficient.

Question: The difference between maximum and minimum input becomes greater in the spring season. What is the reason? Did you use different cultivars?

Sundar: We tested 14 genotypes and the data that I showed in the bar diagram is the mean. During the spring season in the maximum input treatment we provided irrigation, fertilizer, fungicide, herbicide, and insecticide. In the early part of the season we have cooler temperatures. In the later part of the season the temperature rises. We have slight rainfall only at the end of the season. So in the minimum input treatment, the crop is at stress from the beginning because of cold weather and no water or fertilizer. Weeds, insects, and diseases can cause yield reduction in the spring season, in part, because growth duration is longer. As a result the yield

between maximum and minimum is much greater compared to the summer season. During the spring season soybean rust is a serious problem.

Question: What is your reaction to trying some of the promising cultivars selected from your minimum input treatments to see if they are suitable for multiple-cropping?

Sundar: Some of the genotypes that are high yielding under maximum input conditions also appear to be high yielding under minimum input conditions. So maybe we need to select genotypes and test them under stress conditions and then check to see whether the results agree. Also, we conducted our tests in only one location. By taking these cultivars and testing them at different sites we can probably get a better idea, and this is what we are currently doing. We now have experiments in Thailand, and we are planning trials for Indonesia and the Philippines.

Question: In your study how do you characterize the variability of your genotypes for plant height, maturity, etc?

Sundar: Usually the genotypes that appear to be higher yielding and capable of withstanding stress also appear to be taller and late maturing. The genotypes which can give higher yield at maximum input appear to be about 60-65 cm in height, and they have a greater number of branches.

Question: Did you use the same plant population for these two experiments?

Sundar: Yes. Seed rate and planting density were the same.

Comment: I am sure you can increase the yield if you increased the population in the minimum input treatment.

Sundar: If you considerably increased the plant population density, then you probably could increase the yield, but we did not do that so that we could have a comparative study. So if you want to test that hypothesis, an experiment would have to be conducted under different situations. You also have to consider if farmers can afford to put their money into purchasing additional seed.

Question: What is the harvest index when a high yield is recorded?

Sanders: I do not have harvest index information on these experiments, but it is possible that the determinate semi-dwarf soybeans may have a higher harvest index than the indeterminate soybean cultivars reported here.

Question: Did you calculate the price of the inputs or production cost which give maximum economic yield per hectare? What would be the most important input component for maximizing yield?

Sanders: These are long-term experiments and are not yet complete. A couple more years of base data need to be accumulated before a meaningful calculation of maximum economic yields can be calculated for farmers' use. In these experiments, as many factors as possible are eliminated as limiting factors. There are four factors which appear to be contributing most to higher yields under these conditions: Irrigation, cultivar selection, higher fertility, and higher plant populations in narrower rows.

Question: In one of your tables there is a linear increase in maximum yield from 1980 to 1982. What factors were manipulated to cause this increase in maximum yield?

Sanders: Increase in maximum yield from 1980 to 1981 was due to the removal of yield constraints; the increase from 1981 to 1982 was due to adequate water supply up to physiological maturity.

Question: Is the difference in the effectiveness of the same herbicide applied to wet and dry season soybeans associated with different environments or simply to a different weed spectrum in each season?

Sajjapongse: Environment influences the weed flora. For example, on AVRDC's farm the major weeds during the spring season are broadleafs, while in the summer grasses are the biggest problem. Therefore, the use of herbicides should be season-specific. We recommend metolachlor for summer soybean and pendimethalin or metolachlor plus oxyfluorfen for the spring season.

Question: Have you conducted any experiments to investigate the effects of plant population on weed growth? For example, at high plant populations the crop canopy closes earlier in the crop growth cycle. In effect, the crop competes with the weeds.

Sajjapongse: No, we have not conducted this type of experiment. However, under high population densities we have observed broad-leafed cultivars with strong stems that outgrow the weeds.

Question: How many tons of rice straw is needed to mulch a hectare?

Adisarwanto: Five to fifteen tons.

Question: Did you conduct an experiment to compare soybean seeding after burning rice straw and mulching with rice straw after seeding soybean without burning straw?

Adisarwanto: No.

Question: Do you have any flexibility in manipulating the maturity date of your cereal crop?

Minor: Not very much.

Section IV
Diseases and Insects

Recent Advances in Soybean Rust Research

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Introduction

Soybean (Glycine max) and 75 or more other species in 30 genera of cultivated and wild legumes are affected by soybean rust (Phakopsora pachyrhizi) (Sinclair 1982). Soybean yield losses due to rust range from 40 to 90% in Southeast Asia (Bromfield and Yang 1976, Franje and Quebral 1980, Pupipat 1977). The pathogen is also present in Asia, Africa, and Latin America.

Environment and Rust Development

Influence of Photoperiod on Plant and Rust Development

Previous observations showed that later-maturing soybean cultivars developed rust noticeably later than earlier-maturing cultivars. However, rust severities at a particular growth stage were generally similar among cultivars grown in the same environment, regardless of the cultivar's maturity. This indicates that plant growth and development affects rust development.

Photoperiod studies involving three cultivars in two seasons were used to compare plant and rust development under natural photoperiods (avg. 11.2 hr in fall and 12.5 hr in spring) and 14 hr extended photoperiods. Two cultivars were planted in each season: Fall season, PI 230971 (G 8587) and Shih-shih (G 38); spring season, G 38 and Taita Kaohsiung 5 (TK 5). The results of the fall trials are reported elsewhere (Tschanz and Tsai 1982). The effect of photoperiod on soybean flowering and maturity is already well established (Hadley et al. 1984, Shanmugasundaram 1981).

The number of days to flowering (R1) (Fehr and Caviness 1977) and days to maturity (R8) of all cultivars were affected by photoperiod (Table 1). The extended photoperiod treatment delayed the R1 growth stage from 3 to 20 days and the R8 from 12 to 33 days. Rust development on plants grown under the extended photoperiods was always delayed compared with the same cultivar grown under the natural photoperiod (Fig. 1 and 2). The delay in rust development was closely associated with the delay in development and maturity caused by extended photoperiod. Therefore the development and maturation of a soybean cultivar affect soybean rust development.

This indicates that variations in rust development among cultivars grown at the same time, and at the same location, will reflect both the cultivars' level of resistance and their development and maturation. As a result, the comparative level of a cultivar's resistance can only be evaluated against a cultivar with the same or similar levels of development and maturation, unless the influence of plant development and maturation on rust development is minimized (see "Rate-Reducing Resistance" section of this paper).

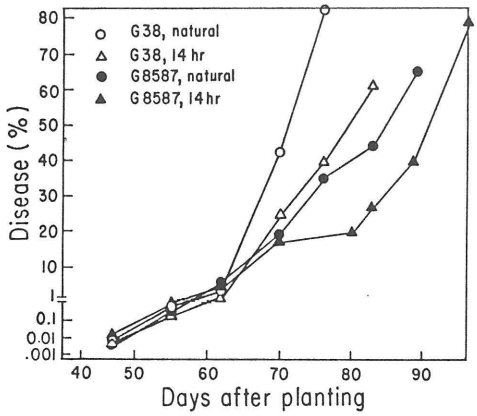

Fig. 1.
The influence of two photoperiod regimes on rust development in two soybean cultivars, fall, 1981. The 14 hr photoperiod delayed soybean maturity (R8) in G 38 by 12 days and in G 8587 by 21 days.

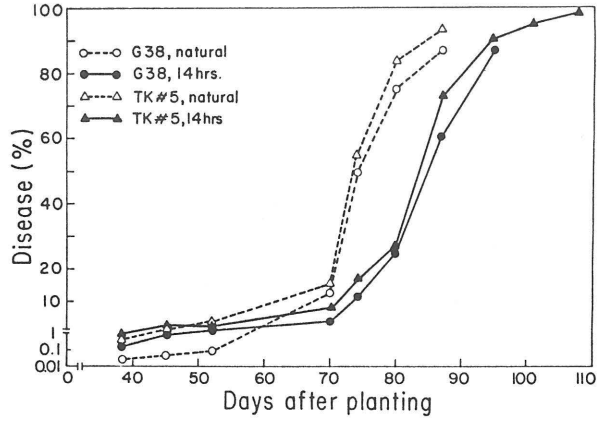

Fig. 2.
The influence of two photoperiod regimes on rust development in two soybean cultivars, spring, 1982. The 14 hr photoperiod delayed soybean maturity (R8) in G 38 by 14 days and in TK 5 by 33 days.

Table 1. The effect of photoperiod on the development of cultivars grown in the field during two seasons at AVRDC[z].

Season	Cultivar	Photoperiod	DAP R1	DAP R8
Fall	PI 230971	Natural	28	99
		14 hr	34	120
	Shih-shih	Natural	29	83
		14 hr	32	95
Spring	Shih-shih	Natural	39	91
		14 hr	46	105
	TK 5	Natural	43	93
		14 hr	63	126

[z] Natural photoperiod was 11.9 to 10.5 hr and 11.5 to 13.5 hr in fall and spring seasons, respectively

Precipitation and Rust Development

Previous studies have shown that rust development is affected by precipitation patterns. A trial was conducted to determine the effect of precipitation and irrigation on rust development. Treatments included furrow irrigation (as needed), no irrigation, and overhead irrigation (daily from 16:30-17:00) through a pipe perforated with small holes (<1 mm) set 0.8 m above ground level. The study was conducted at AVRDC on three planting dates: October 1, 1979 (fall), March 5, 1980 (spring), and October 1, 1980 (fall). Cultivar TK 5 was grown in 10 x 10 m plots (9 x 9 m harvested) with three replications and at a plant density equivalent to 4 x 10^5 plants/ha. Data collection and evaluation procedures are described in Tschanz et al. (1982) and Tschanz and Tsai (1982).

Precipitation in the fall 1979 trial was only 28.5 mm in a six-day period, and the majority (24.4 mm) fell in two days (47 to 48 DAP [days after planting]).

Total precipitation and the number of rainy days were 99.3 mm and 12 days, and 58.7 mm and 8 days for the spring and fall 1980 seasons, respectively, (Fig. 3).

In the fall of 1979 rust first reached an estimated 1% severity in the overhead irrigation treatment, but was delayed in the other two treatments; the greatest delay occurred in the non-irrigated treatment (Table 2). The rate of rust development was also slowest in the non-irrigated treatment; rust development was similar in the other two irrigation treatments.

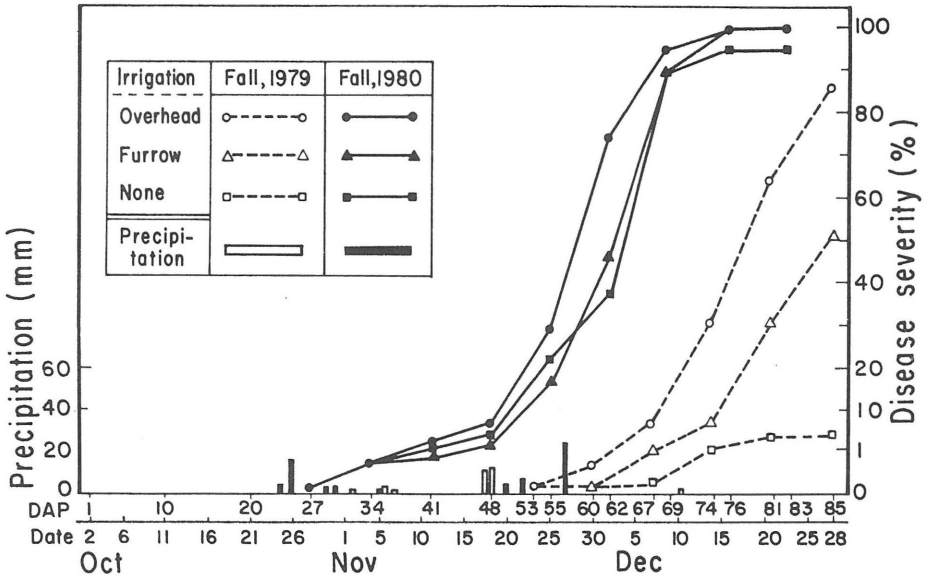

Fig. 3. The influence of precipitation and irrigation practice on soybean rust development during two seasons at AVRDC. Soybean cultivar TK 5 was planted on Oct. 1, 1979 and 1980.

Table 2. Effect of irrigation methods on the initiation and rate of soybean rust development in cultivar TK 5 over three seasons at AVRDC.

Season	Treatment	Rate of Rust Development[z]	Days After Planting 1% rust[y]
Fall 1979	Overhead	0.2224	58.4 b
	Furrow	0.2245	66.3 a
	Non-irrigated[x]	0.0926	72.3
Spring 1980	Overhead	0.2480	39.7 r
	Furrow	0.2774	43.7 r
	Non-irrigated	0.2494	47.1 r
Fall 1980	Overhead	0.2992	42.7 w
	Furrow	0.3015	45.4 w
	Non-irrigated	0.3285	47.0 w

[z] Regression coefficient based on logit of % disease and days after planting, mean of three replications (except 1979 non-irrigated)

[y] Estimated from linear regression; mean separation within columns in each season by Duncan's multiple range test (5% level)

[x] Data were pooled to compute linear regression because of insufficient data points

In the spring and fall of 1980 the rates of rust development and the estimated DAP when rust reached 1% severity were similar for all treatments within seasons (Table 2). Precipitation and soil moisture content were not limiting factors. Therefore, only the data from the fall 1980 experiment were compared with the data from the fall 1979 experiment.

A comparison of rust development in the 1979 and 1980 fall seasons shows that precipitation and irrigation are important factors in rust development (Fig. 3). The development of the rust epidemic in the overhead irrigation treatments (in both seasons) occurred within three weeks of initial precipitation. Complete development of the rust epidemic occurred within seven weeks of the first major precipitation. However, the first major rainfall in the fall of 1979 occurred 22 days later than in fall 1980.

Apparently, precipitation is necessary for the development of a rust epidemic, even when soybean is grown with certain types of irrigation. The overhead irrigation, as applied, did not simulate precipitation as evidenced by the delay in rust development in the fall 1979 season compared with fall 1980. However, in cropping seasons with low precipitation, irrigation method altered both when the development of the epidemic occurred and the rate of rust development.

Temperature and Leaf Wetness

Most of the knowledge concerning the influence of environmental parameters on rust development, primarily temperature and dew period, were obtained from greenhouse or growth chamber studies. A study was conducted at AVRDC to examine the relationships between environmental parameters and rust development under field conditions.

Cultivars TK 5 (determinate) and PI 230971 (indeterminate) were planted once each month from December 1979 to December 1980. Plot size was 6 x 7 m and plant population density was equivalent to 6 x 10^5 plants/ha. Five plants were randomly sampled from each plot as soon as the majority of the plants within each plot reached the next growth stage. The total number of rust lesions/plant was counted. Data from a previous sampling was used when leaves were missing (defoliated). Data on temperature, dew period, precipitation, and aerial spore numbers were collected. Temperature data were separated into mean day temperatures (mean of the bi-hourly average from 06:00-20:00) and mean night temperatures (mean of the bi-hourly average from 20:00-06:00 the next morning). Because rust infection requires free moisture, mean daily night temperature was assumed to be more important because of its close association with leaf wetness.

Mean daily night temperatures ranged from 7.1 to 27.1°C; the lowest temperatures occurred from mid-December until early February, and the highest from early June to early September. Low temperatures from mid-December until mid-February affected rust development in both the 1979-80 and 1980-81 periods. Mean night temperatures were 13.9 ±2.59°C and 13.1 ±2.62°C for the December 11, 1979 to February 11, 1980 and December 11, 1980 to February 11, 1981 periods, respectively. Although aerial rust spores were present, no rust lesions were observed until after February 4, 1981 on either cultivar planted on December 1, 1980. When the cultivars were planted either on December 4 or on December 31, 1979, low levels of rust infection were observed. Total lesion number/plant before February 11, 1980 was <400/plant.

Low temperatures after December 11 also affected rust development in both cultivars planted on October 30, 1980. Rust development after December 13 was substantially reduced, but it was not prevented as it was in the December 1, 1980 planting. Casey (1979) reported that mean daily temperatures below 15°C retarded

rust development. However, our data indicate that rust development is substantially reduced or prevented at mean night temperatures below 14°C, which means that reductions in rust development in Taiwan occur at somewhat higher mean daily temperatures than in Casey's study.

High mean night temperature from June 5 to September 5, 1980 (25.5 ±0.86) did not affect rust development. The highest total lesion number/plant (7.6×10^4) occurred on September 4 with cultivar TK 5 (planted on July 1). Dew period did not limit rust development, except possibly in February, June, and early July.

Rust Resistance and Tolerance

While both rate-reducing and race-specific resistance have been reported, no highly resistant cultivars have been developed. Over 9,000 accessions have been evaluated at AVRDC.

Three independent dominant genes for specific resistance have been identified: One each in cultivars PI 200492, PI 492313 (Ankur), and PI 230970 (Hartwig and Bromfield 1983, McLean and Byth 1980, Singh and Thapliyal 1977). Tainung No. 4, PI 459024, PI 459025 - and one G. soja cultivar, PI 339871 - are believed to contain additional specific genes for resistance (Bromfield and Melching 1982, McLean and Byth 1980). An initial differential set of cultivars, including Ankur, PI 200492, PI 230970, and Wayne, has been used (Bromfield 1981).

Recent research at AVRDC indicates the presence of suspected genes for specific resistance in cultivars Tainung No. 4, PI 459024, PI 459025, PI 339871, and TK 5 (TK 5 is one of our susceptible checks). Studies have also shown that more than one gene may be present in PI 339871, and that PI 230970 and PI 230971 may not have the same resistance gene(s).

At least one rust race from Taiwan, Bromfield's Taiwan 80-2A, has the virulence factors necessary for compatibility with all known specific resistance genes (Bromfield 1981). Rust isolates in Taiwan have the virulence factors needed for compatibility with all known or suspected sources of specific resistance, except PI 459025 (Tschanz, unpublished data).

The occurrence of multiple virulence in P. pachyrhizi is unusual because no soybean cultivar or accession is known to possess, or is suspected of possessing, more than two specific resistance genes. The presence of multiple virulence factors in the pathogen population, and the absence of multiple specific resistance genes in a soybean cultivar, indicates that virulence factors are providing a competitive advantage where there is no selective advantage for excess virulence. Therefore, gene deployment techniques will not be effective in controlling soybean rust.

Rate-Reducing Resistance

Rate-reducing resistance is theoretically effective against all races of a pathogen. This is an important consideration, mainly because the rust pathogen has already evolved into complex races with multiple virulence factors.

The influence of plant development on rust development has confounded the evaluation of rate-reducing resistance in soybean cultivars that are segregating for maturity or in lines that have different maturity duration levels.

A new evaluation method has been developed that partially corrects for variations in soybean development (Tschanz and Tsai 1982). This method uses a

linear regression of relative lifetime (RLT) as the time element (rather than days after planting) regressed on the logit transformation of rust severity. RLT is calculated and expressed as a percentage of the soybean life cycle completed on any particular date. It is calculated as follows:

$$RLT = \frac{\text{Days after planting}}{\text{Days to maturity (R8)}} \times 100$$

The rate of rust development, which is often used to determine the level of rate-reducing resistance, is the slope (regression coefficient) of the linear regression. There may also be other correction techniques that will be more effective than RLT, but this requires further study.

The presence of rate-reducing rust resistance has been implicated (Tschanz et al. 1980) and verified (Tschanz et al. 1982). There also appears to be an interaction between the rate of rust development and predicted severity attained when 70% of the soybean RLT has been completed (Tables 3 and 4). A low rate of rust development is not always associated with a low level of predicted rust severity, e.g. cultivars TK 5 and KS 535 in the spring season (Table 3) and cultivars 78-084 and SRE-Z-15C in the fall season (Table 2). The opposite is also true, but the reasons for this interaction are not clear.

Cultivars SRE-Z-11A, SRE-Z-11B, and SRE-Z-15A have consistently low rates of rust development and low predicted rust severities (Tables 3 and 4). These cultivars represent the best available levels of rate-reducing resistance. They are currently being used as parents in AVRDC's soybean improvement program.

Table 3. Rates of rust development and estimated total rust-affected foliage on advanced breeding lines, commercial cultivars, and accessions; planted Feb. 23, 1982, AVRDC.

Cultivar	Rate of Rust Development[z]	Rust Affected Foliage(%)[y]	Cultivar	Rate of Rust Development	Rust Affected Foliage(%)
SRE-Z-15A	0.0998	22.8	TN 15	0.1245	26.7
SRE-Z-11B (AGS 182)	0.1014	18.6	KS-741	0.1250	35.9
Shih-shih[x]	0.1069	23.6	78-067	0.1252	32.1
SRE-Z-11A (AGS 181)	0.1083	34.9	SRE-Z-15C	0.1267	18.5
TK 5	0.1113	40.3	KS-8	0.2376	30.6
SRE-A-16	0.1126	20.4	G 5524	0.1293	16.6
KS-535	0.1154	32.5	78-084	0.1299	26.4
Hua-78-28	0.1163	28.3	AGS-66	0.1311	21.7
AGS 62	0.1210	16.2	TN 4	0.1358	30.6
AGS 129	0.1214	26.9	SRE-Z-13 (AGS 183)	0.1390	27.2

[z] Regression coefficient of the correlation between total rust affected foliage (rust affected foliage + defoliation) and relative life time (DAP ÷ Days to R8 x 100)
[y] Estimated total rust affected foliage (rust affected foliage + defoliation) when 70% of the soybean life cycle is completed
[x] Check cultivar

Tolerance to Soybean Rust

The difficulties associated with the identification and quantification of rate-reducing resistance and the ineffectiveness of race-specific resistance has prompted AVRDC to develop new methods for improving the yield of rust-affected soybean cultivars. This includes the use of tolerance to soybean rust, with tolerance defined as the relative yielding ability of soybeans affected by rust.

Recent studies have identified tolerance to rust and the existence of significant variations in levels of tolerance among cultivars (Tschanz and Tsai 1983). Grain yields in the spring of 1982 (no fungicide protection) ranged from 0.18 to 1.33 t/ha, with yield losses ranging from 48.0 to 91.3% (Table 5). In the 1982 fall season, yields of the same 20 cultivars (without fungicide) ranged from 0.22 to 0.93 t/ha; yield losses ranged from 57.7 to 90.2%. The yield increase of the most tolerant cultivar, over the best check cultivar, was 22% in the spring and 59% in the fall.

Table 4. Rates of rust development and estimated total rust affected foliage on advanced breeding lines, commercial cultivars, and accessions; planted Sept. 29, 1982, AVRDC.

Cultivar	Rate of Rust Development[z]	Rust Affected Foliage(%)[y]	Cultivar	Rate of Rust Development	Rust Affected Foliage(%)
SRE-Z-11B (AGS 182)	0.1080	42.2	AGS 66	0.1480	47.1
78-084	0.1182	54.9	KS 535	0.1481	60.8
SRE-Z-11A (AGS 181)	0.1198	39.8	Hua 78-28	0.1497	59.0
SRE-Z-15A	0.1233	43.1	KS-741	0.1504	56.2
SRE-Z-15C	0.1243	51.1	TN 4	0.1509	56.7
TN 15	0.1261	45.5	AGS 62	0.1552	40.8
SRE-A-16	0.1281	52.2	78-067	0.1560	69.4
Shih-shih[x]	0.1317	50.3	SRE-Z-13 (AGS 183)	0.1586	64.9
TK 5	0.1449	66.8	G 5524	0.1629	49.3
KS-8	0.1449	71.0	AGS 129	0.1632	48.3

[z] Regression coefficient of the correlation between total rust affected foliage (rust affected foliage + defoliation) and relative life time (DAP ÷ Date R8 x 100)
[y] Estimated total rust affected foliage (rust affected foliage + defoliation) when 70% the soybean life cycle is completed
[x] Check cultivar

Table 5. Selective comparisons of yield and yield loss from 20 cultivars grown under fungicide- and non-fungicide-protected conditions during severe soybean rust epidemics at AVRDC, spring and fall, 1982.

Cultivar	Yield (t/ha) fungicide protected	Yield (t/ha) non-fungicide protected	% Yield Loss
Lowest yield loss, highest yield with rust:			
SRE-Z-11A	2.34[z](2.33)[y]	1.21 (0.93)	48.0 (57.7)
SRE-Z-11B	2.58 (2.11)	1.33 (0.84)	48.1 (60.2)
Highest yield loss, lowest yield with rust:			
78-067	2.17 (2.27)	0.20 (0.22)	90.8 (90.2)
TK 5	2.12 (2.42)	0.18 (0.28)	91.3 (88.5)
Check cultivars:			
Shih-shih	2.70 (2.47)	1.09 (0.59)	59.4 (76.1)
AGS 129	3.29 (2.74)	0.72 (0.55)	78.2 (79.6)
Mean for all cultivars:			
	2.73 (2.42)	0.80 (0.61)	70.0 (74.3)

[z] Experiment planted February 23, 1982
[y] Data in parenthesis are for the fall crop planted September 29, 1982

No correlation was found between yield in the fungicide-protected and the non-fungicide-protected treatments. This was substantiated by the highly significant interaction found between the cultivar and fungicide treatments (analysis of variance). Therefore, the selection of lines for high yield under fungicide-protected conditions may not guarantee high yield under non-fungicide-protected conditions. Selection for yielding ability under rust stress should not prevent later identification of high yielding lines under low or non-rust stress conditions.

The variation in rust tolerance can be readily exploited. Yielding ability can be more easily and accurately assessed and related to tolerance than disease severity can be assessed and related to resistance.

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Differential Reactions of *Phakopsora pachyrhizi* on Soybean in Taiwan

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Introduction

Yeh (1981) reported the presence of Phakopsora pachyrhizi, the causal organism of soybean rust, on 87 hosts. Host differences, in terms of their reaction to infection, suggest the presence of different races (Chan 1977, Singh 1977, Vakili 1978). Lin (1966) showed that the P. pachyrhizi derived from soybean varies in its pathogenicity and virulence among non-soybean hosts. Two races were observed (but not confirmed) at the Asian Vegetable Research and Development Center (Yang et al. 1974). Two infection types found on soybean leaves were believed to be different races (Bromfield 1979, Shanmugasundaram 1980, Shanmugasundaram et al. 1980). Bromfield (1981) also reported the identification of four races on the basis of differential reactions from cultivars Wayne, PI 200492, Ankur, and PI 230970.

The uredospores used by Bromfield were collected with cotton swabs and maintained in a glasshouse on the leaves of cultivar Wayne. The author (unpublished) observed two lesion types identified in Bromfield's study on the leaves of cultivars PI 200492, PI 230970, TK 5, and Shih-Shih that were inoculated with uredospores obtained from soybean plants at the Taiwan Agricultural Research Institute (TARI). Five soybean cultivars and seven legume species were inoculated with 50 single-uredial cultures of P. pachyrhizi to study the rust races found in Taiwan.

Materials and Methods

Crops Tested

The following crops were grown in pots with a pasteurized sandy loam soil: common bean (Phaseolus vulgaris [cv. 5-inch]), cowpea (Vigna unguiculata [cv. Early Ramshorn]), hyacinth bean (Lablab purpureus [local cv.]), lima bean (Phaeseolus lunatus [local cv.]), mungbean (Vigna radiata [local cv.]), pigeon pea (Cajanus cajan [local cv.]), yam bean (Pachyrhizus erosus [local cv.]), and soybean (Glycine max [cvs. Ankur, Taita Kaohsiung 5 - TK 5, Tainung 4 - TN 4, Shih-Shih, PI 200492, and PI 230791]).

Collection and Purification of Inoculum M

Phakopsora pachyrhizi-infected soybean leaves were collected from cultivar TN 4 at TARI, from cultivar TK 5 at AVRDC, and from Shih-Shih in Pingtung, Hualien, and Taitung counties (Fig. 1).

The leaves were gently washed with running tap water, blotted with absorbent tissue to remove excess moisture and old uredospores, and then sealed in transparent plastic bags. Freshly produced uredospores were obtained after the leaves were exposed to room temperatures (20-30°C) for 24 to 48 hr.

Leaves of the same cultivars from which the fungi were originally collected were detached from non-inoculated glasshouse-grown plants, and then washed, blotted, and placed with the lower surface up in sterile culture plates (9 cm) containing a layer of cotton in the bottom and covered with filter paper (Whatman No. 1) saturated with distilled water. The leaves were sprayed with a freshly produced suspension of uredospores (ca. 5,000 spores/ml) distilled water, and Tween 80 (ca. 80 µg/ml). The plates were placed next to a window and exposed to room temperatures.

Two weeks later, ten single uredia from each of the five collections were randomly selected; the uredospores were removed separately from each uredium using a separate, sterile camel hair brush. Uredospores of the 50 isolates were inoculated and maintained on detached leaves of the original cultivars until sufficient uredospores were available for testing.

Inoculation

Intact plants were inoculated in their original pots; detached leaves were inoculated separately with a uredospore suspension (ca. 20,000 spores/ml) obtained from each of the 50 single uredial isolates. The inoculated, intact plants were removed from a moist chamber after 24 hr and kept in a glasshouse (20-31°C) for observation. The detached leaves were placed on a bench in the laboratory. The lesion types were recorded two weeks after inoculation.

Results and Discussion

Two different infection types, TAN and reddish-brown (RB) (Bromfield 1979, Shanmugasundaram et al. 1980) were observed 14 days after inoculation. TAN-type lesions sporulated profusely in most cases (3 to 5 uredia/lesion). RB-type lesions produced less uredospores (0 to 2 uredia/lesion). This is the first report in which an inoculum of each isolate was multiplied from a single uredium. Contrary to other reports, no mixed lesions were observed (Fig. 2) (Shanmugasundaram et al. 1980 and the author [unpublished]).

Three races of P. pachyrhizi were identified on the basis of the differential reactions of the five soybean cultivars. Race 1 produced TAN-type lesions on all soybean cultivars tested; Race 2 produced RB-type lesions on PI 230971 and TAN-type lesions on Ankur, TN 4, TK 5, and PI 200492; Race 3 produced TAN-type lesions on PI 200492 and RB-type lesions on the remaining cultivars (Table 1 and Fig. 2). All 50 uredial isolates produced TAN-type lesions on common bean and yam bean; RB-type lesions were produced on cowpea, hyacinth bean, lima bean, and pigeon pea. Because different lesion types were not observed on these species, their use as differentials is not recommended. However, they have produced different reactions in other studies (Poonpolgul and Surin 1980, Vakili 1978), and may therefore be useful in the future.

A combination of soybean cultivar PI 230971 plus TK 5, TN 4, or Ankur should be used to identify the three races. However, considering the limited number of samples in this study, and the observation of different reaction types on three other soybean cultivars (Chan 1977, Singh 1977), all five soybean cultivars are tentatively suggested as differentials.

The distribution of the three races varied with location. Race 1 was common at AVRDC and Race 2 was present at TARI and in Taitung County. Races 1 and 2 were present in equal amounts at Pingtung; only two isolates of Race 3 were obtained in Hualien (Table 2 and Fig. 1). If collections are made at different locations, and in different years, additional races might be identified.

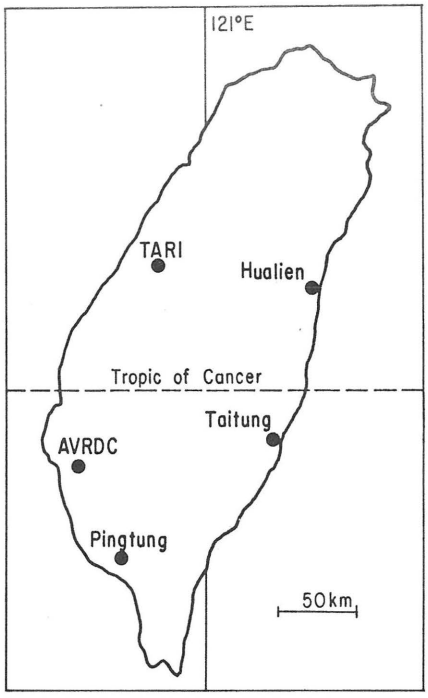

Fig. 1.
Phakopsora pachyrhizi collection sites in Taiwan.

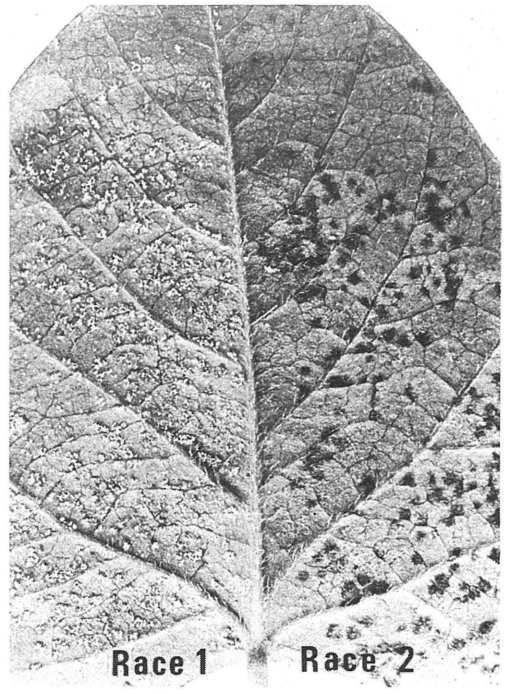

Fig. 2.
TAN (left) and RB (reddish-brown) (right) type lesions caused by Race 1 and 2, respectively, on PI 230971.

Table 1. Reaction of the three races of Phakopsora pachyrhizi on five soybean cultivars.

Cultivar	Race		
	1	2	3
Ankur	TAN[z]	TAN	RB
TN 4	TAN	TAN	RB
TK 5	TAN	TAN	RB
PI 230971	TAN	RB	RB
PI 200492	TAN	TAN	TAN

[z] Lesion type: TAN = tan color lesion
RB = reddish-brown lesion

Table 2. Distribution of the 50 single uredial isolates of Phakopsora pachyrhizi collected at five locations in Taiwan.

Location	Race		
	1	2	3
TARI	2	8	0
AVRDC	9	1	0
Pingtung	5	5	0
Taitung	0	10	0
Hualien	0	8	2

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Soybean Disease Control Strategies for the Tropics and Subtropics

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Introduction

All parts of the soybean (Glycine max) plant are susceptible to diseases. More than 100 pathogens are known to affect soybean, 35 of which are of economical importance. The extent of loss depends on the pathogens involved, the state of plant development when infection occurs, the number of plants infected, and the severity of the disease on individual plants.

Pathogen(s) may be destructive one season and difficult or impossible to find the next. Many require specific environmental conditions to initiate an epidemic. The extent and severity of disease depend on the degree of compatibility between the host and the pathogen and the influence of the environment on this association - the classical disease triangle.

Insects and other vectors are involved in the transmission of viruses; others predispose the pods and seeds to invasions by micro-organisms. Nematodes, arthropods, and insect feeding can produce entry wounds that expose soybean to root-rotting or wilt-inducing agents.

Comprehensive disease management programs should include the following: 1) careful diagnosis; 2) adapted disease resistant or tolerant cultivars, or cultivars with a tendency to escape infection; 3) high-quality seed; 4) fungicide seed treatment, if necessary; 5) nematicides, if necessary; 6) selected planting dates; 7) crop rotation and conservative tillage; 8) balanced fertility and water managment; 9) weed and insect control; and 10) fungicide sprays, if necessary.

Disease Control Strategies

Disease Diagnosis

Diagnosis is an essential part of a disease control strategy because more than one pathogen - and possibly a complex or sequence of pathogens - may be responsible for yield losses and seed quality deterioration.

Many countries have publications that help farmers and extension agents to identify soybean diseases. The most comprehensive one is published by the American Phytopathological Society (Sinclair 1982a).

Cerkauskas and Sinclair (1980) reported the development of a technique for inducing fungal pathogens that cause latent infections. Pods or stem pieces are surface-disinfected with a 1.3% sodium hypochlorite solution (commercial bleach) and are then dipped for 10 seconds in a 1:20 dilution of water and a commercial formulation of paraquat (1, 1'-dimethyl-4, 4'bipyridinium ion) or glyphosate [N-(phosphonomethyl) glycine]. Treated tissues are incubated in a moist chamber for seven days at room temperature and are then examined under a dissecting microscope for acervuli of Colletotrichum and pycnidia of Phomopsis. Other fungi, such as Cercospora spp., may also be detected.

A computer-based advisory system for diagnosing soybean diseases has been developed (Michalski et al. 1983).

Adapted Cultivars

Resistant or tolerant cultivars are the most economical and efficient way of controlling diseases. However, because of soybean's photoperiodic requirements, resistance may not be available in all maturity groups. Some pathogens exist in several races, e.g. downy mildew (Peronospora manshurica), frogeye leafspot (Cercospora sojina), and rust (Phakopsora pachyrhizi). Others, such as soybean mosaic virus and brown stem rot (Phialophora gregata), exist in both mild and severe strains. Sources of resistance to soybean diseases have been summarized for selected pathogens (Tisselli et al. 1980). Additional cultivars or selections may be available locally.

Seed

Fully formed, undamaged, and relatively pathogen-free seed is a prerequisite for reducing losses caused by adverse conditions and diseases (Yorinori et al. 1980). Planting high-quality seed at proper spacings and depths in a well-drained, but moist and fertile seedbed (>20°C) may also benefit the crop (Sinclair and Jackobs 1981). In the tropics and subtropics, where soil temperatures can exceed 30°C at planting, stand establishment problems have been linked to bacteria such as Bacillus subtilis (Ellis et al. 1977, Schiller et al. 1977, Tenne et al. 1977). Mulching can help prevent losses by lowering soil temperatures.

Good seed can be separated from poor seed by screening, forced air, or by floatation. A mixture of glycerin and polyethyleneglycol 400 (60/40) can be used for the latter (Hepperly and Sinclair 1982).

Seed Treatment

Seed treatments have little or no effect on high quality seed, except when the seed is subjected to stress. Seed treatments protect seed and seedlings from many seed- and soil-borne pathogens and help to preserve the germination potential of poor-quality seed subjected to fungi. Seed treatment is required if the seed is planted in soils under 20°C, if a delay in emergence is expected, or if the seed is planted for multiplication purposes. Seed treatment does not affect old or damaged seed. Treated seed should be safely stored and never used for food, feed, or oil production (Sinclair 1982b).

Several fungicides and fungicide combinations are registered with the United States Environmental Protection Agency for use as soybean seed treatments: Captan, captan + hexachlorobenzene (HCB), captan + HCB + maneb, captan + maneb, captan + pentachloronitrobenzene (PCNB), captan + thiram, carboxin + thiram, mancozeb + maneb, maneb + HCB, PCNB + etridiazol (formerly ethazol) (5-ethoxy-3-(trichloromethyl)-1,2,4-thiazole), TCMTB, and thiram.

To avoid damaging Rhizobium inoculum, seed should be treated just prior to planting. Furthermore, soil moisture should be maintained and inoculum doses should be calculated at a slightly higher rate than is ordinarily recommended (Agarwal and Sinclair 1981).

Nematicides

Nematicides are costly and their performance may be erratic if not properly applied or if adequate moisture is not available. They should be used only for

severe infestations, when resistant or tolerant cultivars are unavailable, or if management practices are unable to reduce losses (Sinclair 1982a).

Planting Date

The adjustment of planting schedules can help the crop to mature during a low rainfall period, which, in turn, reduces the plant's contact with seed-borne fungi, e.g. Colletotrichum truncatum, the causal organism of anthracnose (Fig. 1) (Nicholson and Sinclair 1973). Although this technique may result in lower seed yields, compared with crops produced during the rainy season, seed quality is usually enhanced.

Crop Rotation and Conservative Tillage

Tillage practices and rotations vary according to location and soil type. Soybean can be used in many areas as a rotation crop. Although a large number of fungal and bacterial pathogens survive on or in crop debris, decay is more rapid in the tropics than in temperate regions (Sinclair 1982a). Generally, soybean should not be planted immediately after soybean.

Balanced Fertility and Water Management

Susceptibility to pathogens increases in stressed plants. To reduce losses due to abiotic diseases (mineral toxicities and deficiencies) and biotic diseases, soybean should be grown under adequate, balanced fertility and with a near neutral pH.

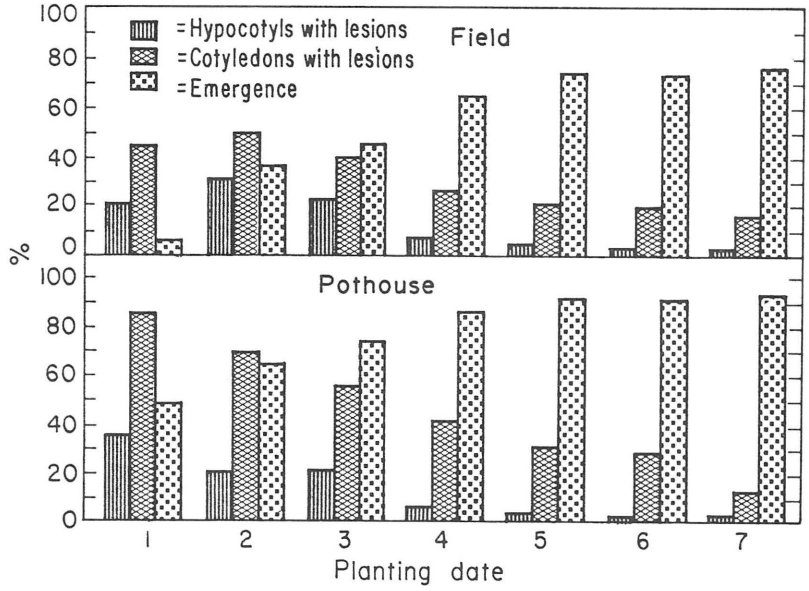

Fig. 1. Effect of seven planting dates (1 = June 1, 2 = June 16, 3 = July 1, 4 = July 16, 5 = July 31, 6 = August 14, and 7 = September 2) on the occurrence of seed-borne Colletotrichum truncatum in five soybean cultivars (Bragg, Davis, Lee, JB-2, and Pb-1) and the effect of lesions developing from the infected cotyledons. Percentages are based on 1000 and 2000 seeds/planting date for pothouse and field trials, respectively. The LSD at P = 0.05 for field emergence, cotyledons with lesions, and hypocotyls with lesions was 9.2, 9.9 and 4.8, respectively; and for pothouse, 10.9, 12.6, and 5.7, respectively.

Water management strategies vary according to soil type and location, and with the diseases found in a given location (Judy and Jackobs 1981). Irrigation can be used to regulate soil moisture and thereby influence soil-borne pathogens such as Marophomina phaseolina, the causal agent of charcoal rot (Sinclair 1982a).

Weed and Insect Control

Weeds are common hosts of disease pathogens (e.g. Colletotrichum and Phomopsis), nematodes (e.g. root-knot and sting), and viruses (e.g. bean pod mottle, soybean mosaic, and tobacco ringspot) (Hepperly et al. 1980, Cerkauskas et al. 1983, Sinclair 1982a). Soybean is more susceptible to diseases when grown under weed or insect stress. Insect control can minimize stress and reduce the injuries that pathogens use to enter the plant; it can also limit the spread of viruses.

Fungicide Sprays

Fungicides have been used in the tropics to control soybean rust (Table 1) (Ford and Sinclair 1977) and Septoria brown spot (Septoria glycines) (Sinclair 1982b, 1983). Many farmers in the subtropics of Brazil and the USA use foliar fungicides to control foliage and stem diseases. Fungicide sprays are also used in the subtropical USA to control seed-borne fungi.

Table 1. Fungicides used as sprays for the control of soybean rust and the locations in which they were tested.

Fungicide[z]	Location
Benomyl	India, Taiwan
Captafol	India
Copper (Bordeaux mixture)	Taiwan
Dichlone	Taiwan
Dinocap	Taiwan
Lime-sulphur	Japan
Mancozeb	India, Taiwan
Maneb + wettable sulphur	Taiwan
o-methylbenzoic acid acetate	Taiwan
Oxycarboxin	India, Taiwan, Thailand
Oxycarboxin + benomyl	Thailand
Triphenol tin chloride	India
Zineb	India, Taiwan
Zineb + wettable sulphur	Taiwan

[z] Not an endorsement or recommendation
Source: Ford and Sinclair (1977)

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The Beanfly Pest Complex of Tropical Soybean

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Introduction

Of all the insect pests that infest soybean (Glycine max) in the tropics and subtropics, Agromyzids - beanflies - are the most destructive. Eight species have been reported: Ophiomyia phaseoli, O. centrosematis, O. shibatsuji, Melanagromyza sojae, M. dolichostigma, M. koizumii, M. vignalis, and Japanagromyza tristella.

O. phaseoli, O. centrosematis, M. sojae, and M. dolichostigma are the most destructive species in tropical Asia. The first three feed mainly in the stems of young seedlings, whereas M. dolichostigma feeds in the young shoots (four weeks or older). In Indonesia, Thailand, and Vietnam beanfly infestation, especially O. phaseoli, can result in losses of up to 100%.

Beanflies are found in most tropical areas, but damage is generally higher in latitudes closer to the equator. The insects feed on a wide variety of cultivated and wild legume crops.

Taxonomy and Identification

The identification and nomenclature of agromyzid flies was unclear until the publication of Spencer's (1973) monograph.

All adult beanfly species have a similar appearance. The key identification criteria are the location of larval feeding sites in the host plants and the shape and size of the insects' anterior and posterior larval and pupal spiracles.

O. phaseoli

The larva has small anterior spiracles that consist of a circle of six minute bulbs. Posterior spiracles are closely adjoined and rise on a conical projection with about 10 bulbs (Fig. 1). The puparium is pale yellow (straw colored) or brown, and 3 mm in length. The major feeding and pupation site is the main stem between the outer epidermis and the cortex.

O. centrosematis

The larva has anterior spiracles on long black stalks and posterior spiracles on short stalks, each with three bulbs (Fig. 1). The puparium is yellow or red-orange. Major feeding and pupation sites are located on the main stem between the outer epidermis and the cortex.

M. sojae

The larva has short, knob-like anterior spiracles with eight minute pores. Posterior spiracles are distinctly separate, and they normally consist of six raised pores around a central truncated horn (Fig. 1). The puparium has a

yellow-brown color. The insect's major feeding and pupation sites are located in the pith of the main stem.

M. dolichostigma

Larval anterior spiracles are unusually long, and have 12 minute pores. Posterior spiracles are shorter, and contain about 15 pores (Fig. 1). The puparium is oval, yellow-brown in color, and 2.5 mm long. The major feeding and pupation sites are the young shoots of 4-week-old plants.

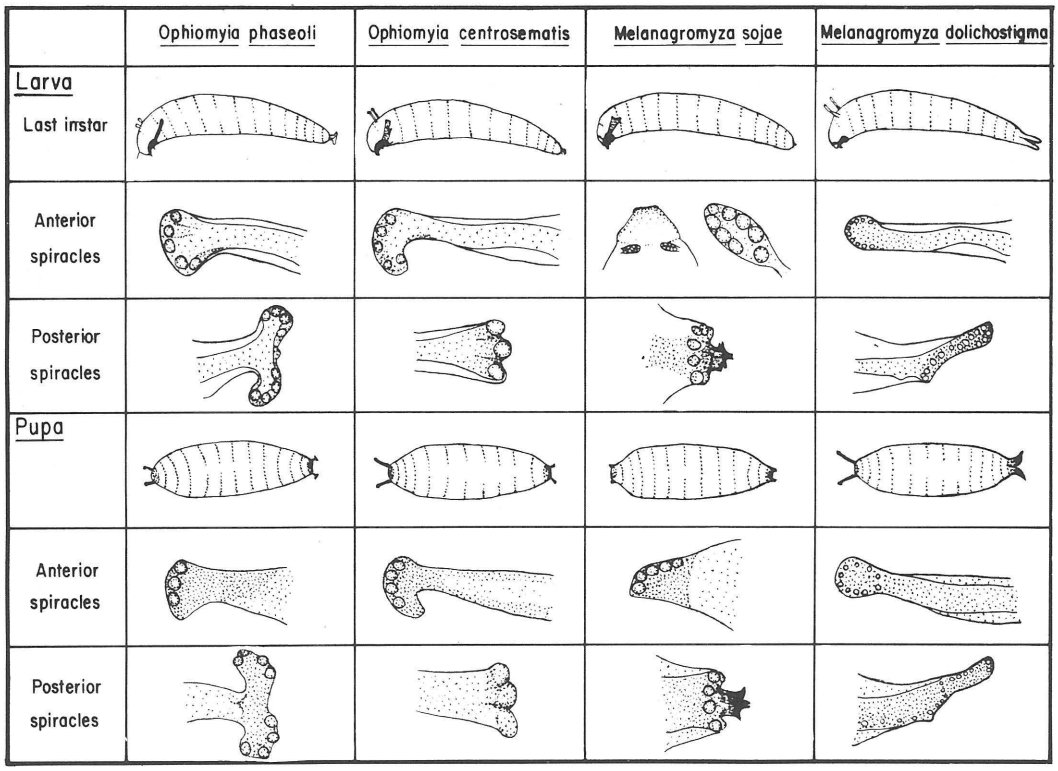


Fig. 1. Morphological characteristics of four beanfly species.

Biology

O. phaseoli

Oviposition takes place in young leaves, both on the upper and lower surfaces (Greathead 1968, Ali 1957). In Indonesia, the insect also lays eggs in soybean cotyledons (van der Goot 1930) (Fig. 2). A single female can lay up to 300 eggs in a 2-week period (Otanes 1918, Raros 1975). The eggs hatch in two to four days. The larvae form a short leaf mine, but then enter the nearest vein and proceed into the petiole and down into the stem. Larval tunnels in the cotyledons are intially directed towards the apex, and later follow an irregular course before reaching the leaf base (van der Goot 1930). In young plants, most feeding takes place in the lower cortical layers of the stem, but some larvae penetrate into the tap root. With heavy infestations, the larvae feed deep inside the stem, as well as higher up on the plant. The larval stage lasts for ten days, and the pupal stage lasts an additional nine or ten days. Both periods

are shorter under higher temperatures or longer under lower temperatures. In Zimbabwe the complete life cycle can take as little as three weeks when temperatures are high (Taylor 1958). In the Indonesian highlands, the larval stage can last from 17 to 22 days, and the pupal period can take as long as 13 to 20 days (van der Goot 1930). Hassan (1947) reported that the life cycle in Egypt can be completed in 17 days. The puparium remains beneath the epidermis, normally near the base of the stem (Greathead 1968).

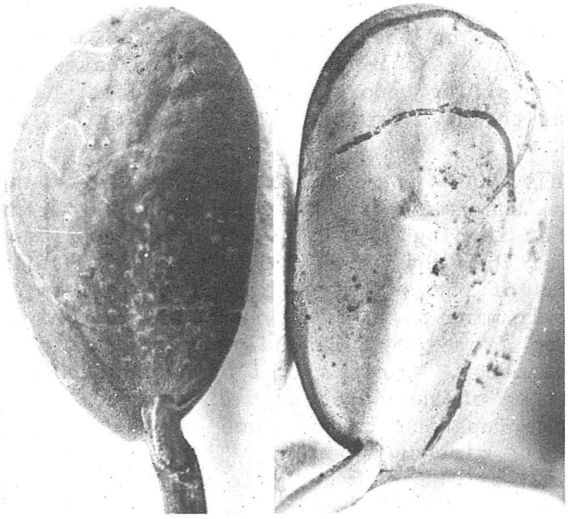


Fig. 2.
Ophiomyia phaeseoli feeding/oviposition punctures and feeding mines on the upper (left) and lower (right) surfaces of soybean cotyledons in Indonesia.

O. centrosematis

Greathead (1968), working in East Africa, showed that oviposition takes place not in the leaves, but in the hypocotyl and stem. Similar oviposition habit was found at AVRDC, but elsewhere in Taiwan Lee (1976) found that the eggs are laid in soybean leaf tissue. The larvae feed just beneath the epidermis of the stem and in part of the tap root. No larvae were found feeding within the pith of the main stem or roots (Lee 1976). The larva pupates just beneath the epidermis. In most cases, the anterior spiracles of the pupae pierce the dry epidermis and project outward. In the laboratory, development time from egg to adult was 30 days at a mean temperature of 21°C (Greathead 1968).

M. sojae

Oviposition takes place exclusively in the leaves. The first trifoliolate leaves are preferred (van der Goot 1930), and the eggs are always laid on the underside of the leaf in the mesophyll tissue. Numerous feeding punctures, however, are made on the upper side of the leaves. The eggs are most frequently laid near the base of the leaf, but can be found elsewhere in the leaf blade (always near the leaf vein) (Spencer 1973). Wang (1979) reported that the female lays an average of 171 eggs (range of 41 to 275 eggs/lifetime).

The larva hatches after two or three days, immediately bores into the nearest vein, and continues feeding through the petiole into the stem. It then feeds internally in the pith, bores down to the root, and then again feeds upwards until it is fully grown. It pupates in the stem, but first mines a hole to the epidermis to assist in the emergence of the adult. Normally only one larva completes its development in a younger plant, although two puparia have been found upon occasion (Spencer 1973).

Larval feeding lasts from 9 to 11 days, while the pupal stage requires 9 or 10 days; the entire life cycle lasts from 16 to 26 days. Females normally mate within five days of emergence. In the laboratory, males fed on water barely lived from 10 to 46 days; females lived from 15 to 36 days (Spencer 1973).

M. dolichostigma

Eggs are laid exclusively on the underside of the leaves and are frequently not inserted into the leaf tissue, but are merely deposited on the surface (van der Goot 1930). Feeding punctures are made on the upper side of the leaves. Three or four eggs may be laid together on a single leaf. Unfolded leaves are usually selected to prevent the eggs from falling before the larva hatches; hairs on the underside of the leaf also prevent the eggs from falling.

After hatching, the larva immediately eats its way into the leaf tissue and the nearest vein, and then moves into the stem via the petiole. It feeds initially on the outer layers, and, after feeding down the stem for 2 or 3 cm, turns and feeds upwards eating ever deeper into the pith. This produces a cavity that is covered only by the outer layers of the stem tissue and the epidermis. Lee (1976) reported that the larvae quickly mine to the stem apex after hatching, working their way down about 2 to 5 cm from the tip, and then start mining beneath the stem surface in a spiral direction. These spiral mines disturb the vascular tissue and result in the withering of the upper part of the stem. The larvae then feed in the withering tip. Pupation takes place in the damaged shoot, which dries and easily breaks by the time of pupation. The larvae do not make exit holes. As a rule only one maggot is found in a single damaged shoot.

The eggs hatch in about two days when average temperatures are about 28°C; the larval and pupal stages last about nine and six to eight days, respectively (at 25.5°C) (Lee 1976).

Ecology

In an on-going study of the seasonality of O. phaseoli, O. centrosematis, and M. sojae in southern Taiwan, soybean was planted once every two weeks over a six-year period. The incidence of the three species was observed by sampling four-week-old plants once every two weeks (Talekar and Chen 1983). The results showed that agromyzid flies infest soybean practically throughout the year, but that infestation is most severe during the dry season (October - December). Almost all plants are damaged by the stem-feeding flies from October through December (Fig. 3). Lee (1976) in Taiwan and Kwon et al. (1980) in South Korea also observed heavy Malanagromyza infestation in the autumn season. Van der Goot (1930) reported greater infestation (O. phaseoli, M. sojae, and M. dolichostigma in the dry season than in the wet season. The most likely explanation is that rainfall physically prevents feeding and oviposition. In Taiwan, although the dry season extends through April, insect infestation is considerably reduced in February and March, probably because of relatively cool temperatures from December through February. Abul-Nasr and Assem (1968) in Egypt and Morgan (1938) in Australia observed a reduction in beanfly infestation on crops planted during the winter months. Agarwal and Pandey (1961) found decreased O. phaseoli larval populations from the third week of December through the second week of February in northern India. They implied that the reduction was due to the presence of cooler weather when most of the larvae entered the pupal stage and became inactive. They also found reduced larval populations in May and June, a phenomenon which was attributed to extreme hot, dry weather, during which time the eggs failed to hatch and the flies survived as adults.

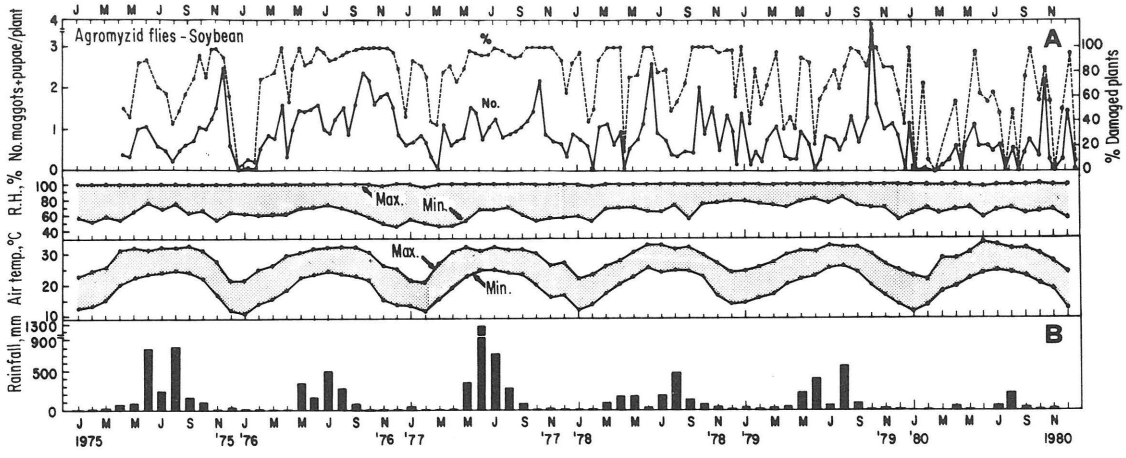


Fig. 3. Seasonality of beanflies, O. phaeseoli, O. centrosematis, and M. sojae (A), and temperature, relative humidity, and rainfall (B), 1975-80 at AVRDC. Source: Talekar and Chen (1983).

Damage

Adult Feeding

The female flies, with the help of their ovipositors, puncture newly emerged leaves. In the case of O. phaseoli, the most prevalent strain in Indonesia, punctures are also made on soybean cotyledons. There are two types of punctures: Oviposition punctures and feeding punctures. Soon after the holes are made, the adult feeds on the sap that bleeds from the plant. Feeding on the sap that bleeds from ovipositional punctures is incidental to oviposition. The punctures create small, yellow, translucent, sunken windows in the leaf epidermis. This injury, however, does not significantly damage the plant.

Larval Feeding

Major damage (reductions in plant growth and yield) results from the feeding of the beanfly larvae, especially on stem tissues.

Feeding Sites

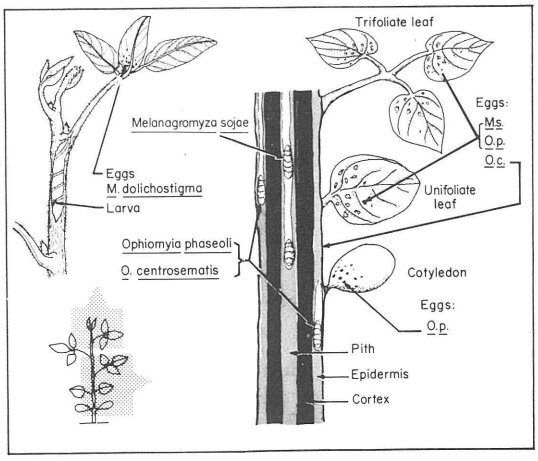
The larvae of the four beanfly species have distinct feeding sites (Fig. 4). O. phaseoli and O. centrosematis feed just beneath the stem epidermis up to the cortex. O. phaseoli feed and subsequently pupate in the main stem. O. centrosematis feeding can extend down to main root (Lee 1976). M. sojae feeds and pupates in the pith. All three species prefer young plants (cotyledons and early trifoliolate leaves). M. dolichostigma, on the other hand, feeds on the terminal parts of young growing shoots when the plants are at least three weeks old.

Critical Damage Period

The importance of beanflies in the tropics lies in the fact that all species, especially those that feed in the main stem, prefer young plants. A biotype of O. phaseoli in Indonesia, for example, lays eggs in the cotyledons and kills the plants, presumably because of early infestation.

The critical protection period, especially for M. sojae, is about three to four weeks after germination (AVRDC 1979). Omethoate, an insecticide which is effective against beanflies, was sprayed once a week - for 9 weeks - beginning four days after germination. Infestation was monitored in 30 plant samples/plots at three and five weeks; yield was recorded at harvest. Seed yield increased with each of the first three sprays, but did not increase thereafter (Fig. 5). Because spraying was initiated when the plants were four days old, the critical period for beanfly protection would be about four weeks after germination.

M. dolichostigma infestation begins when the soybean plants are three to four week old, and the damage is visible two weeks later. By that time the plant is well established and is growing exponentially. M. dolichostigma prefers to infest luxuriously growing plants, and therefore does not cause significant yield losses (van der Goot 1930).



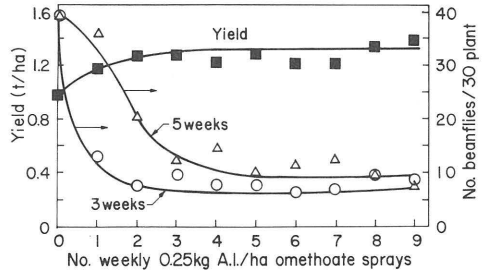


Fig. 4. (left)
Oviposition, feeding, and pupation sites of various beanfly species in soybean.
Fig. 5. (above)
Beanfly control and yield response of soybean to omethoate applications at various intervals.

Damage Characteristics

The nature of the damage caused by O. phaseoli and O. centrosematis is practically identical, except that it is uncertain whether the latter insect lays its eggs in soybean cotyledons. Soybean is the least preferred host of O. phaseoli in the Philippines (Otanes 1918, Rajesus 1976) and Taiwan (Lee 1976, Chiang and Talekar 1980). However, it is particularly destructive in Indonesia (van der Goot 1930).

The larval mines on the cotyledons and unifoliate leaves are initially silver-white, but eventually turn brown. The tunnels extend into the petiole and stem. In slightly older plants the feeding tunnels on the stem are visible as black strips. When cut open, the larvae are found feeding just underneath the epidermis (van der Goot 1930). The number of larvae within each plant varies, but up to 31 were found in one 3-week-old plant at Palembang, Indonesia. As a result of infestation during the cotyledon stage, the plants succumb to the injury within a month after germination. The stronger plants can form new roots above the damaged parts, especially during the rainy season, while slightly damaged ones usually grow through the infestation without noticeable reductions in growth.

M. sojae is a pith feeder, and its damage in the stem is not visible except for a tiny exit hole which the adult uses to escapes after the damage has already occurred. Feeding tunnels with larvae or pupae can be seen when the stems are cut open. Two separate tunnels are often present in slightly older, damaged

plants. Tunnels in the lower halves of the plants are older and are dark-brown in color. They originate roughly at the junction of the unifoliate leaf and extend downward to the soil surface, indicating that infestation results from eggs laid earlier in the unifoliate leaf. The second tunnel starts just under the top of the plant and extends downward to the first tunnel. In the event that the unifoliate leaf escapes infestation, the tunnel can extend up to the soil surface. This type of feeding occurs because of later infestation of the trifoliolate leaves. If the plant is damaged early, the later-infesting larvae may not have enough pith tissue to feed. In that case, the larvae gnaw upward, and produces a cavity in the top of the plant that results in the withering of the top; the lower part of the plant continues to grow.

Due to M. sojae's concealed feeding habit, its damage usually goes unnoticed. However, in controlled experiments where beanfly-free and infested plants are raised side by side, damage in the form of reduced plant growth is clearly visible. At AVRDC, one plot was maintained practically insect-free by applying insecticides near beanfly-infested plants. Observations of various plant characteristics were made soon after pod-set and at the onset of podborer infestation. M. sojae infestation significantly reduced plant height, number of branches/plant, number of trifoliolate leaves, leaf area/plant, and dry matter accumulation (Talekar 1980) (Table 1). The trifoliolate leaves of the infested plants were smaller than those of the insect-free plants.

The most characteristic signs of M. dolichostigma damage is wilting of the growing tip or tip withering. If tips are carefully examined, a spiral-shaped mine can be observed around the stem, 3 to 5 cm beneath the surface. The number of circles in the spiral varies from three to six; in rare cases the mine is neatly coiled but irregular in appearance. As the shoot wilts, the mine becomes increasingly inconspicuous (Lee 1976). As a result of the damage, the growing tip and plant growth is checked until the auxillary buds in the lower nodes develop into branches. This leads to abnormal branching in younger plants.

Table 1. Effect of beanfly (M. sojae) infestation on certain characters of soybean cv. GC 30067-0-8.

Plant Characteristics	Beanfly Protected[z]	Beanfly Infested
No. branches/plant	2.6**	1.2
Plant height (cm)	51.9**	41.8
No. trifoliolate leaves/plant	12.3**	9.0
Leaf area (cm^2/plant)	1093.9**	423.8
Leaf area (cm^2/trifoliolate leaf)	89.3**	47.1

[z] Plants were protected from beanfly infestation by frequent sprays of omethoate 50 EC. Damaged plants in protected area 6%; in infested area 99%

** Difference between beanfly-protected and beanfly-infested significant the at 1% level by the student t test.

Yield Loss

Total plant destruction usually occurs when O. phaseoli infests soybean, especially in the cotyledon stage. Van der Goot (1930) observed up to 100% plant mortality when the pest attacked seedlings. Up to 90% mortality has been recorded in Thailand. If infestation starts in the late seedling stage, yield losses in excess of 50% can be expected (Sepswasdi 1976).

M. sojae infests soybean in the unifoliate and early trifoliolate leaf stages, but infestation rarely results in plant death. Yield loss varies accord-

ing to location. In Taiwan, the loss among 163 soybean accessions was 31% (AVRDC 1981). Bhattacharjee (1980) reported that all but 5 of the 782 plants tested were attacked. He found a highly significant negative correlation between stem length injury and yield and stem length injury and plant height (Fig. 6). There was also a highly significant positive correlation between plant height and yield (r^2=0.61**).

M. dolichostigma damage, which is often highly visible, does not result in significant yield losses.

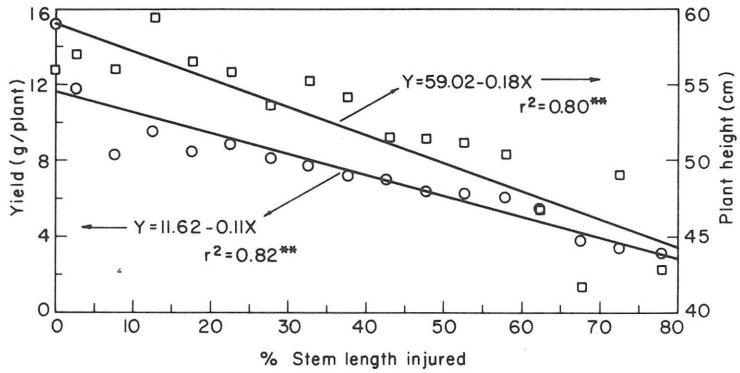


Fig. 6. Plant height and yield response in soybean as influenced by the degree of stem tunneling by M. sojae. Source: Bhattacharjee (1980).

Control

Control measures vary according to location and season, but all emphasize the importance of protecting the plant in the seedling stage.

Cultivar Resistance

Chan et al. (1967) screened 435 accessions for resistance to M. sojae. Accessions PI 56618, PI 88310, PI 227213, and PI 92748 had the least damage. Hsu et al. (1968) screened 137 cultivars for resistance to M. sojae, but found all entries to be susceptible.

Chiang and Talekar (1980) screened 6,775 soybean accessions over a two-year period, and in their final multilocational trial found four wild soybean accessions (G. soja) to be highly resistant to M. sojae (Table 2). Characterization of the resistance mechanism revealed that beanfly infestation is influenced during the early plant growth stage by the trichome density of the abaxial surface of the leaf, as well as by leaf area, leaf moisture content, and stem diameter. When the plant is in the V3 stage (or older), both leaf dry weight/cm^2 of the second trifoliolate and the stem moisture content of the internode between the second and third nodes are positively correlated with the level of beanfly infestation (Chiang and Norris 1983). Breeding is underway to incorporate the resistance of the wild accessions into agronomically acceptable cultivars.

Resistant accessions tested in Indonesia, where O. phaseoli is a major pest, all suffered heavy mortality rates. Efforts are therefore underway to screen the entire AVRDC soybean germplasm collection for resistance to O. phaseoli. Recent screenings in Indonesia revealed that of the 217 entries tested, 2 G. soja and 22 Neonotonia sp. accessions are tolerant. Average mortality was about 35% compared with 100% in the susceptible G. max checks.

Table 2. Response of selected AVRDC soybean accessions to beanflies[z] at six locations in Taiwan[y].

Accession No.	No. Beanfly Larvae + Pupae/10 Plants --weeks after germination--	
	3	6
G 3089	0.4c[x]	2.7c
G 3091	0.3c	1.1c
G 3104	0.2c	0.5c
G 3122	0.6c	1.1c
G 286[w]	12.0a	13.8b
G 3453[w]	14.1a	16.2a

[z] Mainly M. sojae
[y] Combined analysis of three replicates at each location
[x] Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test
[w] Susceptible checks, G. max; first four entries G. soja
Source: Chiang and Talekar 1980

Ridging

When soybean is attacked by O. phaseoli, the plant forms rows of adventitious roots on the stem above the root collar. Van der Goot (1930) tried to encourage the formation of new rootlets by earthing up young plants when adventitious root formation became visible, usually about three weeks after germination. Plants treated in this way reportedly suffered lower mortality rates than the control plants.

Fertilization

Increases in soil fertility promote plant growth, and thereby help the plant to grow through the infestation. Van der Goot (1930) found a higher rate of plant mortality for crops grown on infertile soil (after paddy) than for plants grown on fertile soil (after Crotalaria).

Mulching

Van der Goot (1930) also found significantly less plant mortality when soybean was covered with rice straw mulch (Table 3). The damage in the mulched fields was 44%, compared with 66% in bare fields. Similarly, plant mortality was 38% in the non-mulched fields as compared with only 17% in fields covered with rice straw.

The beneficial effect of rice straw mulch was initially believed to be due to moisture conservation that encouraged plants to grow vigorously, and thereby tolerate beanfly damage. However, mulched plants were found to be consistently less infested than non-mulched plants. This was due to the fact that the rice straw covers the germinating seedlings and cotyledons, thus preventing access for oviposition.

This practice does not prevent M. sojae infestation since the insect does not lay its eggs in cotyledons. In a large-scale experiment at AVRDC, straw mulch, rice stubble culture, plastic or aluminum foil mulch, and fish meal mulch failed to control M. sojae (AVRDC unpublished data). Therefore, it is also unlikely that mulching will control M. dolichostigma.

Table 3. Effect of rice straw mulch on beanfly control in soybean.

Treatment	Sowing Date	No. Plants	No. Damaged	No. Dead	Damaged (%)	Dead (%)
With straw	27-4-1919	999	427	63	42.7	6.3
Without straw	27-4-1919	1110	792	141	21.3	13.6
With straw	9-5-1919	1217	594	140	48.8	11.5
Without straw	9-5-1919	1159	632	162	53.6	13.1
With straw	9-5-1919	1384	786	117	56.7	8.4
Without straw	9-5-1919	1245	616	230	49.4	18.4
With straw	3-6-1919	883	348	196	39.7	22.1
Without straw	3-6-1919	799	470	166	58.8	20.7
With straw	3-6-1919	1137	346	260	30.3	22.8
Without straw	3-6-1919	937	593	589	63.6	63.1
With straw	7-11-1919	1475	547	47	64.2	3.1
Without straw	7-11-1919	1087	961	61	88.4	5.6
With straw	11-5-1920	1861	726	103	39.0	5.5
Without straw	11-5-1920	1628	972	319	59.7	19.5
With straw	21-8-1920	675	441	524	65.3	77.6
Without straw	21-8-1920	1246	1082	462	86.8	37.1
With straw	2-7-1921	586	275	176	47.0	30.1
Without straw	2-7-1921	585	406	275	69.4	46.6
With straw	16-7-1921	615	123	?	20.0	?
Without straw	16-7-1921	570	316	?	55.4	?
With straw	18-8-1921	436	298	134	68.3	30.7
Without straw	18-8-1921	561	414	561	73.8	100
Leaves of uri[z]	16-10-1922	563	227	44	40.3	7.8
Roots of uri[y]	16-10-1922	489	346	51	70.7	10.4
Without straw	16-10-1922	623	455	45	73.0	5.6

[z] Leaves of Imperata cylindrica
[y] Roots of Imperata cylindrica
Source: van der Goot (1930)

Intercropping

Van der Goot (1930) found that intercropping soybean with eggplant and yam bean, a common practice among Javanese farmers, reduces beanfly infestation. He attributed this to the fact that the companion crop shades the soybean, thus reducing the insects' access to the plants.

In a trial at AVRDC, soybean was intercropped with 60 field crops, vegetables, green manure crops, or ornamentals (14 botanical families). Two rows of the companion crops were planted 60 cm apart, four weeks before the soybean was planted as a single row between the two intercropped rows. M. sojae infestation was evaluated four weeks after planting by cutting open 20 soybean plants/5 m row plot and recording the number of larvae and pupae found in the plants and the percentage of beanfly-damaged plants. None of the companion crops significantly affected beanfly infestation compared with the monocrop control (AVRDC unpublished data).

Planting Date

Although beanflies are present in the tropics throughout the year, infestation varies from season to season. For example, van der Goot (1930) found that

without precautionary measures it was impossible to raise a soybean crop in Indonesia during the dry season. In the rainy season, plant mortality was significantly less even though the beanfly population was equal to that found in the drier months. This phenonenon is apparently related to plant vigor.

In Taiwan, beanflies are present throughout the year, but infestation is severe (100%) only from October through December. In the spring, infestation is relatively low and no control measures are required (AVRDC unpublished data).

Whether in Java or Taiwan, soybean planting dates are determined by the cropping system and not by insect pest infestation. The rainy seasons in Indonesia and Taiwan are the rice growing seasons, and despite insect pest problems, most soybean will continue to be planted during the dry season - the period when beanfly infestation is at its worst.

Biological Control

Van der Goot (1930) and Greathead (1968) carried out fairly detailed studies on the biology and parasitism of various beanfly species. Most of the parasites were found to attack beanflies during the larval stage, but did not kill the host until the pupal stage. The parasitism of various beanfly species is shown in Table 4.

Although the existing rate of parasitism is high, sufficient numbers of flies survive to cause substantial damage; the parasites only reduce the level of infestation. Nevertheless, it may be useful to introduce parasites in some locations. One example is the successful introduction of two hymenopterous parasites (Opinus phaseoli and O. importatus), from Uganda to Hawaii in 1969. O. phaseoli was accidently introduced a few years earlier and rapidly spread throughout the island chain (Davis 1970). The parasites were readily established on several islands, and significantly affected the O. phaseoli population.

Chemical Control

Preventive and curative insecticides are commonly used to control beanflies in the tropics and subtropics. Because beanflies mainly attack young soybean plants, early insecticide application provides the best protection.

Prior to the introduction of synthetic insecticides, nicotine sulfate and derris dust were successfully used in Australia to control beanfly infestation in snapbean (Morgan 1938, Caldwell 1939). With the introduction of synthetic organic pesticides in the mid-1940s, a large number of chemicals were tested in the hope of controlling beanflies. In Java, 0.05% DDT or BHC at the rate of 800 l/ha or 5% DDT or BHC (15% gamma-isomer) dust at the rate of 15.2 kg/ha immediately after the soybean plants emerge, and repeated every other day up to seven days, provided satisfactory beanfly control (van der Laan 1949). Van der Laan's later experiments showed that taxophene (0.12% spray or 10% dust) provided better control than DDT or BHC.

Taylor (1959) in Australia and Walker (1960) in Tanzania achieved excellent beanfly control with aldrin, dieldrin, and endrin emulsions applied as seed dressing (0.2% a.i.). Organophosphorus insecticides such as parathion, diazinon, Dipterex, and malathion were shown to be less effective. In Sri Lanka, Wikramasinghe and Fernando (1962) also achieved good beanfly control by soaking seeds in aldrin, dieldrin, endrin, and chlordane.

The use of most organochlorine insecticide was either banned or restricted in the 1970s. An insecticide screening program was therefore initiated at AVRDC in 1974 to find an insecticide that provides satisfactory and economical control

of beanflies, mainly M. sojae. Of the 66 insecticides tested, only three (monocrotophos, dimethoate, and omethoate applied as 0.5 kg a.i./ha sprays after germination at 3, 7, 14, 21, and 28 days) provided consistent, satisfactory control. When applied as granules banded alongside the seeds at planting, none of the compounds controlled beanflies (Table 5). Apparently the chemicals control the insect by killing the adults that visit plants for oviposition and feeding. A study revealed that the three insecticides are structurally related organophosphorus compounds.

Table 4. Parasitism of various beanfly species.

Species	Parasite Species	Average Parasitism	Location	Reference
O. phaseoli	Cynipoide sp. Eurytomia poloni Gir. Eurytoma sp. Trigonogastra agromyza Dodd.	5%	Java	van der Goot 1930
	Paratrigonogastra stella Gir. E. poloni	17%	Philippines	Otanes 1918
	A braconid	ineffective	Rhodesia	Jack 1912
	Opius liogaster Szepl.	effective	Rhodesia	Taylor 1958
	O. melanagromyzae	38%	Madagasar	Greathead 1968
	O. melanagromyzae	20%	Mauritius	Greathead 1968
	Plutarchia sp.	50%	Taiwan	Rose et al. 1976
	O. melanagromyzae	50-93%	Uganda	Greathead 1968
	Opius sp.	3-9%	Uganda	Greathead 1968
	Norbanus sp.	<1%	Uganda	Greathead 1968
	O. phaseoli	4-26%	Hawaii	Raros 1975
	O. importus Halticoptera patellana Dalman	0-26%	Hawaii	Raros 1975
	Sphegigaster sp.		Taiwan	Chu and Chou 1965
	Opius sp.		Taiwan	Chu and Chou 1965
	Eucolidea sp.		Taiwan	Chu and Chou 1965
	Eurytoma sp.		Taiwan	Chu and Chou 1965
O. phaseoli	Cryptoprymna sp.		Taiwan	Chu and Chou 1965
	Halticoptera sp.		Taiwan	Chu and Chou 1965
O. Centrosematis	Eucoilidea sp.	20%	Uganda	Greathead 1968
	Eurytoma sp.		Taiwan	Chu and Chou 1965
	Cryptoprymna sp.		Taiwan	Chu and Chou 1965
	Halticoptera sp.		Taiwan	Chu and Chou 1965
	Sphegigaster sp.		Taiwan	Chu and Chou 1965
M. sojae	Secodella sp. Cynipoide sp. Trigonogastra agromyzidae Dodd. Eurytoma sp.	30-56%	Java	van der Goot 1930
	Eucoilidea sp.		Taiwan	Chu and Chou 1965
	Eurytoma sp.		Taiwan	Chu and Chou 1965
	Crytoprymna sp.		Taiwan	Chu and Chou 1965
	Halticoptera sp.		Taiwan	Chu and Chou 1965
	Sphegigaster sp.		Taiwan	Chu and Chou 1965
	Stenomalina sp.		Taiwan	Chu and Chou 1965
M. dolichostigma	Secodella sp. Cynipoide sp. Eurytoma poloni Gir. Trigonogastra agromyzidae Dodd. Eurytoma sp.	10-47%	Java	van der Goot 1930

Systemic insecticides (e.g. phorate and carbofuran), when banded along the seeds at sowing time, provided satisfactory control of O. phaseoli at other locations (Roongsook et al. 1973, Hussein 1978). However, these insecticides do not control beanflies at AVRDC. This could be due to the slightly alkaline pH of

AVRDC soil (pH 7.5 to 8). Organophosphorus and carbamate are degraded rapidly under alkaline conditions.

Table 5. Effect of mode of application of selected insecticides in the control of beanflies on soybean[z,y,x].

Insecticide	kg a.i./ha	No. Maggots+Pupae/ 30 Plants	Damaged Plants (%)
Monocrotophos 2.5G	2.0	24.25a	85.825a
Dimethoate 2.5G	2.0	21.50a	82.525a
Omethoate 2.5G	2.0	21.00a	82.525a
Monocrotophos 55EC	0.5	2.00c	10.000d
Dimethoate 44EC	0.5	4.50c	25.850c
Omethoate 50EC	0.5	0.75c	4.175d
Control		22.75a	87.500a

[z] Insecticide granules (laboratory made) were applied alongside the seeds at planting. EC formulations were sprayed at 3, 7, 14, 21, and 28 days after germination

[y] Data shown are means of four replicates. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test

[x] Plot size = 10 m^2

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Discussion Section IV

Question: Why do you use the detached leaf culture when it is well known that it can break the resistance through water congestion. Don't you think that intact leaf culture might be a better technique in screening resistant cultivars?

Yeh: In Taiwan we are testing a great many cultivars, and using intact leaves will be too much work.

Question: How do you select a set of differential host cultivars to identify your pathogenic races?

Yeh: The cultivars which have been reported to have variable reaction to rust were chosen as differential hosts and tested to determine physiologic races.

Question: Is there any difference in virulence among different rust races?

Yeh: Race 1 is more virulent than 2 and 3.

Question: How did the heat treatment used to control seed-borne organisms affect the seed-borne viruses?

Sinclair: We haven't studied this yet because the temperatures which might affect the viruses might also be harmful to the seed embryos.

Question: ARS scientists in the USA have observed that certain soybean cultivars were resistant to podborer (Heliothis armigera or H. zea) which feed on the soybean leaves and seed pods. Scientists have identified a chemical, Pinitol, one of the active compounds in polar extracts, as a growth inhibitor of feeding larvae. Are you conducting any study along this line?

Ohba: No.

Question: Is there any relationship between pubescence and insect resistance?

Ohba: Some insects do not like pubescence, but others prefer pubescent types.

Question: In spraying monocrotophos could you specify dosage and method and time of spray?

Talekar: Monocrotophos is sprayed at the rate of 0.5 kg a.i./ha once a week beginning soon after germination and up to 4 weeks. We use knapsack sprayers and spray on the foliage. Spraying at 3, 7, 14, 21, 28 days after germination gives complete control.

Question: What is the mechanism for resistance to beanfly damage in Glycine soja?

Talekar: We have not studied the mechanism of resistance in the G. soja cultivars, however, research elsewhere indicates the possibility of the presence of antibiotic chemicals in these cultivars.

Question: How do you grade the damage by beanfly? Have you screened for resistance to beanflies? How do you define resistance in your study?

Talekar: We cut open each plant in a sample and count the number of larvae and pupae found inside. We have screened over 6,000 soybean accessions for resistance. A resistant accession is one that has relatively fewer insects feeding inside the plant or has consistently fewer plants with beanfly damage.

Question: Why are we not thinking of a mechanical way of controlling O. phaseoli through breeding, because, as you know, in West Java the farmers take off the cotelydon for use as vegetables and to avoid O. phaseoli attack? Second, soybean is epigeal in its germination, and maybe we have to look for hypogeal types to be crossed with soybean.

Talekar: Covering cotyledons with rice straw helps to reduce beanfly infestation of cotyledons, especially in Indonesia where O. phaseoli attack soybean cotyledons. Other beanflies species attack unifoliolate leaves. In such cases, covering or removing the cotyledons will not help. Removing the cotyledon is laborious and its effect on plant growth is unknown. Removing unifoliolate leaves, as we found at AVRDC, adversely affects plant growth.

It would be very useful if we could develop a soybean with hypogeal germination. That will definitely reduce O. phaseoli infestation of the cotyledon and drastically reduce plant mortality due to beanflies. I do not know if hypogeal soybeans exist.

Section V
Plant Nutrition

Developing Cost-Effective Rhizobium Technology for the Tropics and Subtropics

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Introduction

Soybean (Glycine max) can fix between 14 and 300 kg N/ha, depending upon its yield potential, the availability of soil N, and the genetic interaction between the host genotype and the Rhizobium japonicum strain (Cassman et al. 1981, LaRue and Patterson 1981). Soybean's high yield potential, coupled with the diversity of tropical lands suitable for cultivation (Hittle 1974), requires that effective R. japonicum strains be introduced that are adaptable to specific soil environments. The challenge will be to produce, market, and introduce strains that meet N requirements for maximum yield. This paper discusses some of the factors that affect the establishment of a soybean-R. japonicum symbiosis in the tropics.

Yield Response and Inoculation

Rainfall, drought, salinity, acidity, low P, and the presence of toxic ions hinder the establishment of symbiotic N fixation in tropical soils. These stress factors adversely influence the symbiosis by: 1) affecting rhizobial survival, 2) slowing growth and inhibiting colonization of root surfaces, 3) affecting the early processes of root hair infection, and 4) affecting nodule function either by direct action or by indirectly reducing host photosynthesis.

Date and Halliday (1979) advocated the selection of Rhizobium adapted to acidic conditions in the savannah zones of South America. Keyser and Munns (1978a, 1978b) demonstrated that rhizobial strains differed in their ability to grow under low pH conditions and the associated stresses of low P and Ca and high Mn and Al. They suggested that reduced growth due to soil stress may reduce root colonization, nodulation, and subsequent N fixation by introduced, intolerant strains. These studies did not consider the effect of soil stress on plant yield potential and the decline in N_2 fixation due to reduced N demand by the plant.

Singleton et al. (1982) concluded that the ability of Rhizobium to grow and survive in a saline environment was greater than that of the host plant. In other studies, Singleton (1983) and Singleton and Bohlool (1983) subjected the components of soybean symbiosis to salinity and concluded that plant yield potential first limits the soybean symbiosis in saline environments. Huang et al. (1975) reached similar conclusions with drought-stressed soybean.

By identifying the first aspect of symbiosis that is limited by stress, N fixation can be enhanced either by applying appropriate management practices or by introducing Rhizobium selected for the stress environment. If tolerance to a particular stress can be eliminated as a strain selection criterion, as in the case of salinity, then emphasis can be placed upon other criteria, i.e. strain-cultivar interactions, competitiveness, and adaptation to inoculum carrier materials.

Interactions between Inoculation and Other Inputs

The greatest return, with respect to Rhizobium technology introduction, will occur when all other yield constraints are eliminated. It is logical to assume that yields of symbiotically grown legumes are subject to the same "law of the minimum" for limiting factors as are non-symbiotic plants. Symbiotic soybean fixes no more N than it requires to meet the yield potential defined by other inputs in the system. Aside from stress factors, the symbiosis may also be limited by the availability of soil N and the presence of less effective strains of Rhizobium.

The selection of Rhizobium should be conducted under maximum yield potential and low soil N conditions. Strain selection tests in the field may not be able to differentiate between superior and only moderately effective strains under conditions of moderate yield potential. Hardy and Havelka (1973) demonstrated that photosynthates limited N fixation in soybean. This is not to say that all Rhizobium will produce the same N yield if photosynthates are not limited; however, genetic differences between strains should be magnified when N demand is high.

The enhancement of nodulation and plant vigor as a function of timely N applications has been reported (Loneragan 1972, Cassman 1979). Other studies (Hatfield et al. 1974, Chen and Phillips 1977) indicate that a large, continuous N supply suppresses symbiosis. In order for field tests to differentiate between strains of varying effectiveness (maximum 38%), soil-derived N must be less than 45% of total N accumulation (Williams et al. 1981). In temperate regions where corn and soybean rotations are grown, up to 75% of soybean N is soil-derived (Hardy et al. 1971). Maximum returns can be obtained with inoculation when soil N is available in quantities capable of avoiding yield declines due to N stress prior to fixation (Cassman 1979). However, soil N must be low enough to avoid inhibiting the symbiosis.

The introduction and establishment of R. japonicum strains in the tropics should not be hampered by the presence of invasive, native rhizobia. Although Lange (1961) found that many slow-growing 'cowpea miscellany' isolates nodulate soybean, this should not be a problem under field conditions. The phenomenon of cross inoculation is often the result of pure culture techniques.

In the tropics, competition between established strains and inoculum strains is significant only after the original inoculum has colonized the soil. This emphasizes the need for evaluation and strain selection before the introduction of the first inoculum strain. The introduction of a strain capable of sustaining maximum yield could be hindered if an inferior strain is already present.

The use of inoculum in soils with an invasive rhizobial population does not always produce an inoculation response. Soil strain effectiveness may vary in terms of symbiotic capabilities with a particular host. Bergersen (1970) indicated that the effectiveness of some rhizobial populations had a normal frequency distribution, and that the mean effectiveness of the soil population was only 52% of a selected inoculum strain. Even when large proportions (50%) of the nodules are formed by the inoculum strain, response to inoculation is not always guaranteed (Diatloff and Langford 1975). Weaver and Frederick (1974a, 1974b) claimed that soybean grown in soil containing 1000 or more rhizobia/g is not likely to respond to inoculation or to nodulate extensively. Singleton (1983) demonstrated that 95% of the maximum N accumulation in young soybean could be obtained when 25% of the nodules are ineffective. This occurs because the host compensates for a reduction in effective nodulation by increasing the average size of effective nodules.

Given the complex interaction between yield potential, soil N availability, and the effectiveness of soil strains, predicting a response to inoculation may be difficult. To maximize the returns to development and the use of inoculants, the parameters involved in inoculation response should be clearly defined.

Assessing the Need for Inoculation

When introducing legumes to a new area, assessing the need to inoculate, or determining the rhizobial status of the soil, may be as important as soil analysis. Various methods have been proposed (Date 1982, Nutman 1976).

Most probable number (MPN) estimates of soil dilutions provide information on the number of invasive Rhizobium of a particular species (Vincent, 1970). High numbers of invasive rhizobia ($\geq 10^3$/g soil) may be an indicator of serious competition problems. In that case, higher inoculum rates and/or an extremely competitive inoculum strain may be required. Inoculating and planting soil cores or pots, and then comparing early growth with uninoculated controls, may indicate the effectiveness of the soil population (Vincent, 1970).

Experimental designs that are used to field test Rhizobium strains and management variables were reviewed by Nutman (1976), Vincent (1970), and Brockwell et al. (1982). The IBP experiments proposed by Vincent (Nutman 1976) involved four N variables combined with two fertility levels and four inoculation treatments. These experiments estimated fixed N and the interactions between inoculation and fertility. The inoculation experiments conducted by Brockwell et al. (1982) are more conducive for testing large numbers of strains.

International Network of Legume Inoculation Trials (INLIT)

USAID funded a workshop at NifTAL in 1979 (Harris 1979) for scientists representing donor agencies, national programs, and international agricultural research centers. There was a consensus that a coordinated, worldwide program was needed for legume inoculation research based on: 1) the fact that demand for legume inoculants in the developing countries was unable to support substantial commercial inoculant production; 2) that in countries where inoculant production facilities existed, demand fell short of production capacity; 3) that most studies with tropical legumes failed to conform to the criteria considered necessary for definitive inoculation trials; and 4) that individual trials would be more meaningful if coordinated by an international network.

NifTAL, the network coordinator, subsequently contacted legume researchers in Asia, Africa, and Latin America to explain the INLIT concept. According to the plan, researchers would be linked to a worldwide communications network, and because all workers would use a standardized experimental design, the trials could be analyzed on a regional, national, or worldwide basis.

The INLIT trials were designed in three stages (A, B, and C). The A experiments would determine inoculation response with the best available strains of serologically distinct Rhizobium. In the B experiments, pot trials would be conducted to test local isolates (based on the results of the A experiments). The C experiment would essentially repeat the A experiment in the field by evaluating the best B-strains against the A experiment inoculum.

Many INLIT cooperators conducted only the A experiment, either because they lacked microbiological expertise or because the results from the A experiment failed to indicate a need for additional research. The following section focusses on the A experiment

INLIT A Experiment

NifTAL supplies an inoculant composed of three highly effective strains selected for their N fixation efficiency, diversity of origin, and for their distinct serological characteristics. If a cooperator has developed a high quality inoculant using local strains, this product can be substituted for the INLIT inoculant. NifTAL also supplies antisera for its strains. Most cooperators have elected to use the NifTAL inoculant in their initial experiments.

Lack of inoculation response is often due to competition from native soil rhizobia. Serological nodule typing can reveal whether or not this is the case; it is also useful to serotype nodules in follow-up experiments that monitor the establishment and persistence of inoculum strains.

The A experiment is conducted at two fertility levels. The lower level - designated F - represents the local practice, while the higher level - designated M - represents a level of fertility other than N that ensures maximum yield. The trial is conducted with six treatments in a randomized complete block design with four replications:

Treatment	Bag Nitrogen	Rhizobium Inoculant
F1	-	-
F2	+	-
F3	-	+
M1	-	-
M2	+	-
M3	-	+

Specific single-degree-of-freedom comparisons among the six treatment means indicate: 1) if inoculation increases yields; 2) if higher yields can be obtained with inoculation rather than with N fertilizer, or vice versa; and 3) if inoculation increases yield, and whether it does so at both high and low levels of fertility.

Some data from INLIT cooperators have been received, and composite analyses have been made on the crops where sufficient data exist.

The A experiment data for soybean grain yield at twelve locations have been analyzed. Combined analyses show an interaction between locations and rhizobial comparisons. One variable was if the site had a history of a previous inoculated soybean crop. Good nodulation in the control treatments was accepted as evidence of such a crop.

Data analysis showed that a farmer who applied the inoculant could expect yield increases of 0.38 to 0.52 t/ha in a field with no previous history of inoculation. Bag N and inoculation were equally effective when N was applied in split doses. Caution must be exercised, however, in extrapolating from these experiments, and more data is needed so that the use of inoculants can be properly analyzed for cost effectiveness and other benefits.

Cost Effectiveness of Inoculation and Inoculum Production

The effective use of inoculants requires an efficient distribution and extension network, largely because of the perishability of inoculants. The development of production, distribution capabilities, and extension services for inoculants should coincide with the promotion of other production inputs.

Inoculant production and distribution in the tropics also faces special problems. For example, soybean planting in the tropics takes place during specific, concentrated periods, which means that expensive storage facilities are needed to preserve the inoculants. Somasegaran et al (1983) sent gamma-irradiated peat inoculants of ten Rhizobium species to 13 tropical countries by air. The packages contained a maximum recording thermometer and media for enumerating the number of viable cells. Unacceptable losses in viability (loss below 1 x 10^8 cells/g peat) were found in 15% of the samples, mostly because of exposure to excessive heat (>40°C) during transport (6 to 54 days). Similar problems were reported by Burton (1979). The log number of viable cells/g peat declined by two over a period of six weeks. Decline in viable numbers is generally greater in non-sterile peat (Roughley 1968).

The greater shelf life (at 26°C) of inocula produced in sterile peat has implications for inoculant producers in the tropics. The currently acceptable methods of carrier sterilization are gamma irradiation and autoclaving. Gas sterilization (ethylene oxide and methyl bromide) and sterilization by long-term exposure to high temperatures are unsatisfactory (Roughley and Vincent 1967, Roughley 1970, Strijdom and Descholdt 1976). Both autoclaving and gamma irradiation require expensive, large-scale equipment, and many soybean production schemes may not reach a level that justifies the investment. Given the perishability of inoculants, it is advisable to centralize the carrier preparation activity of inoculant production, and then ship the pre-sterilized carrier to the production site.

The use of sterile carrier material permits the manufacture of high quality inoculums (>1 x 10^9 cells/peat) with a minimum investment in fermentation equipment. Yeast extract broth culture at 10^9 cells/ml can be diluted by a factor of 1000 prior to inoculating sterile peat (Somasegaran and Halliday 1982, Roughley and Pulsford 1982). Rhizobia grow rapidly in sterile peat, reaching 10^9 cells/g peat after one week of incubation at 28°C (Somasegaran and Halliday 1982). A 180 g packet of high quality inoculum contains enough viable cells to supply each soybean seed in 1 ha with approximately 1 x 10^6 cells. The volume of broth inoculum required to produce one packet is only 0.2 to 1.0 ml. Large quantities of sterile diluent water can be easily produced by filter sterilization. By taking advantage of the ability of Rhizobium to grow in sterile peat, one liter of broth at 10^9 cells/ml, diluted 1:100, will produce enough carrier to inoculate 1000 ha.

Using a dilution technique, small-scale inoculant production units can be established near soybean producing areas. These units could be standardized in simple specialized production techniques, including the use of sterilized, prepackaged peat or other carrier materials. Standard methodologies, prepackaged materials, training, and quality control could be supervised by a regional center. By limiting the number of operations and tasks of the production unit to growing and diluting small quantities of inoculum and injecting the inoculum into sterile carriers, quality control problems can be minimized. Proximity to the market will reduce transit time to the field and will allow flexibility in producing strains tailored to local needs.

The use of the dilution technique in inoculant production is labor intensive and may not be cost effective in areas where wages are high. However, increased labor costs can be offset by the expense involved in refrigerated transport and storage.

Quality control may be a problem, however. A lack of trained workers, combined with small-scale production, may limit the amount of effort expended in product testing and control. This problem can be overcome by removing the responsibility of the local producer for long-term culture storage, authentica-

tion, and other checks for culture purity and quality control. The operations of the local producer can be integrated with those of the regional center that develops simple and fail-safe production methodologies, including the provision of sterile carriers and starter inoculum. The regional center would be responsible for monitoring the product quality of the local production units, much as seed and vegetable canning operations check and coordinate the operations of small producers. This type of organization would resolve the need for expensive, specialized storage and shipping facilities, and would reduce the lag time between inoculant production and application in the field. Only small quantities of cultures and starter inoculum would require specialized shipping and handling in this type of scheme.

Large investments in personnel and equipment would be required only at the regional centers, where greater utilization would justify the cost. Larger centers would be more efficient in testing and developing appropriate methodologies for the region. The availability of a multi-disciplinary staff would ensure that problems are addressed from a broad perspective.

Some quality control procedures could take place at the production unit if simple, packaged techniques for enumeration and culture purity checks are provided. The use of the enzyme-linked immunosorbent assay (ELISA) (Berger et al. 1979) could be used to test culture purity. Simple techniques and the prefabricated assays used by modern hospitals could also be modified for inoculant production.

Production units can be tied to distributors of agricultural inputs and to local extension services. Extension work and credit facilities should be directed at broad-based input distributors; technical assistance can be provided by the inoculant producer. In this way, the distribution and application of a broad mix of agricultural inputs can be integrated.

As mentioned, the cost of production with sterile peat in small plants will be higher than in large-scale, automated facilities. Production costs for peat inoculum at NifTAL have been estimated at US $3.00/ha (D. L. McNeil and Pinchin, NifTAL unpublished data). This estimate includes the cost of shipping peat from the U.S. mainland to Hawaii. Seed-applied peat inoculum from the Nitragin Company is currently selling for US $1.08, FOB Milwaukee, Wisconsin, USA (Burton, personal communication). The cost of air transport to Hawaii would add US $ 1.00 to each packet.

The application of inoculum to seed is inexpensive, and inoculation is compatible with most agricultural operations, except for some seed-applied pesticides (Burton 1979). Burton (unpublished data) estimated that the labor cost for inoculating 1 ha of soybean in the USA is US $1.00. He also calculated that even with low amounts of fixed N (60 kg N/ha), net returns would total US $15.20/ha (if N costs US $0.28/kg). Monetary returns on soils that carry effective native R. japonicum strains is more difficult to assess because contributions to N_2 fixation by native versus inoculant strains cannot be separated. Controlled experiments allow the marginal returns of inoculation to be quantified. Decisions about the use of inoculants can therefore be made on the basis of inoculation cost.

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Quantifying N_2 Fixation in Field-Grown Soybeans Using ^{15}N Isotope Dilution

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Introduction

Until recently it was impossible to accurately quantify N_2 fixation in annual legumes. Without a means of determining %Ndfa (% nitrogen [plant] derived from the atmosphere) and the actual amounts of N_2 that are fixed, no base line exists to: 1) assess the agronomic significance and impact of N_2 fixation, 2) modify host plant and bacterium to increase N_2 fixation rates, and 3) confidently transfer this capability to the farmer.

Because of the relationship between N_2-fixing bacteria and legumes, improvement requires selection, breeding, and/or mutations in both partners. Plant breeders must select for superior nis, defined as the nitrogen fixation supportive trait (Rennie 1981, Rennie et al. 1982), i.e., the ability of the plant to support and ultimately benefit from its N_2-fixing association with a procaryotic organism. The plant breeder (and the plant microbiologist) need nis selection techniques that are fast, inexpensive, partially or non-destructive to the plant, and suitable for screening large plant populations. Several techniques exist, and while none of them fulfills all of these criteria, they can be used as selection tools under specifically designed experimental conditions.

This paper discusses potential techniques for quantifying soybean (Glycine max) N_2 fixation, with particular emphasis on field evaluation. The presentation is selective rather than comprehensive. Emphasis is placed on quantifying %Ndfa by measuring the true substrate, N_2, using ^{15}N isotopic techniques. This report is based primarily on a recent review (Rennie and Rennie 1983), but includes several practical examples where ^{15}N isotope dilution has been used to determine the effects of soybean cultivars, strains of Rhizobium japonicum, and agronomic practices on symbiotic N_2 fixation.

Indirect Methods of Quantifying N_2 Fixation

Acetylene Reduction Assay (ARA)

Nitrogenase not only reduces N_2 to NH_3, but also reduces C_2H_2 to C_2H_4. The two latter gases can be rapidly and accurately analyzed on a gas chromatograph equipped with a flame ionization detector (Bergersen 1970, Hardy et al. 1968 and 1973, Postgate 1971). Detailed assay techniques for greenhouse and field experiments with legumes have been described (Dart et al. 1972, Balandreau and Dommergues 1973, Hardy et al. 1973, Ham 1975), and a portable gas chromatograph has been specifically designed for ARA in the field (Mallard et al. 1977).

Limitations on the use of ARA with legumes have been clearly described (Bergersen 1970, Hardy et al. 1968 and 1973, Turner and Gibson 1980), but these guidelines have been largely ignored. ARA is a short-term kinetic measurement. The existence of diurnal and seasonal variations in N_2 fixation brings into question the validity of ranking cultivars and extrapolating to total N_2 fixed

over a growing season. More accurate estimates of N_2 fixation can be obtained when a time course of nitrogenese activity is established based on frequent ARA measurements over time (Ham 1975, Tuner and Gibson 1980).

Yield-Dependent Criteria

Several yield-dependent techniques can be used to assess N_2 fixation with legumes.

In Vitro Evaluation: Plant production in an N-free medium forces total dependence on seed and, if inoculated, atmospheric N_2. This provides a convenient screening procedure for nis in legumes before field experimentation (Graham 1981, Rennie 1981). The inherent genetic ability of a plant to support N_2 fixation (i.e. genotype) should not be altered under field conditions, although the phenotypic expression of nis may be affected by the efficiency of fertilizer- or soil N-use, or both (Rennie 1979, Rennie and Kemp 1983).

Dry matter yield and %N may or may not be related to the N_2 fixed because of dilution effects. Total N yields remove these concentrations (dilution effects) and permit actual measurements of N_2 fixed in an N-free growth medium by the classical difference method as follows:

$$N_2 \text{ fixed} = \text{total N(fs)} - \text{total N(nfs)} \qquad [1]$$

or

$$N_2 \text{ fixed} = \text{total N(fs)} - \text{seed N(fs)} \qquad [2]$$

where fs and nfs are fixing and non-fixing systems, respectively.

The latter calculation assumes complete utilization of seed N. We have found, in vitro, that dry matter and total N yield (and thus the N_2 fixed) are highly correlated (Rennie and Kemp 1981). Dry matter yield has been successfully used to screen for nitrogenase activity in field beans under N-free growth conditions. However, far too often plants exhibit differing conversion efficiencies, a fact which results in dilution effects noted in %N. In these situations only total N yield can be used as a quantitative measurement of the N_2 fixed. Because it is impossible to predict when a %N dilution effect may occur, it is prudent to measure N_2 fixation in vitro based exclusively on N yield.

In Vivo Evaluation: In a field where a plant in the N_2-fixing mode has two or three sources of N (atmosphere, soil, and perhaps fertilizer), neither dry matter nor N yield can be used as an absolute or acceptable criterion. The classical difference method (equation 1) has often been used in the field to compare N yields of fixing and appropriate non-N_2-fixing legume systems (LaRue and Patterson 1981), but such evaluations are prone to error. For example, an increase in total plant N due to inoculation with an N_2-fixing bacterium may be due to N_2 fixation, increased fertilizer efficiency, or soil N use due to alteration of rooting habits that results from bacterial inoculation. Similarly, equal N yields between inoculated and uninoculated plants may indicate no N_2 fixation (substitution) by fixed N_2 of the soil or fertilizer N in the inoculated plant. When fixing and non-fixing plants have equal nitrogen yields, no N_2 fixation may have occurred or N_2 fixation occurred while less soil and/or N fertilizer was assimilated. The plant may have a genetic yield maximum and an ability to alter its use of N from different N sources to achieve that maximum. Thus, under field conditions, some other technique must be used to accurately quantify N_2 fixation.

Nitrogen Isotope Techniques (Yield-Independent Criteria)

Introduction

Several N isotopes exist (Table 1) which vary in mass number from 12 to 17. In agriculture, the two most important are the radioactive nuclide ^{13}N, whose half-life of 10.05 minutes severely limits its usefulness (Nicholas et al. 1961, Campbell et al. 1967, Wolk 1980), and the stable nuclide ^{15}N.

Table 1. Natural occurrence of nitrogen isotopes.

Mass Number	Natural Abundance	Half-Life
12	--	0.0125 s
13	--	10.05 min
14	99.636	-
15	0.366	-
16	--	7.36 s
17	--	4.14 s

^{14}N:^{15}N ratio of the atmosphere = 272±0.3, yielding 0.3663 ±0.0004 at.%^{15}N or 3660 ppm ^{15}N

The use of ^{15}N has several advantages: It is non-radioactive, and thus pose no health or environmental hazards, nor is policing of the laboratory or waste disposal a problem. ^{15}N is relatively inexpensive for field experiments since ^{15}N enrichments of 0.5 to 1% are sufficient for a one-year experiment (I.A.E.A. 1976). The expense of purchasing and maintaining an isotope ratio mass spectrometer has been partially offset by the introduction of less expensive instruments designed specifically for ^{15}N analysis (accuracy of 0.005 at.%^{15}N).

To properly interpret the result of N_2 fixation experiments that employ ^{15}N, it is important to understand the various isotope terminologies and calculations employed in relation to N_2 fixation (I.A.E.A. 1976, Hauck and Bremner 1976, Rennie et al. 1978, Rennie and Rennie 1983 [also see Appendix]).

$^{15}N_2$ ($^{13}N_2$) Reduction

Traditionally, ^{15}N has been used primarily as a definitive test to prove that N_2 fixation has occurred. Thus, in a well-designed experiment, if a presumptive N_2-reducing system is subjected to exposure of $^{15}N_2$ for a short, specific (<48-72 hr) time, and $^{15}NH_3$ or its derivatives are found in the sample, the occurrence of N_2 fixation will be confirmed. Percent Ndfa is then calculated as follows:

$$\%Ndfa = \left(\frac{\text{atom } \%^{15}N \text{ ex. (fs)}}{\text{atom } \%^{15}N \text{ ex. (atmosphere)}} \right) \times 100 \qquad [3]$$

and

$$N_2 \text{ fixed} = \frac{\%Ndfa}{100} \times \text{total N(fs)} \qquad [4]$$

Far too often, fixed N_2 is incorrectly calculated by multiplying at.%^{15}N ex.(fs) x total N(fs). This applies only when at.%^{15}N(atmosphere) is equal to 100%. (The same principles apply to the reduction of radioactive $^{13}N_2$).

The second major use of $^{15}N_2$ is for the experimental establishment of the true N_2:C_2H_2 ratio so that correct conversion from C_2H_4 produced to NH_3 can be made. This is seldom done in the case of C_2H_2 reduction assays associated with legumes, despite warnings (Bremner 1975) that the theoretical 3:1 ratio of N_2:C_2H_2 is not acceptable under field conditions.

The use of $^{15}N_2$ (or $^{13}N_2$) is a short-term kinetic measurement like ARA, and, as such, is no more applicable to field quantification of %Ndfa than is ARA. It is a definitive but rather awkward means of proving N_2 fixation in situ and will likely be superceded by ^{15}N isotope dilution techniques. An excellent treatise on $^{15}N_2$ methodology usage is now available (Bergersen 1980).

^{15}N Isotope Dilution

Recent improvements in ^{15}N tracer techniques permit quantification of N_2 fixation in legumes by labeling the soil (Legg and Sloger 1975, Kohl and Shearer 1981, Rennie 1982, Rennie et al. 1982) or fertilizer N (Fried and Broeshart 1975, McAuliffe et al. 1958) with ^{15}N or by measuring changes in the abundance of naturally occurring ^{15}N (Rennie et al. 1976, Virginia and Delwiche 1982). The technique of labeling the soil, instead of atmospheric N_2, invokes the principle of isotope dilution which has been used to accurately quantify N_2 fixation in legumes under field conditions (Rennie et al. 1978, Rennie and Rennie 1983, Vose et al. 1981).

The use of isotope dilution to calculate %Ndfa is dependent on the comparison of a fixing (fs) and non-fixing system (nfs) (Fig. 1). The nfs has two possible N sources, soil and fertilizer, while the fs has a third source, atmosphere. Thus plant N derived from the soil is slightly or highly enriched in ^{15}N and will be diluted by $^{14}N_2$ from the atmosphere via N_2 fixation. The nfs is essential to assess the contribution of soil (%Ndfs) and/or fertilizer (%Ndff) N to the fs. There are several possible nfs but each must assimilate its N from the soil and/or fertilizer N pools at similar times (i.e. identical ^{15}N:^{14}N composition) but not necessarily in the identical quantity as the fs.

While similar days to maturity and rooting patterns may aid in fs and nfs sampling, the same isotopic composition in the soil and fertilizer N pools are not essential. If a constant $^{15}N/^{14}N$ ratio is mineralized from the organic matter, then small differences in maturity are acceptable.

Similarly, because a majority of the N in the soil is in the upper horizons (assuming that it is of similar isotopic composition), the roots of fs and nfs may explore different soil volumes since it is the isotope ratio that is critical and not the amount of soil N that is assimilated. The volume of soil explored by the roots of the fs and nfs may be more crucial in studies conducted at natural levels of ^{15}N abundance.

Two theoretical uptake patterns of N can occur when comparing fs and nfs. Under ideal conditions (Fig. 2), both fs and nfs_1 assimilate mineral N according to the same pattern, and thus at the same ^{15}N:^{14}N ratio. If N uptake patterns (fs and nfs_2) are different (Fig. 2), then differences in ^{15}N:^{14}N in plant N at harvest will not be solely due to dilution by ^{14}N from the atmosphere but also from ^{14}N from the soil or fertilizer N.

Several possible nfs exist (Rennie et al. 1978, Rennie 1982) (for nomenclature see Bell and Nutman 1971).

1. 0 (uninoculated: An excellent control to study the effect of inoculation if the bacterium added as an inoculant is not indigenous to the soil (Rennie 1982).

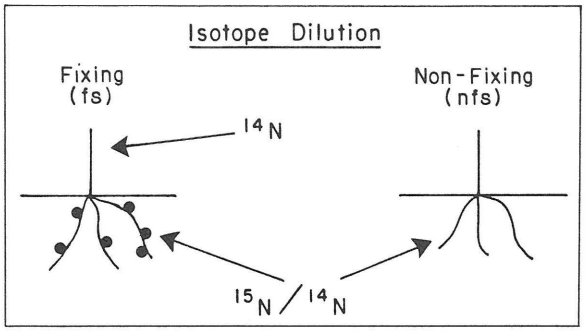

Fig. 1. (above)
The fixing (fs) and non-fixing (nfs) system as applied to calculating %Ndfa by ^{15}N isotope dilution by $^{14}N_2$ from the atmosphere.

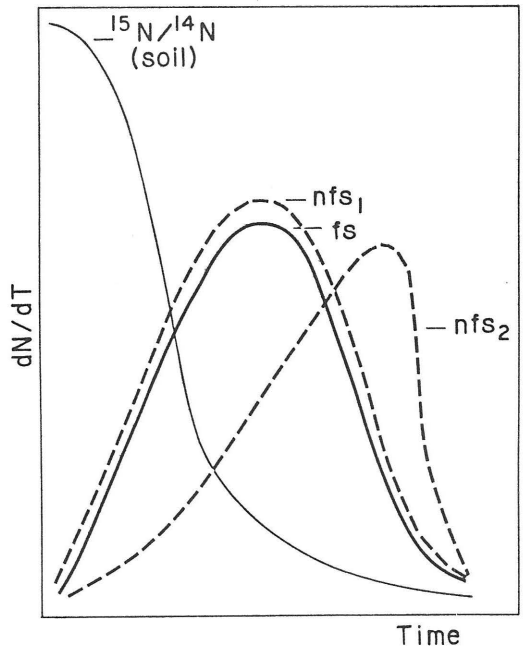

Fig. 2. (right)
Ideal (nfs_1) and non-ideal (nfs_2) N uptake pattern in relation to $^{15}N:^{14}N$ content of soil N pool for fixing (fs) and non-fixing systems (nfs).

2. I (ineffective inoculation): An excellent control if a bacterium exists that invades the plant but does not establish an effective N_2-fixing association.

3. N (non-nodulating isoline): Non-fixing soybean clones have been identified that function in a manner similar to non-nodulating legume isolines.

4. NL (non-legume): Non-legumes with similar N uptake patterns.

5. HN (high N): Application of N fertilizer at levels sufficient to inhibit N_2 fixation by indigenous or added bacteria.

Controls O, N, and I have been used to quantify N_2 fixation in association with soybean (Rennie 1982). The application of high levels of N (option 5) preclude the use of isotope dilution to calculate %Ndfa, although the 'A'-value could be used. Option 4 (NL) has been used extensively with legumes.

Isotope dilution assumes that the soil N pool is uniformly labeled with ^{15}N, although this is virtually impossible (Fried and Dean 1952). It also assumes that no significant isotopic discrimination occurs in any biological nitrogen cycle process. If, however, N_2 fixation does occur in association with nfs due to indigenous soil bacteria, isotope dilution would underestimate, but never overestimate, %Ndfa in the fs due to inoculation.

The use of the proper nfs can only fail if inoculation of the fs with a N_2-fixing bacterium alters the rooting pattern and thus exposes the plant to an N pool with significantly different $^{15}N:^{14}N$ composition. However, in field-grown soybean, control, O, I, and NL are all excellent nfs (Rennie 1982).

Detailed research on the use of appropriate nfs to estimate %Ndfa in soybean by ^{15}N isotope dilution has just begun (Rennie 1982, Wagner and Zapata 1982). It

may be prudent to use two or more controls for each experiment until a better understanding of nfs exists.

$\sigma a^{15}N$ (Natural Abundance)

Natural N substances with positive or negative $\sigma a^{15}N$ values are tracer materials with low levels of ^{15}N enrichment or depletion (Hauck 1973). It has been suggested, both for legumes and non-legumes, that the $\sigma a^{15}N$ of plant N (legumes and non-legumes) can be used to indicate the source of plant N, be it soil, fertilizer, or atmosphere (Bardin et al. 1977, Delwiche et al. 1979, Domenach et al. 1979, Kohl and Shearer 1980, Kohl et al. 1980, Rennie et al. 1976, Rennie 1982, Rennie et al. 1982). The $\sigma a^{15}N$ of the atmosphere is $0.0°/_{oo}$, while that of total soil N is 8.8 ± 1.2 in the chernozemic soils of western Canada (Rennie et al. 1976, Karamanos et al. 1981). Thus, at natural abundance levels of ^{15}N, %Ndfa can be determined by ^{15}N isotope dilution as follows:

$$\%Ndfa = \left(1 - \frac{\sigma^{15}N(fs)}{\sigma a^{15}N(nfs)}\right) \times 100 \qquad [5]$$

$$\text{where } \sigma a^{15}N = \frac{\text{at.}\%^{15}N(\text{sample}) - \text{at.}\%^{15}N(\text{atmosphere})}{\text{at.}\%^{15}N(\text{atmosphere})} \times 1000 \qquad [6]$$

One σa^{15}unit equals 0.00037 at.$\%^{15}N$. A positive $\sigma a^{15}N$ indicates an enrichment in ^{15}N relative to atmospheric N. The N of the atmosphere has an approximately constant ^{15}N enrichment of 0.3663 at.$\%^{15}N$ and thus, by definition, $\sigma a^{15}N = 0.0°/_{oo}$. Biological processes in the soil favor the lighter isotope, ^{14}N, over the heavier isotope, ^{15}N. This results in the soil usually having a natural abundance of ^{15}N that is slightly above that of atmospheric ^{15}N.

Although the chemical properties of ^{14}N and ^{15}N are identical, discrimination may occur anywhere in the N cycle because of the mass differences (and physical properties) between ^{14}N and ^{15}N (Bigeleisen 1949). This discrimination is usually mainfested as isotope shifts, changes in diffusion or reaction rates, or changes in isotope distribution at equilibrium.

It may be necessary to take into account isotope discrimination at the site of N_2 fixation. Equation [5] would then become (Bardin et al. 1977, Domenach et al. 1979):

$$\%Ndfa = \left(\frac{\text{at.}\%^{15}N(fs) - \text{at.}\%^{15}N(nfs)}{[(1/\beta)\text{at.}\%^{15}N(atm.)] - \text{at.}\%^{15}N(nfs)}\right) \times 100 \qquad [7]$$

$$\text{where } \beta = \frac{\text{at.}\%^{15}N/^{14}N(atm.)}{\text{at.}\%^{15}N/^{14}N(fs)} \qquad [8]$$

Although there is no conclusive evidence to suggest that significant isotope discrimination occurs in N_2 fixation in the field, it does occur at low levels during N_2 fixation *in vivo* and in other parts of the N cycle. Hoering and Ford (1960) studied four *Azotobacter* spp. but found no consistent isotope effect in N_2 fixation. However, Delwiche and Steyn (1970) found discrimination for N_2 fixation with *A. vinelandii* (β = 1.0031 to 1.0054), and concluded that $^{14}N_2$ reduction may be slightly favored. Bardin et al. (1977) found isotope discrimination (β =

1.0038) for G. max grown in N-free Hoagland's solution, but Kohl and Shearer (1980), and Mariotti et al. (1980) found less than 1.0020 and 0.999, respectively, for soybean. Rennie et al. (1976) found no discrimination in N_2 fixation in Vicia faba in the field (β = 0.9985 in grain, 0.9990 in straw). It is difficult to develop a field experiment to prove discrimination during N_2 fixation because in vitro discrimination for N_2 fixation is less than that for NO_3^- assimilation (Mariotti et al. 1980).

The use of isotope dilution at natural abundance levels has several advantages. First, it is not necessary to label the soil with ^{15}N, which in turn eliminates the problems of uniform labeling and the lack of homogeneity for isotope dilution theorists. Isotope dilution is also much less expensive, since ^{15}N (US $100/g) does not have to be applied. Perhaps most important is the fact that it permits %Ndfa quantification in natural ecosystems without the need to alter the ecosystem.

The problems involved in using natural abundance techniques to quantify %Ndfa are summarized below (Vose et al. 1981). Because of these constraints, and until further experimental evidence is at hand, this method must be considered as a semi-quantitative procedure.

Soil: The higher the soil $\sigma a^{15}N$, the more it approaches the situation of ^{15}N enrichment, and thus experimental accuracy in determining %Ndfa is improved. Soils in western Canada have an average $\sigma a^{15}N$ of 8.8±1.2 °/₀₀ (Rennie et al. 1976), but values may be unique to pedogenic processes. Shearer et al. (1978) reported the range for total soil N of 39 samples from 20 American states to fall between + 5.1 and + 12.3°/₀₀. This covers the range reported by several other authors (Bremner et al. 1966, Cheng et al. 1964, Rennie et al. 1976). The $\sigma a^{15}N$ of soil N is determined by processes that occur simultaneously (Karamanos and Rennie 1980a): Incomplete oxidation of mineralized NH_4^+ resulting in $^{15}NH_4$ accumulation, associated with the downward leaching of NO_3^- depleted in ^{15}N and denitrification. The leaching of ^{15}N-depleted NO_3^--N may explain the observation that the $\sigma a^{15}N$ at lower depths may be less than that at surface horizons (Rennie et al. 1976, Karamanos and Rennie 1980b). Typical values for $\sigma a^{15}N$ with depth are shown in Fig. 3. In general, profile variations with depth are minimal; if they were significantly lower it would be impossible to differentiate between ^{14}N coming from the atmosphere and ^{14}N coming from soil N at lower depths. Thus it is critical that the fs and nfs have similar rooting habits and explore similar soil N pools over the entire growth cycle. Fortunately the $\sigma a^{15}N$ profile differs only slightly in most soils (Feigin et al. 1974, Karamanos and Rennie 1980b).

The $\sigma a^{15}N$ of total soil N represents past soil-forming processes, while that of NO_3^--N reflects recent N cycle stresses (Karamanos and Rennie 1980b). The $\sigma a^{15}N$ of soil NO_3^--N is often lower than that of total soil N (Feigin et al. 1974, Delwiche and Steyn 1970, Edwards 1973) but this is not always the case (Rennie et al. 1976) and the values are, of course, dependent on the time of sampling.

Sampling: It is difficult to obtain a soil sample that will give a representative measure of available soil N over the entire growing season. The nfs thus assumes primary importance. The non-fixing system is the measure of available soil N pool. It can be envisaged as being equivalent to sampling with time with >100 pipettes.

Fertilizer N: Fertilizers may have $\sigma a^{15}N$ values similar to those of the atmosphere. This will cause confusion between the two sources of plant N, and will result in incorrect estimates of %Ndfa. Rennie et al. (1976) (Table 2) found that NH_4^+ had $\sigma a^{15}N$ values ranging from +4.8 in $(NH_4)_2SO_4$ to -0.6 in NH_4NO_3 fertilizers. The formulation and the brand of fertilizer used had a significant

effect on the $\sigma a^{15}N$ values. In field studies to determine %Ndfa in Phaseolus vulgaris, Rennie and Kemp (1983) demonstrated that the addition of N fertilizer >20 kg/ha made it impossible to calculate %Ndfa using $\sigma a^{15}N$ measurement.

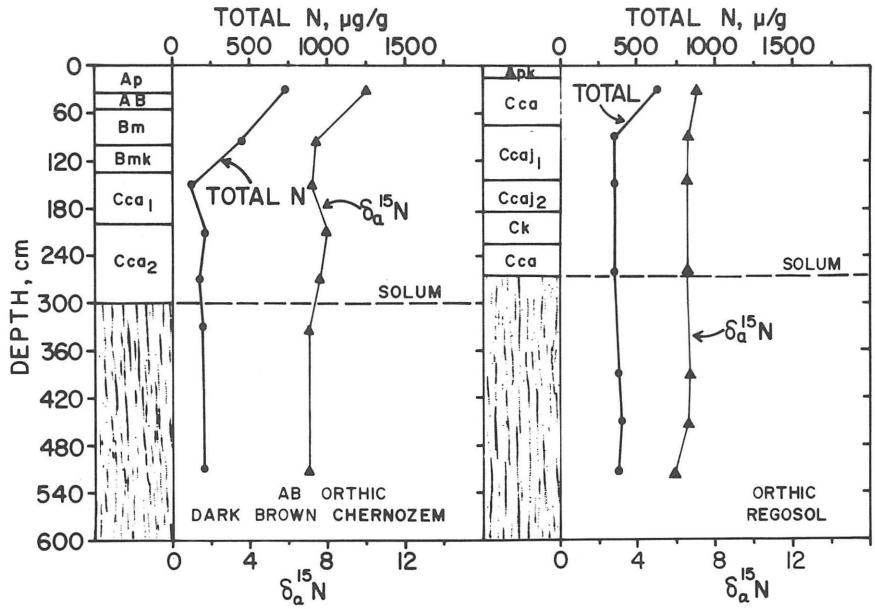

Fig. 3. Distribution of and total N and corresponding $\sigma a^{15}N$ values in typical western Canadian soil profiles (Karamanos and Rennie 1980b).

Accuracy: Significant changes in the at.%^{15}N at levels of natural abundance occur at the point of maximal analytical precision of most mass spectrometers. One $\sigma a^{15}N$ unit is 0.00037 at.%^{15}N. Accordingly, Broadbent et al. (1980) found that the magnitude of natural variation of $\sigma a^{15}N$ values of soil N, laterally and vertically, was so high as to preclude the tracing of biological events in the soil. They also proposed that spatial variability in $\sigma a^{15}N$ values was of the same order of magnitude as the difference between soil and atmospheric N. The soils under study had $\sigma a^{15}N$ of less than 4°/$_{oo}$ in the surface horizon, and this may be the cause of the comments of Broadbent et al. (1980). These findings are in direct contrast to those of other researchers (Kohl et al. 1981). Rennie (1982) showed that the precision of determining %Ndfa with ^{15}N enriched and natural abundance in soybean was idential (Table 3). It was suggested that the greater sampling accuracy offered by ^{15}N enrichment is counter-balanced by the greater homogeneity of labeling soil N in systems approaching natural abundance.

However, analytical determinations of such small amounts of ^{15}N require the use of a double collector type of mass spectrometer with an instrumental error of no more than ± 0.1 °/$_{oo}$.

The use of ^{15}N natural abundance techniques to qualitatively rank or determine %Ndfa quantities has received attention primarily in relation to N_2 fixation with legumes. It has been shown to be accurate compared with ^{15}N-enriched techniques in the field for determining %Ndfa with soybean (Domenach et al. 1979, Rennie 1982), field beans (Rennie and Kemp 1983), and clover (Trifolium sp.) and alfalfa (Medicago sativa) (Bardin et al. 1977).

Calculation of %Ndfa using $\sigma a^{15}N$ values shows great promise with legumes. Experimental precision will be particularly important when low levels of ^{15}N

enrichment are studied. Based on coefficients of variation of 10 to 15% for $\sigma a^{15}N$ determination in southern Alberta (Rennie and Kemp 1983), the limit for detecting N_2 fixation is approximately 10 to 20% of total plant N. Any lower level of N_2 fixation can only be detected with ^{15}N-enriched procedures.

Table 2. Natural ^{15}N abundance of different N fertilizer sources (Rennie et al. 1976).

Brand	Formulation	Compound	$\sigma a^{15}N$	
			NH_4^+-N	NO_3^--N
1	34-0-0	NH_4NO_3	-0.6	3.6
2	34-0-0	NH_4NO_3	1.0	4.8
3	21-0-0	$(NH_4)_2SO_4$	4.8	--
4	11-55-0	$NH_4H_2PO_4$	1.3	--

Table 3. Precision of ^{15}N isotope dilution technique to quantify %Ndfa in ^{15}N enriched and natural abundance experiments (Rennie 1982).

Experiment	Enrich			Natural Abundance		
	atom $\%^{15}N$ $(\underline{E})^z$			atom $\%^{15}N$ $(\underline{E})$		
	$\bar{x}$	s	cv (%)	$\bar{x}$	s	cv (%)
Milk River				0.3684	0.0049	1.3
Seibersdorf				0.3838	0.0225	5.9
Vauxhall	0.3929	0.0274	6.0			
Seibersdorf	0.7731	0.0610	7.9			
Sussenbrunn	0.9163	0.0830	9.1			

[z]Mean ($\bar{x}$) and standard deviation (s) of $\underline{E}$ (effectively inoculated nodulating isoline)

Applications of ^{15}N Isotope Dilution

Screening Soybean Cultivars for *NIS*

Plant breeders regard legumes as cereals, and breed for desirable agronomic traits under high fertility conditions, usually when the plant is in a non-fixing mode. It is imperative to select for nis, and since this trait has never been used as a basis for selection, sufficient natural variation probably exists in present populations.

Maple Amber (MA) is superior to X005 and Maple Presto (MP) in nis (Table 4). In 1981, Maple Amber fixed 96 kg N/ha (average of six strains of R. japonicum) compared with 91 and 60 kg N/ha for X005 and Maple Presto, respectively. Maple Amber was also superior to X005 in 1982.

Dinitrogen fixation in King Grain line X005 is also less sensitive to mineral N than Maple Presto. For X005, N_2 fixation was constant as N fertilizer increased from 0 to 80 kg/ha, but decreased by 24% when 160 kg N/ha was applied. Maple Presto's N_2 fixation was constant as N fertilizer increased from 0 to 40

kg/ha but decreased by 21% when 80 or 160 kg N/ha was applied (Rennie et al. 1982).

Screening Strains of *Rhizobium japonicum*

Strain-cultivar specificity, as well as competition problems between rhizobium added as inoculant and strains indigenous to the soil, require the study of strain effects on N_2 fixation. The use of R. japonicum strains 61A148 (USDA 142) and 61A118 (USDA 138) was consistently superior in terms of N_2 fixation with all Canadian soybean cultivars (Table 4), and resulted in higher N_2 fixation and higher seed yields than other strains. Strain 61A101 was a consistently inefficient N_2 fixer. Efficiency differences between strains were not related to an ability to take up H_2 evolved by nitrogenase because, although strain 61A148 was Hup^+, strain 61A118 was Hup^-.

Inter-strain competition occurred with one multi-strain inoculant to the detriment of plant yield. In 1981 a commercial mix containing four strains (61A101, 651A118, 61A124, 61A148) had low N_2 fixation (equal to that of strain 61A101). This suggested that strain 61A101 was highly competitive and may have formed a majority of the nodules, thereby excluding highly efficient strains 61A118 and 61A148. However, in 1982 a new commercial mix containing three strains that were clones of 61A101, 61A118, and 61A124 did not exhibit any detrimental inter-strain competition.

Several strains resulted in %Ndfa exceeding 50% with N_2 fixed as high as 151 kg N/ha for strain 61A148 on King Grain line X005. Line-strain combinations resulting in lower levels of N_2 fixation assimilated more soil N so that total N yields (not shown) over lines and strains were generally similar.

Table 4. Shoot nitrogen yield and N_2 fixed (determined by ^{15}N-isotope dilution) in Vauxhall's experiment.

Rhizobium Japonicum strain	N_2 Fixed (kg/ha) 1981				N_2 Fixed (kg/ha) 1982		
	X005	MP	MA	$\bar{x}$	X005	MA	$\bar{x}$
Uninoc.	0	0	0	0	0	0	0
Mix A	34	49	53	45			
Mix B					70	103	87
61A89	106	44	95	82	49	57	53
61A101	33	33	91	52	33	67	50
61A118	147	105	95	116	100	106	103
61A124	72	55	120	82	74	84	79
61A148	151	74	122	116	106	73	89
61A101c					105	74	89
61A118b					68	83	76
61A124a					69	123	96
x	91[y]	60	96		75	86	
$\omega(P<0.05)$[z] Cult.		8				10	
Strain		13				22	
Cult. x Strain		23				31	

[z]Tukey's honest significant difference
[y]Mean of inoculated treatments only

Effect of Biocides on N_2 Fixation

When using granular inoculant, herbicide or fungicide had a significant effect on nodulation, acetylene-reducing activity, or %Ndfa measured using ^{15}N isotope dilution (Table 5). However, in previous studies where higher rates of

the biocide were applied, thiram and trifluralin adversely affected nodulation, but not acetylene-reducing activity. We concluded that these herbicides and seed-applied fungicides have no effect on nodulation and N_2 fixation when granular inoculant is applied under Canadian growing conditions.

Table 5. Effect of selected fungicides and herbicides on seed and shoot yield and nodulation parameters in King Grain line X005 soybeans at anthesis (1982).

	Seed Yield[z] (kg/ha)	Shoot Yield (g/plant)	ARA Shoot N yield (kg/ha)	(nmol C_2H_4) min/plant	Nodulation[y]	$\sigma a^{15}N$ (o/oo)	Ndfa[x] (%)
Control	2242	9.0	45	271	3.0	6.0	54.8
Thiram	2192	10.8	55	251	2.8	6.6	50.1
Captan	2199	9.8	50	272	2.8	6.0	55.2
Carbathiin	2136	11.0	56	305	2.6	6.0	55.1
Chloramben	2153	10.2	56	342	2.6	5.2	61.5
Trifluralin	2153	9.7	50	201	2.4	6.4	51.9
Diclofop	2199	10.4	52	331	2.8	6.2	53.9
LSD (P 0.05)	ns[w]	1.4	8	ns	0.7	0.9	7.3

[z]Maturity harvest (R9)
[y]Scale: 0 = no nodules; 3 = control nodules
[x]Calculated using Hordeum vulgare cv. Galt as non-fixing system ($\sigma a^{15}N$ = 13.4 o/oo)
[w]Non-significant

Appendix

1. Percent N (plant) derived from fertilizer (%Ndff);

$$\%Ndff = \left(\frac{\text{at.}\%^{15}N \text{ ex. (plant)}}{\text{at.}\%^{15}N \text{ ex. (nutrient solution)}} \right) \times 100$$

where nutrient solution in the field is fertilizer N.

2. Percent N (plant) derived from atmosphere (%Ndfa):

$$\%Ndfa = 1 - \left(\frac{\text{at.}\%^{15}N \text{ ex.(fs)}}{\text{at.}\%^{15}N \text{ ex.(nfs)}} \right) \times 100$$

where fs and nfs are fixing and non-fixing systems, respectively.

3. Percent N (plant) derived from soil (%Ndfs):

$$\%Ndfs = 100 - (\%Ndff + \%Ndfa)$$

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Response of Soybean to Supplemental Nitrogen After Flowering

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Introduction

The amount of basal N applied to soybean (Gylcine max) is usually far less than the amount applied to other crops. Excessive basal N promotes soybean vegetative growth, which can lead to lodging or a reduction in the development of nitrogen-fixing nodules. Soybean has a relatively high N requirement, especially in the latter growth stages. Hanway and Weber (1971) found that about half of the N in mature soybean seed is translocated from other parts of the plant and that the remainder is derived from the soil and nodules. Approximately 300 kg N is needed to produce 3 t/ha of soybean; rice requires 100 kg N to produce 5 t/ha.

Soybean's N demand during the ripening stage, and its low response to basal fertilizer, might best be resolved by applying supplemental N after flowering. This practice could increase carbon assimilation by augmenting photosynthesis; it might also increase nitrogen assimilation to meet N requirements for seed development. The application of supplemental N after flowering has been tried before, but the results have been conflicting.

Carbon and Nitrogen Assimilation

Photosynthesis and Dry Matter Production

The effect of supplemental N on the photosynthesis of individual leaves and plants was examined. The rate of photosynthesis of individual leaves grown under saturated light tended to increase after 10 days (range of 91 to 192% compared with the control) (Table 1). Increases in photosynthesis lasted until at least 24 days after treatment initiation. The increase in average photosynthetic rate per unit leaf area was about 5% (Table 2), but because of lower rates of defoliation among the lower leaves, photosynthesis (of the whole plant) increased by about 8% at 10 to 14 days after treatment. No positive effects were observed 31 to 38 days after treatment.

In the shaded plot, the effect of top dressing on the photosynthesis of the whole plant, 10 days after treatment, was about the same as in the non-shaded plot, mainly because of an increase in plant leaf area (less defoliation). This effect could still be observed in the non-shaded plots 30 to 38 days after treatment, but in this case the causal factor was an increase in the average photosynthetic rate of whole plant leaves. This effect persisted for a longer period in the shaded plots, which suggests that supplementary N may increase yield more under shaded than under non-shaded conditions.

Among the five cultivars tested, 30 kg supplemental N/ha increased the total dry matter weight of all cultivars by 3 to 6%, except Dewamusume. Although stem weights increased in all cultivars, seed weights per unit area increased only in Norin 1, Norin 2, and Enrei (Table 3).

Table 1. Effect of supplemental N on photosynthetic rate of individual leaves grown under saturated light (Tabuchi et al. 1982b).

Cultivar	Treatment	Days After Treatment (mg $CO_2/dm^2/hr$ 1)[z] (ratio to control [%]) 10		24		
		upper leaf[y]	lower leaf[x]	upper leaf	lower leaf	Mean
Norin 1	control	29.4	17.8	16.3	17.0	20.1
	supplemental N[w]	26.7	18.8	22.8	18.3	21.7
		(91)	(106)	(140)	(108)	(108)
Norin 2	control	32.3	17.6	32.1	20.1	25.5
	+ N	39.4	17.0	31.9	14.5	25.7
		(122)	(97)	(99)	(72)	(101)
Enrei	control	24.0	9.3	28.3	15.9	19.4
	+ N	33.4	17.9	35.1	22.2	27.2
		(139)	(192)	(124)	(140)	(140)
Amsou	control	38.6	23.1	28.1	17.6	26.9
	+ N	39.3	22.4	38.0	24.5	31.1
		(102)	(97)	(135)	(139)	(166)
T 202	control	22.3	14.6	28.8	22.5	22.1
	+ N	26.3	16.5	30.1	27.3	25.1
		(118)	(113)	(105)	(121)	(114)
Mean	control	29.3	16.5	26.7	18.6	22.8
	+ N	33.0	18.5	31.6	21.4	26.1
		(113)	(113)	(118)	(115)	(114)

[z] Mean of 5 leaves
[y] Most active leaf on the main stem
[x] Lowest leaf on the main stem
[w] Supplemental N (ammonium sulphate) of 1 g N/pot applied 70 days after flowering

Nitrogen Fixation and Total Nitrogen Assimilation

Approximately 30% of total N accumulation is allotted to the seeds (Hanway and Weber 1971). Tanaka et al. (1978) reported a positive correlation between yield and N accumulation. Supplemental N reportedly increases both carbon and N accumulation. Symbiotic N fixation, however, is inhibited by N fertilizer. Therefore, the absorption of supplemental N may be negated by the depression of N fixation.

Fig. 1 shows the changes that occurred in the N accumulation of potted plants, as affected by the amount of supplemental N over the plants' entire life cycle. The absorption of the supplemental N increased linearly as N dosage increased (curve A); absorption efficiency was about 50% throughout the plant's life cycle. Cumulative N fixation increased linearly as supplemental N increased (curve B). This finding was based on C_2H_2 reduction and a 1:1 conversion factor obtained in another experiment (using an isotope dilution technique). This indicates that the amount of supplemental N absorbed, plus estimated fixed N, increased linearly as supplemental N increased (curve c). Total nitrogen accumulation (total N from soil, basal fertilizer, supplemental N, and fixed N) also increased with the increase in supplemental N (curve D). Because the slopes of curves c and d were almost the same, the estimate of N fixation from C_2H_2 reduction was correct, meaning that absorption of supplemantal N increased total N assimilation.

Table 2. Effect of supplemental N and shading on the photosynthetic rate of an entire plant (cv. Enrei).

Treatment	10 to 14 Days After Treatment									31 to 38 Days After Treatment								
	photosynthesis of a plant (P) $mgCO_2/plant/hr^z$			mean photosynthetic rate of leaves (Pm) $mgCO_2/dm^2/hr$			leaf area of a plant (L) $dm^2/plant$			(P) $mgCO_2/plant\ hr^z$			(Pm) $mgCO_2/dm^2/hr$			(L) $dm^2/plant$		
	A^y	B^x	C^w	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Control	738	100	-	18.4	100		42.6	100		714	100		15.7	100		45.6	100	
+ N^w	844	108	-	19.4	105		43.5	102		698	98		16.0	102		43.5	95	
$Shading^u$	686	88	100	17.9	97	100	38.4	90	100	595	83	100	15.2	97	100	39.1	86	100
Shading+N	738	94	108	17.5	95	98	42.2	99	110	630	88	106	16.4	104	108	38.4	84	98

^{z}mean of 5 plants
^{y}actual value
^{x}ratio to control (%)
^{w}ratio to shading (%)
^{w}supplemental N (ammonium sulphate), 1 g N/pot applied 14 days after flowering
^{u}plants were kept shaded (light penetration 60 to 70%) 14 days after flowering until maturity

Table 3. Effect of supplemental N on dry matter weight at harvest (Tabuchi et al. 1982b).

Cultivar	Treatment	Total Wt. g/m^2	Stem Wt. g/m^2	Seed Wt. g/m^2	Seed-Stem Ratio
Harosoy	control	696	141	423	3.00
	+ N	(101)	(102)	(99)	(97)
Dewamusume	control	699	220	371	1.69
	+ N	(100)	(106)	(97)	(91)
Norin 1	control	629	176	319	1.81
	+ N	(103)	(105)	(108)	(104)
Norin 2	control	632	180	320	1.78
	+ N	(106)	(104)	(108)	(103)
Enrei	control	672	207	322	1.56
	+ N	(105)	(104)	(106)	(104)
Mean	+ N	(103.0)	(104.2)	(103.6)	(99.8)

( ): ratio to control (%); supplemental nitrogen (ammonium sulphate) 30 kg N/ha applied 68 days after planting

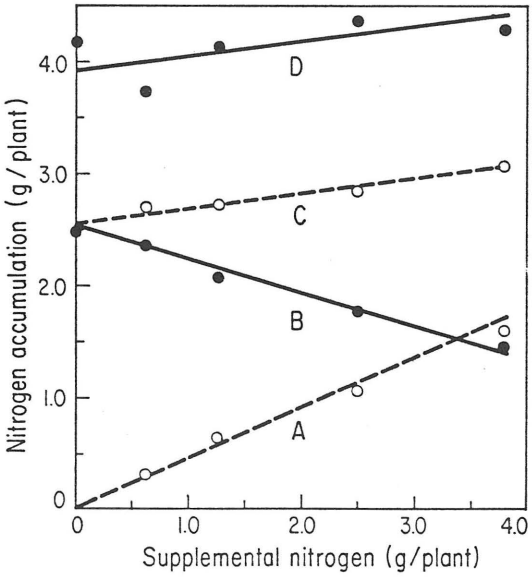

Fig. 1.
Change in accumulated N from different sources as affected by supplemental N. Cv. Bonminori was cultured in pots with a basal dressing of 1.2 g N/plant. Supplemental N (ammonium sulphate) was applied at flowering. A = supplemental N, B = fixed N estimated by C_2H_2 reduction of nodules, C = A + B, D = total N (from soil, basal, supplemental N, fixed N).
Source: Nakano et al. (unpublished)

Yield and Protein Increases

A field experiment was carried out using six determinate and six indeterminate cultivars. The 60 and 120 kg N/ha applied 10 days after flowering increased average yields by 4.8 and 6.7%, respectively (Table 4). Yield increases were mainly due to increases in 100-seed weight.

Table 4. Analysis of variance on the effect of supplemental N on yield and yield components (Watanabe et al. 1982).

Character	Source	F Value	Ratio to F_0 (%)	
			F_6	F_{12}
Yield/plot	F	17.90**	105	107
	SF	0.36		
Number of pods/plot	F	0.89	101	101
	SF	0.27		
Number of seeds/pod	F	3.25*	101	101
	SF	0.40		
100-seed weight	F	61.90**	103	105
	SF	0.29		

From a field experiment of 12 cultivars (Waseshiroge, Bonminori, Karumai, Nanbushirome, Shinanomejiro, Tamahomare, Chippewa, Harosoy 63, Hawkeye, Lincoln, Woodworth, and Illinois). Supplemental N (ammonium sulphate) 60 (F_6) or 120 (F_{12}) kg N/ha was applied 10 days after flowering. F: main effect of nitrogen, SF: interaction between nitrogen and spacing, F_0: control, *, **: significant at 5 or 1% level, respectively

The response varied according to cultivar, however (Fig. 2). With cultivar Chippewa, yield, pod number, seed number/pod, and 100-seed weight increased. Cultivar Waseshiroge's increase in 100-seed weight was negated by a decrease in pod number. Seed number/pod remained almost constant, which in turn limited the

yield increase. The yield increases recorded for early and medium maturing cultivars appeared to be due to increases in 100-seed weight; yield increases in late cultivars were associated with an increase in pod number. No differences were observed between determinate and indeterminate cultivars.

Seed N content (protein content) increased an average of 3.3% for all twelve cultivars. The most sensitive cultivar was Hawkeye (6.5%) and the least sensitive was Nanbushirome (1%). N yield per unit land area increased an average of 10.3%. The most sensitive cultivar was Hawkeye (15.4%) and the least sensitive was Waseshiroge (4.8%).

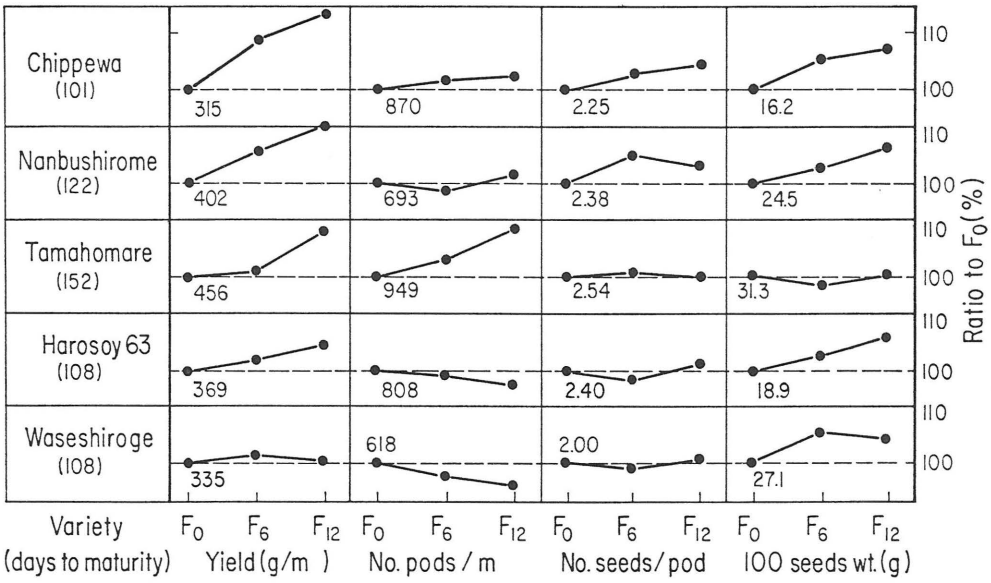

Fig. 2. Effect of supplemental N (ammonium sulphate) on yield and yield components. Sixty (F_6) or 120 (F_{12}) kg N/ha was applied 10 days after flowering (control data (F_0) are indicated).
Source: Watanabe et al. (1982)

Effectiveness of Supplemental Nitrogen

Amount of Nitrogen Applied

Supplemental N (ammonium sulphate), in varying amounts, was applied at flowering to cultivar Bonminori. Yields increased in direct proportion to N application up to a saturation point of 180 kg/ha of (Fig. 3B). In this experiment the yield of the control plot was lower than expected, so the percent increase in the test cultivars seemed quite high. However, the data suggested that optimum N may actually be higher than is presently believed. For this reason experimental results for the past three years were checked to determine the relationship between N application and yield (Fig. 3A). The analysis indicated that the N saturation point is approximately 100 kg N/ha, when yield increases about 10%.

Soil Fertility

It was presumed that plant response to applied N may vary according to the soil fertility level in a given location. The results of a field experiment with

12 cultivars suggested that the cultivars' responses could be classified into four groups judging from the productivity of the control plots. Variation in productivity was apparently due to variations in soil fertility as shown in Fig 4E.

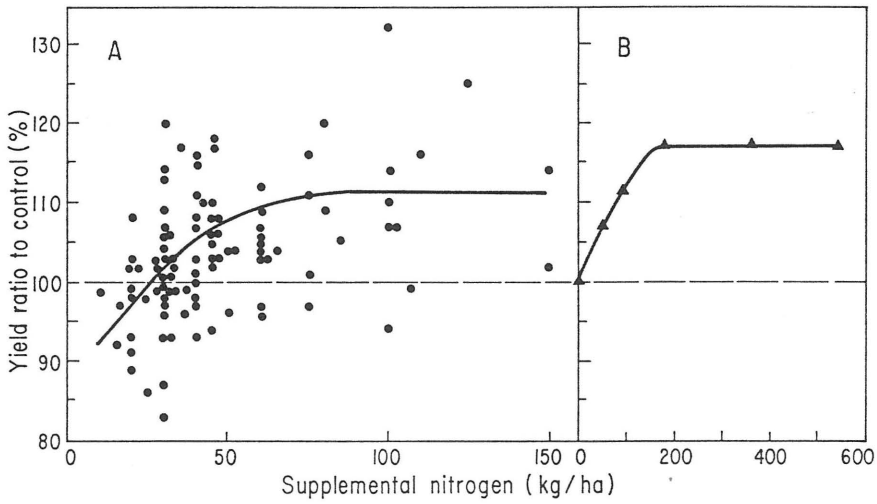

Fig. 3. Yield increase as affected by applied nitrogen. A = Summarized review of experiments carried out at prefectural agriculture experiment stations in Japan, 1979-81. Supplemental N (mostly ammonium sulphate) was applied from flowering to pod setting, in most cases. B = Ammonium sulphate applied to Bonminori at flowering (average 6 replications) Source: Watanabe and Nakano (1982) and Nakano et al. (1982)

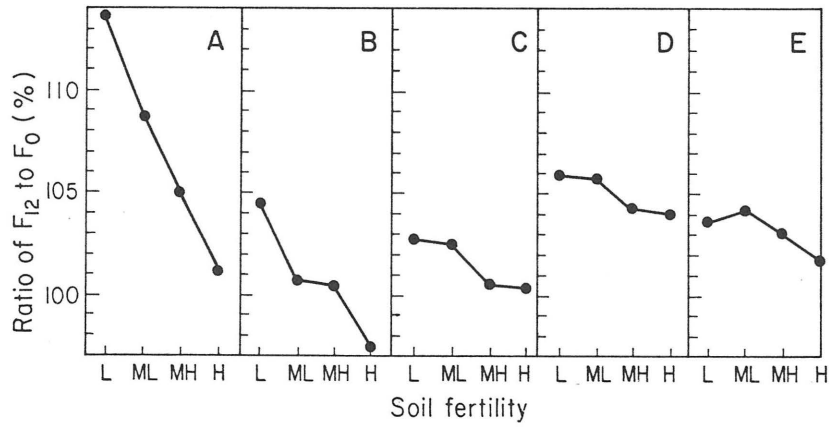

Fig. 4. Effect of supplemental N on the yield, yield components, and N content of seed as affected by soil fertility (also see F_{12} Table 4). A = yield, B = number of pods, C = number of seeds per pod, D = 100-seed weight, E = nitrogen content of seed, L = low fertility, ML = medium low fertility, MH = medium high fertility, H = high fertility.
Source: Watanabe (1982a)

Yield increases due to applied N were negated by the increase in soil fertility (Fig. 4A). All yield components tended to decrease in more fertile

soil (Fig. 4 B-D). Cultivars Chippewa, Karumai, Shinanomejiro, and Nanbushirome had the highest N response. Yields increased by 4.1% when 120 kg N/ha was applied. The least responsive cultivars were Waseshiroge and Harosoy 63; yields decreased by 3.6%, mainly because of decreases in pod number per unit land area.

Generally, supplemental N applied on fields converted from paddy rice (Oryza sativa), showed that the response to N increased with time (Table 5).

Table 5. Effect of supplemental N on the yield of soybean cultivated on fields converted from paddy-rice as affected by N application (Watanabe 1982 b)[z,y].

Nitrogen (kg N/ha)	Field History (years from paddy at sowing) 0	1	2 ≦
< 34	99.2	103.4	102.9
35 - 64	101.3	102.5	107.6
65 <	104.8	106.9	109.8
Mean	101.8	104.3	106.8

[z] From summarized review of the experiments on supplemental nitrogen on fields converted from paddy at prefectural agriculture experiment stations, 1979-81

[y] The effect is shown in relative ratio of the yield against the control (%)

Solar Radiation

Photosynthesis experiments with potted plants showed that supplemental N may be more effective under shaded rather than non-shaded conditions. We examined this phenomenon in a field experiment (Table 6). A total of 12 g N/m^2 was applied to cultivar Enrei 10 days after flowering. In the shaded plot, a layer of cheesecloth covered the field from the time of N application until maturity. Light penetration in the shading 1 and 2 treatments was about 60 to 70% and 45 to 50%, respectively. The yield response to N was greater in the shading 1 treatment (15%) than in the control (8%). Yield was reduced by 12% in the shading 1 treatment, but recovered when supplementary N was applied. Shading reduced 100-seed weight severely, but N increased both seed number/pod and pod number. In the shading 2 treatment, however, no yield/N effect was observed. It appears that application of N under slight shading increases photosynthesis, but that it reduces nodule activity (Tabuchi et al. 1982a). This, in turn, increases the plants' dependency on applied N.

Table 6. Effect of supplemental N and shading on the yield and yield components of soybean cultivar Enrei. (Tabuchi et al. 1983).

Treatment	Yield			Pod Number			Seed Number			100-seed wt.		
	g/m^2	ratio	%	per m^2	ratio	%	seeds/pod	ratio	%	g	ratio	%
Control	242	100		457	100		1.70	100		31.3	100	
+ N	262	108		512	112		1.68	99		30.5	97	
Shading 1	213	88	100	453	99	100	1.82	107	100	25.8	82	100
Shading 1 + N	244	101	115	494	108	109	1.91	112	105	25.9	83	101
Shading 2	165	68	100	349	76	100	1.78	105	100	26.5	85	100
Shading 2 + N	162	67	99	396	87	114	1.58	93	89	25.7	82	97

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Soil Tests for Predicting Soybean Phosphorus and Potassium Requirements

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Introduction

A series of experiments was conducted over a ten-year period in Queensland, Australia to study the phosphorus and potassium nutrition requirements of soybean (Glycine max). The objectives were to assess the usefulness of soil tests in diagnosing nutrient deficiencies and to develop techniques for predicting optimum fertilizer requirements (Kurtz 1975).

Materials and Methods

Phosphorus

Phosphorus fertilizer rate experiments were carried out at 27 field sites. Representative soil samples (0 to 10 cm) were taken at all sites prior to fertilizer application. Each sample was analyzed using several soil P tests: Resin extractable P (P_R), 0.5 M $NaHCO_3$ extractable P (P_B), 0.005 M H_2SO_4 extractable P, 0.01 M $CaCl_2$ extractable P (P_C), and equilibrium phosphorus concentration (EPC) and phosphorus buffer capacity derived from P sorption curves (Moody et al. 1983).

Potassium

Nineteen potassium rate experiments were conducted from 1973-77. Soil samples (0 to 10 cm) were taken at all sites; available soil K levels were determined by 0.05 M HCl extraction (Dickson et al. 1983).

Although field rate experiments are still being conducted, since 1977 a number of alternative K availability indices have been used: Exchangeable K (K_{EX}), 0.05 M HCl extractable K (K_A), total K, 0.005 M $CaCl_2$ extractable K (K_C), and boiling NH_4Cl extractable K. Availability indices were also calculated:

$$1)\ \frac{K_{EX}}{\text{cation exchange capacity}} \qquad 2)\ \frac{K_{EX}}{\text{exch (Ca + Mg + Na + K)}}$$

Results and Discussion

Phosphorus

Significant ($P<0.01$) grain yield increases were observed at ten sites when P fertilizer was applied.

EPC and P_C were well correlated with relative grain yield (Table 1). Soybean responded to the intensity factor of the soil supply, i.e. phosphorus concentration of the soil solution. Critical soil levels for EPC and P_C were 0.0065 µg P/ml and 0.051 µg P/g, respectively.

The amount of band-applied P required for 90% maximum grain yield was found to be highly correlated with EPC by the equation:

$$y = 167.7 - 25426.8\ x\ (r^2 = 0.83^{**},\ n = 10)$$

(where y = banded P required (kg/ha) and x = EPC (µg P/ml)).

The equation covers P requirements from 0 to 76 kg P/ha, and is used to predict P requirements for field validation experiments, both on latosols and other soil types where soybean is grown.

Potassium

Significant ($P<0.01$) yield responses were observed at only four sites, and responses were not consistent with low soil test values. Thus, grain response could not be calculated in relation to the soil test.

Table 2 shows that sites 4, 6, and 8 responded to K application; all had low soil K levels as determined by K_C.

The Cate and Nelson (1962) method was used to define the critical soil test value. This was unsuccessful for all soil tests and availability indices, with the exception of K_C where a significant ($r^2 = 0.68^{***}$) separation of responsive and non-responsive sites was obtained at a critical soil test value of 0.04 meq K/100 g soil. More sites are being assessed so that continuous regression models can be fitted to soil tests and relative grain yield data.

Conclusions

Test results indicate that soybean response to phosphorus and potassium is best estimated by an intensity related measurement. A dilute $CaCl_2$ soil extract can be used to diagnose both P and K deficiencies for soybean.

Table 1. Percent variation in relative grain yield accounted for by soil test regressions.

Soil Test	(%) Variation Accounted For
P_R	1 (1)[z]
P_B	15 (2)
EPC	80 (1)
P_C	73 (1)

[z] Values in parenthesis refer to the regression models of best fit: (1) $Y = b_0 + b_1x + b_2x^2$; (2) $Y = b_0 + b_1\sqrt{x} + b_2x$.

Table 2. Relative yield and some chemical characteristics of the potassium test sites.

Site No.	RGY[z]	K_C[y]	K_{EX}[x]	K_A[w]
		meq/100 g		
1	92	0.05	0.08	0.09
2	90	0.09	0.20	0.13
3	100	0.09	0.23	0.27
4	84	0.03	0.10	0.10
5	95	0.05	0.09	0.09
6	74	0.04	0.14	0.14
7	96	0.07	0.55	0.29
8	62	0.04	0.13	0.15
9	94	0.07	0.13	0.10

[z] Relative grain yield = $\frac{\text{Yield at zero K applied}}{\text{maximum measured yield}} \times 100$

[y] 0.005 M $CaCl_2$ extraction

[x] 1 M NH_4Cl extraction

[w] 0.05 M HCl extraction

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Soybean Tolerance to Manganese in the Tropics

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Introduction

A survey of superficial soil horizons in the State of São Paulo, Brazil (Valadares and Camargo 1981) showed Mn variations of 3 to 190 mg/l. Mascarenhas et al. (1981a) observed that the toxic effects of Mn in distrophic, dusky red latosols reduced soybean yield. It was also shown that the amount of lime required to reduce Mn toxicity is greater than the amount required to eliminate Al. Similar results were obtained by Mascarenhas et al. (1981b) and Quaggio et al. (1982).

At present, there is no practical or economical way of incorporating lime near the soybean root zone. An alternative would be to select soybean cultivars that are Mn tolerant. The objective of the present study was to develop a screening method to identify Mn tolerant cultivars.

Materials and Methods

Experiment 1

An experiment was conducted using a split plot design with two replications; the main plots were four Mn concentrations (0.11, 2.0, 4, and 6 mg/l) and the subplots were cultivars IAC-9, Santa Rosa, Biloxi, and Forrest (see Spehar et al., eds.). Forrest, which is reportedly sensitive to Mn toxicity (Ohki et al. 1980), was used as the check.

Seeds were germinated in paper towels at 28°C for 48 hr. Twenty seedlings per cultivar were selected and inserted in the open spaces of a nylon screen attached to an open-top lid. The lid was placed over a plastic pot containing 8.3 l of nutrient solution. Contact was established between the screen and the solution so that the emerging radicals would have a ready supply of nutrients. The composition of the nutrient solution was $Ca(NO_3)_2$ 0.4mM, $MgSO_4$ 0.2mM, KNO_3 0.4mM, $(NH_4)_2SO_4$ 0.435mM, KH_2PO_4 0.05mM, H_3BO_3 1µM, $CuSO_4$ 0.03µM, $ZnSO_4$ 0.08µM, Na_2MoO_4 0.01µM, and Fe CL_3 10µM. Mn, in the form of $MnSO_4.4H_2O$ (0.11, 2.0, 4.0, and 6.0 mg/l) was added to each pot. The solution was continuously aerated, and its pH was adjusted daily to 4.8 using H_2SO_4. The plastic pots were placed in water to maintain a constant temperature of 25°C (±1°C).

The roots were separated from the tops after a period of 15 days. Roots and tops of each treatment were oven-dried (60°C/5 days) and then weighed for dry matter content. The tops were analyzed for P, K, Ca, Mg, and Mn (Bataglia et al. 1978).

Experiment 2

Dusky red latosol soil from four locations (20-40 cm depth) in the State of São Paulo were analyzed for their chemical constituents.

The experiment (split plot design with six replications) was conducted in the winter using two cultivars selected in experiment 1: Forest (Mn susceptible) and Biloxi (Mn tolerant). The test pots contained 4 kg of unfertilized soil that was high in P and K. Four seeds of each cultivar were planted per pot. The pots were thinned to one plant per pot when the first unifoliolate leaf appeared. The tops and roots of 27-day-old plants were separated, washed with distilled water, oven dried (60°C), and weighed. The tops were also analyzed for macronutrients and Mn (Bataglia et al. 1978).

Plant susceptibility or tolerance to Mn were scored before harvesting based on the following criteria:

Score 1	Symptoms of necrosis starting from the first unifoliolate leaf;
Score 2	Symptoms of necrosis starting from the first trifoliolate leaf;
Score 3	Symptoms of necrosis starting from the second trifoliolate leaf;
Score 4	Symptoms of necrosis starting from the third trifoliolate leaf; and
Score 5	No symptoms

Results and Discussion

Experiment 1

Initial Mn toxicity symptoms appeared on Forrest seven days after the transfer of the seedlings to the 6 mg/l Mn nutrient solution. Symptoms subsequently appeared on IAC-9, Santa Rosa, and Biloxi, in that order. Symptoms were similar to those described by Heenan and Carter (1976). Both Forrest and IAC-9 showed severe Mn symptoms in the 6 and 4 mg/l treatments after 15 days; the symptoms were less intense at 2 mg/l. Santa Rosa and Biloxi had more severe symptoms at 6 mg/l than at 4 mg/l, but the symptoms were less severe than those found in Forrest and IAC-9 grown at comparable solution rates.

At 2 mg/l, Forrest's dry weight was reduced by 33% compared with the resistant check; both Biloxi and Santa Rosa were more tolerant (Table 1). The visual symptoms confirmed the susceptibility of Forrest and the tolerance of Biloxi at 4 mg/l. All cultivars showed susceptibility at 6 mg/l. Plant top dry matter appeared to be a good parameter for evaluating susceptibility or tolerance. This confirms a preliminary observation made by Mascarenhas et al. (1982). Root dry matter was not a reliable parameter.

P and K (but not Ca and Mg) concentrations in the tops increased as Mn solution levels rose (Table 2).

Mn concentration was not necessarily reflected in the tolerance or susceptibility of a cultivar; Biloxi had the highest Mn concentration (tops) but was rated as tolerant.

Experiment 2

All four soils were shown to have high concentrations of P and K (Table 3). As Ca and Mg decreased (from Campinas to Candido Mota), Mn concentrations increased; Al levels were high only at Candido Mota.

In the Campinas soil, Biloxi and Forrest showed no visual symptoms of Mn toxicity at an Mn level of 2.9 ppm. However, Forrest showed initial Mn toxicity

symptoms at Guaíra (Table 4), consisting of inward curling of the leaf margins, crinkling or puckering on the leaf surface, and necrosis of the veins. Mn concentrations at Guaíra were 220% higher than at Campinas. Both cultivars showed Mn toxicity symptoms in Guatapará and Candido Mota soils. The symptoms were more severe in Forrest than in Biloxi. Forrest, in addition to normal Mn toxicity symptoms, suffered from restricted vegetative growth (dwarfism) and shortened internodes. The Mn concentration in both soils was four times higher than in the soil found at Campinas.

Analysis of variance of the dry weights of the tops and roots showed significant differences in the behavior of each cultivar, independent of soil type (Table 4). With Forrest, Mn toxicity reduced root dry weight by a factor of four in Guatapará and Candido Mota soils, compared with Biloxi grown in the same soils.

Chemical analysis of the tops of both cultivars in four soil location types showed greater N concentrations (Table 5) when Mn toxicity symptoms were observed (Guatapará and Candido Mota). Greater P concentrations were detected in Forrest. There was also a general potassium increase in both cultivars as one moved from Campinas to Candido Mota. Mn concentrations in the tops were far lower at Campinas and Guaíra than at Guatapará and Candido Mota. This resulted in dry weight reductions in the tops and roots (Table 4).

Table 6 shows the quantity of Mn absorbed by both cultivars and the relationship between Mn concentrations in the tops and dry weight. Biloxi absorbed almost twice as much Mn as Forrest in Guatapará and Candido Mota soils. On the other hand, Forrest showed vegetative stunting due to Mn toxicity. The Mn tolerance index (Mn concentration/dry weight), visual scores, and the dry weight of the tops (Table 4) all proved to be good parameters for distinguishing between tolerance and susceptibility. This confirms that visual scoring can be used for rapid screening for Mn tolerance. The results obtained in the nutrient solution experiment were confirmed in the soil pot culture experiment, indicating that screening for Mn tolerance can also be conducted with nutrient solutions.

Table 1. Effect of different Mn concentrations on the average yield of top and root dry matter and the relative productivity of four cultivars grown in nutrient solution.

Mn[z]	Top Dry Matter Yield							
	IAC-9		Santa Rosa		Biloxi		Forrest	
	mg	%	mg	%	mg	%	mg	%
0.11	193	100	206	100	164	100	138	100
2.0	153	79	168	82	144	88	93	67
4.0	114	59	145	70	122	74	78	57
6.0	112	58	91	44	109	66	63	46
	Root Dry Matter Yield							
0.11	40	100	39	100	29	100	16	100
2.0	36	90	29	74	24	83	15	94
4.0	27	68	28	72	26	90	16	100
6.0	27	68	23	59	24	83	14	88

[z]concentration mg/l

Table 2. Effect of different Mn concentrations on the concentration of P, K, Ca, Mg, and Mn in the tops of four cultivars.

Mg^z	Concentration of Nutrients in the Tops				
	P	K	Ca	Mg	Mn
	(%)				(ppm)
			IAC-9		
0.11	0.332	2.10	1.00	0.33	40
2.0	0.379	2.36	1.01	0.34	692
4.0	0.433	2.74	0.97	0.34	1078
6.0	0.489	3.08	0.98	0.37	1308
			Santa Rosa		
0.11	0.281	1.84	0.93	0.26	56
2.0	0.335	2.32	0.97	0.30	703
4.0	0.385	2.68	0.93	0.33	1081
6.0	0.486	3.45	0.99	0.36	1339
			Biloxi		
0.11	0.33	1.78	0.91	0.27	56
2.0	0.317	1.83	0.86	0.28	765
4.0	0.387	2.31	1.04	0.25	1278
6.0	0.435	2.88	1.14	0.38	1441
			Forrest		
0.11	0.249	2.00	0.73	0.31	30
2.0	0.447	2.16	0.85	0.38	714
4.0	0.551	2.92	0.70	0.36	1143
6.0	0.572	3.63	0.65	0.32	1288

[z] concentration mg/l

Table 3. Pot culture soil analysis.

Locations	Chemical Properties						
	pH	P	K	Ca^{+2}	Mg^{+2}	Al^{+3}	Mn
		-ug/ml-		(meq/100 ml of dry soil)			(ppm)
Campinas	6.8	12.0	164	2.0	0.5	0.0	2.9
Guaíra	5.4	20.4	200	1.5	0.5	0.0	6.4
Guatapará	5.8	19.1	112	1.1	0.4	0.4	11.3
Candido Mota	5.0	21.7	172	0.6	0.4	1.4	12.9

Table 4 on next page

Table 5. Nutrient concentrations in the top dry matter of two soybean cultivars grown in soils from four locations.

Location	Cultivar	N	P	K	Ca	Mg	Mn	Fe	Zn	Al
		(%)					(ppm)			
Campinas	Biloxi	2.68	0.195	2.05	1.28	0.32	67	152	20.5	165
	Forrest	2.57	0.195	2.29	1.21	0.33	61	148	21.4	128
Guaíra	Biloxi	3.06	0.159	2.28	0.69	0.31	110	119	24.2	113
	Forrest	3.25	0.178	2.57	0.72	0.34	115	114	23.6	103
Guatapará	Biloxi	5.39	0.121	2.14	0.89	0.31	365	137	19.9	115
	Forrest	5.39	0.248	2.80	1.02	0.38	418	116	30.0	82
Candido Mota	Biloxi	5.39	0.174	2.55	0.42	0.30	679	114	21.4	195
	Forrest	6.42	0.269	3.57	0.48	0.40	701	110	33.2	334

Table 4. Visual scores and average dry matter yield of tops and roots of two cultivars grown in soils from four locations.

Cultivar	Location				
	Campinas	Guaíra	Guatapará	Candido Mota	Average
			Scores on visual symptoms		
Biloxi	5.0a[z]	5.0a	4.3a	3.5a	4.4a
Forrest	5.0a	4.2b	2.3b	1.5b	3.2b
			Dry weight of tops (g/plant)		
Biloxi	1.21a	1.23a	0.69a	0.77a	0.98a
Forrest	1.03b	1.11b	0.32b	0.39b	0.72b
			Dry weight of roots (g/plant)		
Biloxi	0.58a	0.56a	0.34a	0.34a	0.46a
Forrest	0.44b	0.48b	0.09b	0.09b	0.28b

[z]t test at 0.05 level

Table 6. Mn absorption (µg/plant) and the relationship between the concentration of Mn in the tops and top dry weight.

Cultivar	Locations			
	Campinas	Guaíra	Guatapará	Candido Mota
			µg/plant	
Biloxi	81	135	252	523
Forrest	62	128	134	273
			Concentration Mn/top dry weight	
Biloxi	55	89	529	882
Forrest	59	104	1306	1797

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Discussion Section V

General Comment by L. R. Frederick:

There have been several reports of inoculation trials in which no yield response was found. How can these results be evaluated? What do they really mean? They most definitely do not prove that inoculation is not needed or useful. Here are some pertinent questions.

1. Was there a nitrogen deficiency? As Dr. Rennie pointed out, if soil nitrogen meets the need for the yield obtained, no response to nitrogen fixation or nodulation should be expected. Low yields often require little extra nitrogen.

2. Did the inoculant carry live rhizobia of the right kind in adequate numbers? This question is really two separate questions, but rarely is enough information available to provide the answers. Even the best inoculant is perishable, and the rhizobia can die off due to excessive heat or drying either in the bag or after the inoculant is applied to the seed or the soil. Under good field conditions, application of more than one million rhizobia per seed have increased yields over lower numbers. Under poor field conditions, even higher numbers may be needed. Yet, normal recommendations are likely to provide less than ten thousand rhizobia per seed. If the rhizobia are not the proper ones for the soybean cultivar used, little or no fixation results. Could soybean productivity be evaluated with seed of unknown germination, unknown purity, and seed that is planted at less than optimum plant populations? Inoculant quality also needs to be assured, and it can be by proper microbiological and plant growth tests. If the quality is satisfactory, and nodulation is still not adequate, tests using very high rates should be made.

3. Did the inoculant rhizobia actually form the nodules on the soybean? If the soil does not contain rhizobia for soybean (no nodules on uninoculated plants), then one usually can assume the nodules were formed by the inoculant strain. But, when soil rhizobia are present and the soil rhizobia form the nodules, in both uninoculated and inoculated treatments, no response would be expected. Note that the effect of the inoculant strain was not tested. Larger numbers of rhizobia should be applied or a more aggressive strain should be used (or both) to obtain nodules formed by the inoculated strain. The fate of the inoculated strain can be traced by using a "marked" strain. Marking is usually done by serological reaction or antibiotic resistance. Relatively simple laboratory tests can accomplish this, and they can be a regular part of current inoculation trials. NifTAL can provide both marked test strains and antisera for soybeans and other legumes, and can assist in the identification of the marked strains.

   Legume inoculation with high quality inoculant assures that soybeans can make use of the nitrogen in the air, but legume inoculation does not replace other nutrients, good husbandry, or good seed of good cultivars. Legume inoculation trials are relatively simple to do, but results showing no yield response are difficult to interpret and should not automatically be assumed to show that inoculation is not needed or not useful.

Question: Is there some antagonistic effect between Azolla and rhizobia in sequential cropping of rice and soybeans?

Rennie: We do not know.

Nodulation by indigenous rhizobia, which may be by natural selection, does not necessarily favor higher N_2 fixation. Many of these competitive strains are, in fact, very poor N_2 fixers. When it is said, "There was no response to inoculation", it implies no yield increase due to inoculation. This does not mean inoculation was unsuccessful. The inoculated treatment may have more N_2 fixed but less soil N uptake. Thus, inoculation may not result in a yield increase but rather an alternation of N sources permitting attainment of that yield. Increasing soil pH by Azolla in rice would be more of a problem for soybean itself rather than R. japonicum. Peat-based inoculant carriers have a high cation exchange capacity which buffers against pH changes. Also, Rhizobium strains which exhibit pH tolerance may be selected. Thus pH extremes will be easier to resolve in R. japonicum than in the soybean cultivars.

Question: What is the prospect and potential of vesicular arbuscular mycorrhizae (VAM) on soybean?

Dickson: We are looking at VAM and phosphorous nutrition in Australia.

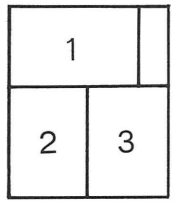
Question: What can we recommend to the soybean farmer as far as encouraging the plants to have an early supply of starch to the growing rhizobium nodules to compensate for the 10 kg/kg of nitrogen fixed in the nodules?

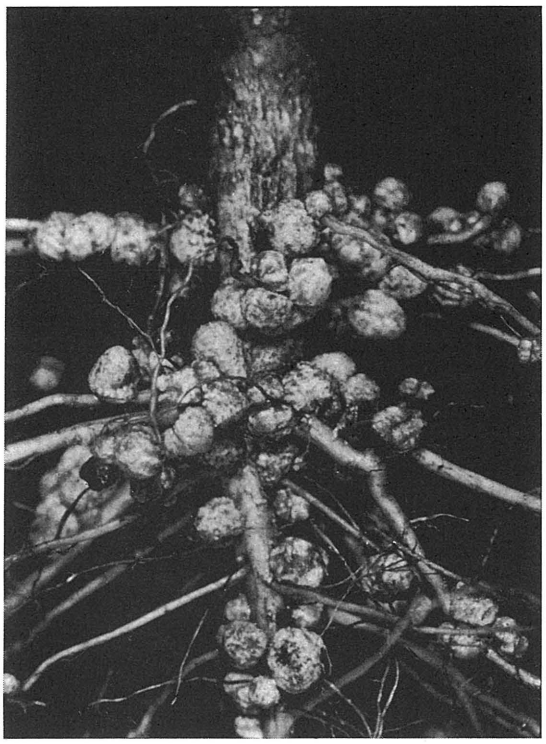
Unknown: The partitioning of the photosynthetic products between the developing shoots and the growing roots is the problem, and not the total starch product which judges the supply of the growing Rhizobium with energy.

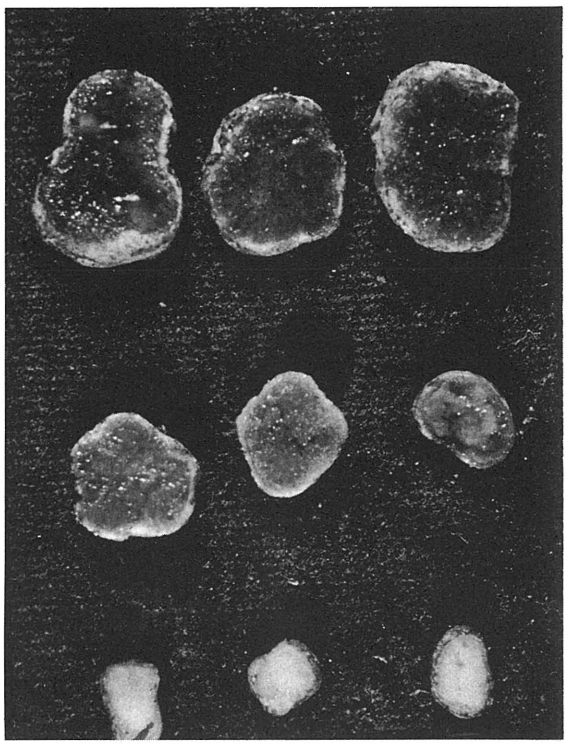
Summerfield: Pot experiments can be a useful adjunct to field work only if plants grown under such situations closely resemble - morphologically, phenologically, and physiologically (if this can be quantified!) - plants grown in the field. Careful attention should be given to pot volume, color, material with which the pot is made, the rooting medium used, how it is irrigated, and the diurnal regime in which it is placed. The conditions and objectives of pot experiments should be defined very carefully.

Soybean Nodulation Guide

1) Inoculated (dark) and uninoculated (light) soybean in a field with no previous history of soybean cropping. 2) An example of a well nodulated soybean root system. 3) Cross sections of effective soybean root nodules with leghaemoglobin pigmentation (top), moderately effective nodules (center), and ineffective nodules (bottom). The ineffective nodules are characterized by the absence of leghaemoglobin. Photos courtesy of J. C. Burton







Section VI
Physiology

The Physiology of Soybean Yield Improvement

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Introduction

Soybean (Glycine max) offers a number of advantages over other crops, e.g. its ability to fix N_2, its low phosphorus requirements (Tadano and Tanaka 1980), its tolerance to low pH and high levels of Al (Tanaka and Hayakawa 1975), and its tolerance to high soil moisture content (Tadano et al. 1979).

The data in Table 1, which were obtained from a long-term NPK experiment at Hokkaido University in Japan demonstrate that:

1. Yield in the PK treatment, relative to the NPK treatment, was far higher for soybean than for maize (Zea mays) and potato (Solanum tuberosum), although absolute soybean yield was the lowest of the three crops tested, and

2. That soybean seed yield in the NPK treatment was lower than that of any other crop when expressed on a dry weight basis.

These two facts, which are characteristic of soybean, are discussed in the following paper.

Table 1. Result of NPK trial using soybean, maize, and potato (avg. 1977-78).

Crops	Yield with NPK (t/ha)	Relative Yield (yield with NPK [%])		
		PK	NK	NP
Soybean	3.05	112	79	54
Maize	6.92	8	87	96
Potato	9.61	43	78	24

Dinitrogen Fixation and Combined Nitrogen Absorption

Because of its ability to fix N_2, soybean grown without N can produce seed yields equal to, and sometimes greater than, soybean grown with N fertilizer. Soybean N_2 fixation is higher than that of many other grain legumes, including field beans (Tanaka et al. 1978).

In our experiments, two isogenic lines, A62-1 (nodulating) and A62-2 (non-nodulating), were tested. Both lines were grown with graded levels of ammonium sulfate (Fujita and Tanaka 1982). A62-1 yield increased slightly as N application increased (Fig. 1A). A62-2 yield was far lower without N than in the corresponding treatment for A62-1.

The amount of N that accumulated in the plants was greater in A62-1 than in A62-2 when no N was applied, but increased in both lines as N application increased. N accumulation was greater in A62-1 than in A62-2 (Fig. 1B).

We assumed that: 1) the amount of N accumulated by A62-2 without N application is the amount of soil N absorbed by the plant, 2) the balance between the amount of N accumulated in the plant without N application and that at a given level of N application in A62-2 is the amount of N absorbed from fertilizer, and 3) the balance between N accumulation by both cultivars at a given level of N application is the amount of N fixed by A62-1. In this experiment the soil N absorbed was 101 kg/ha; the amount fixed was 128 kg/ha in A62-1 without N application; and the amount of N absorbed increased while the amount of fixed N decreased when fertilizer application levels rose. Consequently, the total N that accumulated in the plants in A62-1 increased only slightly with N application. In another experiment it was estimated that the test plants fixed as much as 190 kg N/ha without N fertilizer (Tanaka et al. 1978).

The proportion of ureide-N to total N in the xylem sap in A62-1 was more than 50% without N application, but decreased as fertilizer application levels rose (Fig. 2) (Fujita and Tanaka 1982). Ureide-N in A62-2 was only 7% of the total N in the xylem sap with no N application. With heavy N applications, asparagine was found to be the major N compound in the xylem sap in both test cultivars. These data demonstrate that ureide-N is the major form of N produced by N_2 fixation and that ureide-N translocates from the root nodules.

There was a positive correlation between seed yield and the amount of N accumulated (Fig. 3). No differences were detected between A62-1 and A62-2.

Ishizuka (1972) reported that allantoin is the N compound that translocates from the root nodules and can be efficiently utilized for seed production. However, our studies showed no difference in seed production efficiency between allantoin and other N compounds. In other words, seed yield can be improved by increasing accumulated N, irregardless of the N source.

As N_2 fixation is an energy consuming process, root nodules need to actively respire when fixing N_2. The respiration rate of the nodules can be extremely high. For example, the respiration rate of A62-1 was 3.30, 3.04, and 13.08 mg CO_2/g/hr in the shoot, roots, and root nodules, respectively, when grown in a culture solution (10 ppm NH_4NO_3-N) from the onset of flowering to pod development (Yamaguchi and Tanaka 1981). Respiratory consumption of photosynthates by the nodules was also substantial; nodule respiration, at times, occupied more than 20% of the total plant respiration.

The ability of soybean to produce considerable yield without N application, owing to its ability to fix N_2, is useful to farmers who can not afford to use large amounts of fertilizer. However, it is interesting to estimate how much additional yield might be produced if N_2 fixation, which is an energy consuming process, is substituted by the absorption of combined N.

It is difficult to get reliable information on this question. We tried to estimate the efficiency of respiration to fix N_2 and to absorb combined N using data on root and nodule respiration and the amount of absorbed and fixed N obtained from soybean grown in culture solution. Our best estimate, based on certain assumptions, is as follows: When using 1 g of CH_2O for respiration, 720 mg of combined N is absorbed or 190 mg of N_2 is fixed (Yamaguchi and Tanaka 1981). This suggests that the efficiency of respiration to absorb combined N is about four times greater than the efficiency to fix N_2.

By combining these data with the growth efficiency of ripening seeds ([the amount of seed growth]/[the amount of substances translocated into the seeds] = 45%), we estimated that 39 and 43 g of seed (protein content 6%) are produced by N_2 fixation and combined N absorption, respectively, from 100 g of new photosynthates (CH_2O). These figures indicate that about 10% more seeds is produced

when a liberal amount of N fertilizer is applied than when fixed N is the only N source. If we consider both the amount of photosynthates that become constituents of the nodules and the amount that is respired for growth and maintenance of the nodules, the difference in seed yield should be larger.

A62-1 and A62-2 were grown without and with N fertilizer at 240 kg N/ha, and each treatment was divided into two sub-treatments: With and without shading (40% natural light) (Tanaka et al. 1980). Under natural lighting conditions and with applications of 240 kg N/ha, A62-2 yielded slightly more than A62-1 (Table 2). Seed yield decreased in the shaded treatments. The yield decrease in the shaded treatments was smaller in A62-2 than in A62-1. The yield of A62-2 was also higher than that of shaded A62-1 with 240 kg N/ha. The weight of root and root nodules also decreased with shading. The degree of the decrease was in the order of the root nodules > root > total. Thus, nodules appear to be the most sensitive of all soybean organs to decreases in solar energy. When photosynthetic activity decreases because of lower solar energy supplies, root nodules suffer most and N_2 fixation decreases more than combined N absorption. When soybean is grown with combined N, seed yield reductions - as a result of lower levels of solar energy - are less than when the crop is grown with fixed N alone. This indicates that when soybean is grown with heavy N applications, rather than with fixed N alone, yields may be higher and more stable.

In Japan, 1 kg of N fertilizer and 1 kg of soybean both cost about US $0.85. Thus, efforts to improve the efficiency of N fertilizer usage have proven to be uneconomical.

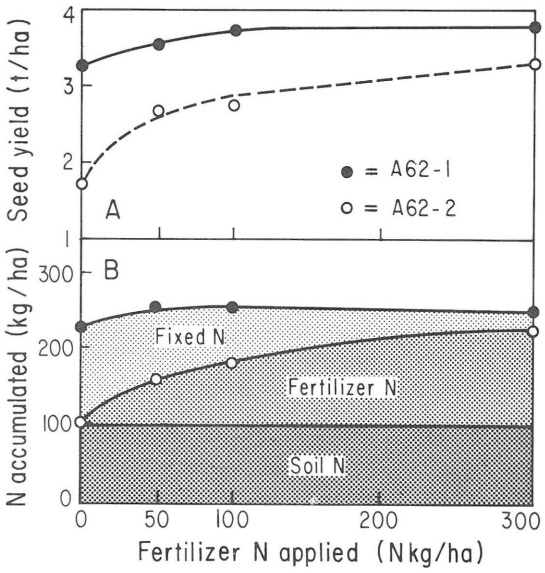

Fig. 1. (above)
Seed yield and N accumulation as affected by N fertilizer application.

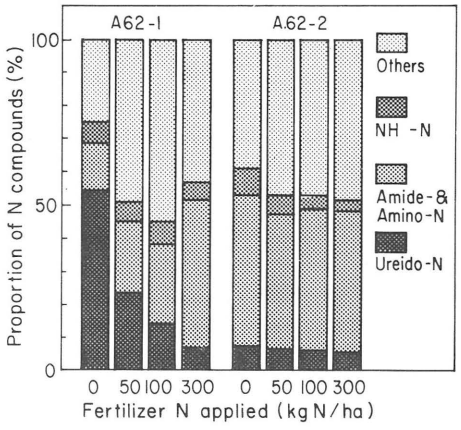

Fig. 2. (upper right)
Effect of N fertilizer application on the proportion of various forms of N based on total N in the xylem sap.

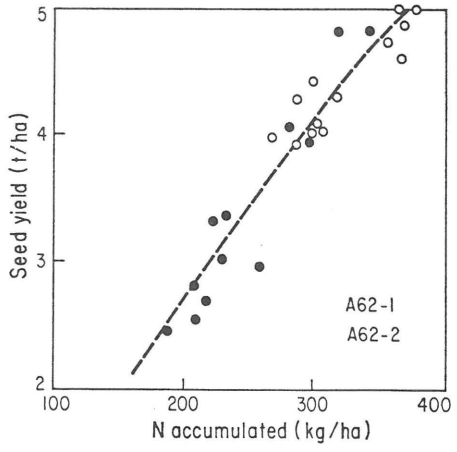

Fig. 3. (right)
Relationship between N accumulation in the plant and A62-1 and A62-2 seed yield.

Methods of N Fertilizer Application

With an increase in the concentration of combined N in the growth media, soybean's N_2 fixing ability decreases, mostly because of decreases in root nodule weight, and, to a smaller extent, because of a decrease in the specific activity of the nodules (Table 3). As mentioned, the total N accumulated under field conditions changes only slightly with N application. This tendency suggests that N_2 fixation and combined N absorption compensate for one another. These processes are controlled by a common factor: The availability of photosynthates - the factor which controls total N accumulation and seed yield.

Soybean plants grow slowly during the early stages of growth. Leaf and stem growth both increase with time, and continue until the initiation of seed development; leaf and stem weight is maintained until full maturation (including the weight of fallen leaves). Pod-wall weight starts to increase prior to the initiation of seed development, continues to increase for about two weeks, and then remains almost constant. Seed weight starts to increase rapidly about 20 days after the commencement of flowering and continues to increase until maturation (Fig. 4).

N accumulation is relatively slow during the early growth stages, becomes more active at a later date, and thereafter maintains its rate of accumulation at an almost constant level until maturation (Fig. 4B). The amount of N accumulated in the leaves reaches a maximum level at the start of seed growth, and decreases rapidly thereafter. The amount of N in the seed increases throughout seed development, using both N accumulated in the plant and N retranslocated from the leaves. Many leaves senesce and fall off during ripening because of the effects of translocation.

Meeting seed N demand during seed ripening is the key to higher yields. It is therefore necessary to increase N_2 fixation and/or combined N absorption during this period. Because N_2 fixation and combined-N absorption compensate for one another, it is difficult to improve yields by manipulating N fertilizer application of N.

Fig. 5 illustrates the N_2 fixing activity at successive growth stages of soybean that received different amounts of N at planting (Fujita and Tanaka 1982). Generally, N_2 fixation decreased as N application increased. However, when small amounts of N were applied at planting (e.g. 50 kg N/ha), N fixation increased during the latter growth stages, a period when N fertilizer in the soil had already been exhausted.

Because the N_2 fixing activity of the root nodules is weak during the plant's early growth stages, basal N application can be used to promote growth. During the plants' later growth stages, N_2 fixation becomes active even with a small amount of basal N. Thus, larger quantities of N can be accumulated during the growth cycle. Consequently, applications of 20 to 30 kg N/ha at planting is recommended in Hakkaido.

N top dressing during the late growth stages is also beneficial (Hoshi et al. 1978). Seed demand for N is high during ripening, a period when the N_2 fixation activity tends to decrease. Consequently, if combined N is available in the soil, and is absorbed by the plants, yield will increase. However, as the amount of N that accumulates in the seeds is quite high, it is difficult to apply such a large amount of N as top dressing. Therefore, high yields are usually obtained only on soils that supply large amounts of N during the late growth stages.

Table 2. Effect of fertilizer N application and shading on yield and weight of various plant organs (A62-1 and A62-2).

	N Application (kg/ha)	A62-1		A62-2	
		shading			
		without	with	without	with
Seed yield (t/ha) (15% moisture)	0	3.45	1.40	1.49	1.29
	240	3.67	1.56	3.76	2.04
Relative weight[z]					
Total	0	100	47	70	53
	240	108	51	113	70
Roots	0	100	34	105	49
	240	94	37	103	50
Root nodules	0	100	26	-	-
	240	11	7	-	-

[z] Given the weight of A62-1 without fertilizer N under natural conditions as 100

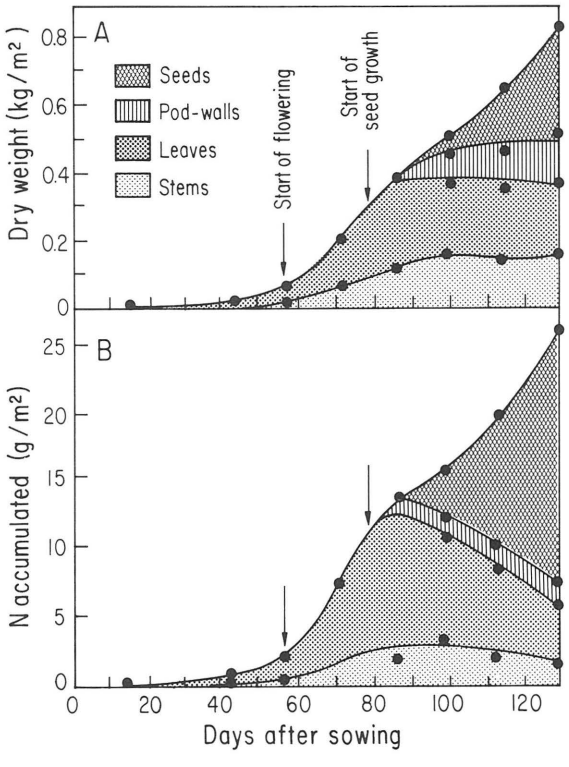

Fig. 4. (left)
Dry weight and amount of accumulated N at successive plant growth stages.

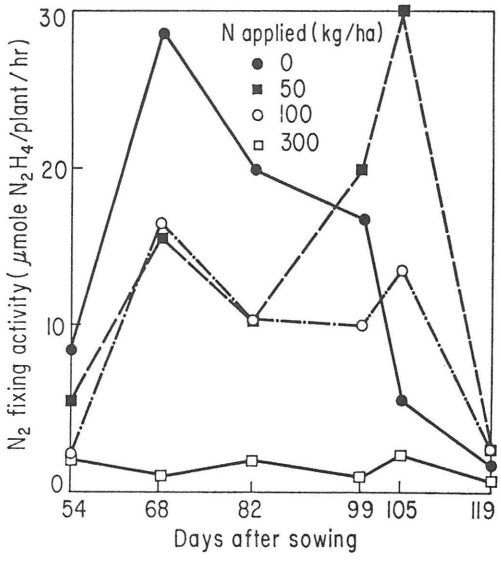

Fig. 5. (above)
N_2 fixation activity at successive growth stages of soybean grown with graded N fertilizer application levels.

As mentioned, nodule growth is retarded by the presence of combined N in the growth medium. However, active nodule growth can be maintained in the portion of the root system that is not directly subjected to combined N, even if other parts of the roots come in contact with combined N.

In another experiment, soybean plants were grown under field conditions with four treatments: 1) no N, 2) compost mixed with soil in furrows, 3) ammonium sulfate mixed with soil in furrows, and (4) ammonium sulfate banded at 10 cm from the plant row and 10 cm beneath the soil surface. A total of 300 kg N/ha was applied in treatments 2, 3, and 4. Seed yield was highest in the ammonium sulfate-banded treatment (Table 4). When ammonium sulfate was banded, N_2 fixing activity was considerably higher during the early growth stages than when ammonium sulfate was mixed with soil in furrows. The amount of N that accumulated in the plants was greater in this treatment than in any other.

These results indicate that by placing N fertilizers in a confined spot in the soil, high soybean yield can be achieved by maximizing N accumulation through the absorbtion of N fertilizer by one portion of the root system, while maintaining high levels of N_2 fixation at another.

Table 3. Effect of nitrate nitrogen on the N_2 fixing activity of soybean (water culture).

Nitrate Concentraton (ppm N)	0	2	5	10
N_2 fixing activity (µmole C_2H_4/plant /hr)	70.1	21.1	10.4	12.3
Root nodule weight (g/plant)	0.90	0.35	0.32	0.28
Specific activity (µmole C_2H_4/g/hr)	77.6	55.2	32.9	44.5

Table 4. Seed yields and N_2 fixing activity of soybean plants grown with various fertilizer treatments.

Treatment	Seed Yield (t/ha) (15% moisture)	N_2 Fixing Activity (µmole C_2H_4/plant/hr) days after planting			Amount of N Accumulated (kg N/ha)
		37	55	89	
No nitrogen	3.28	10.1	36.4	19.9	201
Compost[z]	3.43	7.7	26.2	33.3	277
Ammonium sulfate mixed (furrow)[z]	3.87	0.6	3.2	7.7	298
Ammonium sulfate banded[z]	4.59	12.7	16.0	9.0	338

[z]300 kg N/ha

Productivity

Photosynthesis is the factor that principally determines crop yield (under good management). With soybean, however, N is often the most important yield limiting factor because of the crop's large N requirements and because N_2 fixation is difficult to control with management practices. Nevertheless, photosynthesis may control yield through N_2 fixation because the root nodules consume a considerable amount of carbohydrates.

Soybean shoots (leaves) are the source of photosynthates and the pods are the sink of both photosynthates and N. The root system, including root nodules, is the photosynthate sink and the N source. The limiting factor of N_2 fixation

can be: 1) the potential of root nodules to fix N_2, 2) the ability of leaves to send photosynthates to the root nodules, or 3) the ability of seed to accumulate N.

A grafting experiment was conducted in which three treatments were established at flower initiation: 1) one shoot/one root system (S/R), 2) one shoot/two root system (S/2R), and 3) two shoots/one root system (2S/R) (Fujita and Tanaka 1980). Seed yield and the amount of N accumulated was far larger in 2S/R, and only slightly larger in S/2R, than in 2S/R (Table 5).

This suggests that the shoots control N_2 fixation. N_2 fixing activity is increased not by improving the ability of root nodules to fix N_2, but by improving the capacity of the leaves to send photosynthates to the root nodules and/or by improving the ability of the pods to accumulate N.

The maximum soybean yield reported in Japan is 6.49 t/ha (Onuma et al. 1981). This figure is far lower than the record yields of a number of other crops. However, protein and fat production require much more energy than carbohydrate production. Consequently, respiratory losses during ripening are higher in soybean than in other crops. For this reason, soybean seed yield is bound to be lower when expressed in dry weight.

Table 5. Grafting results.

Parameters	Treatment[z]		
	S/R	S/2R	2S/R
Seed yield (g/hill)	41	46	64
Nitrogen accumulated (g N/hill)	3.25	4.02	5.40

[z] S/R = One shoot grafted on one root system
S/2R = One shoot grafted on two root system
2S/R = Two shoot grafted on one root system

One unit weight of new photosynthates (CH_2O) produces 0.84 units of carbohydrates, 0.38 units of proteins, or 0.31 units of fat (Yamaguchi 1978). Using these figures and the chemical composition of the harvested material, the amount of material produced from 100 g of new photosynthate was calculated for various crops. The values for soybean, field bean, maize, rice (Oryza sativa), and potato were 45, 62, 70, 73, and 75 g, respectively.

Maximum rice yield is reported to be about 14 t/ha, but since this value includes husks, maximum yield is equivalent to about 10.5 t/ha. On the basis of the amount of new photosynthates required to produce this amount, 10.5 t/ha of rice is equivalent to about 6.5 t of soybean - the maximum yield reported for soybean.

The maximum yields reported for various other crops, along with their growth duration periods are listed in Table 6 (Tanaka 1980). Maturity differences between crops is significant. For example, one year is required to produce sugarcane (Saccharum officinarum) or cassava (Manihot esculenta), whereas only 80 days are needed for sorghum (Sorghum vulgare). High sugarcane and cassava yields are basically a function of their long growth periods and greater exposure to solar radiation. Consequently, yield expressed in dry weight is not the best way of expressing productivity. A more logical method is to express productivity as a function of the new photosynthates used to produce equivalent yields per day.

Equivalent yield ranged from 9 g glucose/m^2/day in field beans to 14 g glucose/m^2/day in maize and potato (Table 6). In many crops it is 9 to 12 g glucose/m^2/day, indicating that differences in productivity are not significant. Using this system, soybean is as productive as rice, but soybean and rice are both less productive than maize or potato. High maize productivity may be due to the high photosynthetic rate of the leaves, whereas the productivity of potato is probably the result of the tubers' high sink activity.

The productivity of a tropical cropping system should be measured by the total equivalent yield per year, and not by individual crop yields.

On this basis, soybean productivity is almost the same as maize or potato. To improve soybean productivity, studies should be conducted on photosynthesis or the source-sink relationship between the leaves, pods, roots, and root nodules.

Table 6. Recorded maximum yield and productivity of various field crops.

Crop	Maximum Yield[z] (t/ha, dry matter) (i)	Growth Duration[z] (days)(ii)	Harvest Index	Equivalent Yield Per Day (g glucose/m^2/day)
Rice	14 (ST)	190	-	10.0
	11 (T)	125	0.05	11.9
Wheat	12 (TM)	-	-	-
	8 (T) (a)	120	0.35	9.3
Maize	22 (TM)(b)	-	-	-
	13 (ST)	130	0.50	14.3
Sorghum	7 (T)	80	0.50	11.9
Sugarcane	[22] (T)	365	[0.35]	[6.6]
Potato	20 (ST)	-	-	-
	18 (TM)	162	0.80	14.3
Sweet potato	17 (TM)(c)	180	0.80	11.7
Cassava	28 (T)(a)	365	0.60	9.6
Sugarbeet	[19](ST)	240	[0.45]	[8.7]
Soybean	7 (TM)(c)	120	0.45	11.8
Field beans	5 (T)(d)	90	0.45	8.6
Groundnut (seeds)	6 (TM)(c)	140	0.40	9.3

[z]Values cited by Cooper (1975) plus those obtained (a) at CIMMYT, (b) by a farmer in Michigan, USA, (c) in Japan, and (d) at CIAT
(TM), (ST), and (T) indicate data obtained in the temperate, sub-tropics and tropics, respectively
[ ] data are expressed in terms of sugar

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Soybean Adaptation to Photo-Thermal Environments and Implications for Screening Germplasm

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Introduction

Although most commercial soybean (Glycine max) production is concentrated between 25° and 45°N, and at altitudes below 1000 m, the crop is now grown from the equator to latitude 55°N or S and from below sea level to altitudes close to 2000 m (Whigham 1983).

Soybean cultivars have been selected for different regions and production areas based on their responsiveness to environment during the growing season. For example, cultivars from temperate latitudes are said to be so sensitive to climate that they produce maximum yields only within a latitude band of 80 km (Hamner 1969). Tropical cultivars grown in temperate climates are likely to flower and mature late, to grow excessively tall and so be prone to lodge, and to produce only poor yields. Conversely, when temperate cultivars are moved south they tend to flower early and mature rapidly, to have a short and compact habit, and so have little capacity yield well (Whigham 1983). Some cultivars can, however, produce reasonable yields in a range of contrasting environments (Summerfield and Roberts 1985).

The objectives of this paper are to review the environmental regulation of the timing of reproductive events, especially the onset of flowering, and to suggest ways in which soybean breeders might select parents and progenies so that the cultivars released to farmers are well adapted to the climates for which they are intended, especially to the tropical and subtropical regions.

Adaptation to Aerial Environment

Soybean improvement programs in the USA, Canada, Brazil, Japan, Taiwan, and Africa now have resources for hybridization and selection on a scale much larger than has been possible hitherto. These programs emphasize the importance of collecting, exchanging, introducing, and maintaining germplasm to provide a wide range of genetic diversity for plant breeders to exploit (Shanmugasundaram, 1979a).

Most soybean genotypes are sensitive to variations in climate, particularly in terms of developmental responses to photoperiod (Major and Johnson 1977). Rates of phenological development, and so the areas to which cultivars are best adapted, are largely dictated by photoperiodic response (Shanmugasundaram, 1981). However, in virtually every case where studies have been sufficiently extensive, in domesticated or wild species, photoperiodic responses have been readily modified by temperature (Salisbury 1981). Indeed, it is now clear that the timing of reproductive events not only in soybeans but also in all grain legume crops is modulated strongly by both photoperiod and temperature, and that genotypes differ markedly in their relative sensitivity to either or both of these factors (Tables 1 and 2). However, past research has inclined us to a too

Table 1. Responses to air temperature and to photoperiod in grain legumes of economic importance (based on a literature survey of data published between 1920 and 1978)[z].

Tribe/Species	Juvenile Period	Venalization Requirement	Optimum Photoperiod for Flowering			Flowering Sooner in Response to Warmer Air Temperature				Ind.
			SD	IND	LD	day	night	mean	constant	
Vicieae/Cicereae										
Cicer arietinum		±		+	+	+	+	±	±	
Lens culinaris	+	±		+	+				+	
Pisum sativum		±		+	+		+	±	±	+
Vicia faba	-	±		+	+				-	
Phaseoleae										
Cajanus cajan	±		+	+						
Glycine max	-	-	+	+		+	+	+	+	+
Phaseolus lunatus			+	+		+	+	+	+	+
P. vulgaris			+	+		+	+	+		+
Psophocarpus tetragonolobus			+					±		
V. mungo			+	+				+		
V. radiata			+	+				+		
V. unguiculata	-		+	+			+	+	+	+
Genisteae										
Lupinus albus		±		+	+					
L. angustifolius		±		+	+			+		
L. cosentinii		±			+			+		
L. luteus		±			+			+		
Aeschynomeneae										
Arachis hypogaea		-		+				+	+	

Comments: a. SD usually 12 hr duration, or less; LD usually 14 to 16 hr duration or longer; indifference (IND) based on responses in photoperiods from 14 to 24 hr duration

b. Where day-night temperatures have not been combined factorially it is possible only to describe flowering response in terms of a range of weighted mean temperatures of the diurnal fluctuations investigated

c. Constant temperatures refer to studies without a diurnally-changing thermal regime

d. Indifference (Ind.) rating based on widely differing temperature ranges between species and/or experiments

e. Data based on the findings reported in 487 publications from 1920 to 1978

[z] Source: Summerfield and Wien (1980)

+ = positive response or presence, - = absence, and blank = no data available

Table 2. Summary of flowering responses of grain legume crops to photoperiod and cold temperature vernalization (compiled from numerous sources).

Species	Tribe	Center of Origin	Photoperiodic Response[z]					Vernalization Response	
			short day		DN[y]	long day			
			O	Q		O	Q	O	Q
Arachis hypogaea	Aeschynomeneae	S. America/Africa			*				
Lupinus spp.	Genisteae	Africa/Mediterranean			*		*		*
Cicer arietinum	Cicereae	Asia			*		*		*
Lens culinaris	Vicieae	Asia/Mediterranean			*		*		*
Vicia faba	Vicieae	Asia/Mediterranean			*		*		*
Pisum sativum/arvense	Vicieae	Asia/Mediterranean			*		*	*	*
Cajanus cajan	Phaseoleae	Africa/India	*	*	*				
Glycine max	Phaseoleae	N.E. China	*	*	*				
Phaseolus lunatus	Phaseoleae	Mexico/Guatemala		*	*				
Phaseolus vulgaris	Phaseoleae	Mexico/Guatemala/Peru (?)		*	*				
Psophocarpus tetragonolobus	Phaseoleae	Papua New Guinea (?)		*					
Vigna mungo/radiata	Phaseoleae	Asia/India	*	*	*				
Vigna unguiculata	Phaseoleae	Africa/India	*	*	*				

[z] O and Q denote obligate and quantitative responses, respectively
[y] DN:day-neutral

absolute view of the need for a specific photoperiodic stimulus for flower evocation (Evans 1969). Researchers have also concentrated too much on photoperiodic effects rather than those of photoperiod and temperature which, in fact, combine to modulate the rate of reproductive ontogeny (Summerfield and Wien 1980).

In those annual legume crops which, like many soybean cultivars, are botanically indeterminate, flowering, fruit growth and senescence often occur simultaneously in different parts of the same plant. Furthermore, the amount and distribution of dry matter accumulated during successive stages of development are often determined or limited by those environmental factors (e.g. photoperiod and temperature) that also initiate phase changes (Summerfield 1980). And so, genotypes and environments can interact to produce wide ranges of morphological and phenological diversity. It is these responses which need to be quantified, predicted and exploited.

It seems desirable to explain how environmental variations in time affect phenology and physiological processes, rather than merely to describe the outcome by purely statistical procedures (Bunting 1975). The statistical approach has restricted objectives and is almost always unrewarding; attempts to correlate seasonal changes in compound quantities, e.g. net assimilation rate and relative growth rate throughout the life of a crop, with the state of the environment is one of the least productive exercises of traditional crop ecology (Monteith 1975).

Floral Characteristics

Flower initiation in soybean, as in other species, involves both qualitative (flowering or not) and quantitative (number of flowers) components. The simplest qualitative measure is the proportion (%) of plants that initiate at least a single flower in response to a particular treatment. This can be determined by recording the presence of visible buds and flowers or by dissecting apices and examining them under a microscope (Guard 1931; Thomas and Raper 1983). Since conditions that favor the growth and development of buds into flowers are not always the same as those that are conducive to flower initiation, the dissection method is probably more reliable. In general, the number of flowering nodes and the number of nodes (leaves) that precede the first flower are better quantitative measures of the relative success of initiation than are the number of buds initiated (the latter is affected by genetic differences and environmental factors that may or may not exert a major influence on initiation (van Schaik and Probst 1958).

Soybean cultivars may flower from 25 to 50 days after planting (DAP) or later, depending upon the genotype and when and where it is planted (Carlson 1973, Whigham 1983). Flowers are produced in axillary racemes in indeterminate types and in axillary and terminal racemes in the determinates. Axillary racemes in tropical cultivars can be as long as 10 cm whereas those of temperate cultivars are much shorter (Shibles et al. 1975). Individual racemes may produce 2 to 35 flowers, which in turn produce anywhere from 0 to 20 mature pods (Whigham 1983).

The duration of blooming is influenced by the time of planting, presumably by exposing the crop to different environmental conditions (Inouye and Shanmugasundaram in this volume, Shibles et al. 1975). With indeterminate genotypes, flowering initially progresses upwards from nodes 4 to 8 on the main stem; flowering on the branches begins a few days later. Flowers are most abundant on the middle nodes. The semi-determinates (dt_2) follow a similar sequence, but

flowers on determinate (dt_1) types first appear at the eighth or ninth node, and, within a few days, at every node including those on branches and apices. Between 10 and 18 days are required for all flowers to open on an axillary raceme of the primary branch. Racemes on secondary branches usually develop and flower; those on tertiary branches do so only rarely (Shibles 1980).

Environmental Regulation of Flowering

Soybean is a short-day plant (SDP); some genotypes respond as quantitative SDPs while others respond qualitatively. Several reviews on this topic have appeared during the past 50 years (see citations in Summerfield and Roberts 1985). A considerable proportion of the early research dealt with the responses of cultivar Biloxi (Vince-Prue 1975), a genotype with a pronounced critical photoperiod close to 13 hr 30 min and an ability to initiate flower buds in response to only two short days (Evans and King 1975). In comparison, modern cultivars have less exacting requirements for short days, and several early maturing genotypes from temperate latitudes and some late maturing genotypes of tropical origin are almost completely insensitive to daylength (Criswell and Hume 1972, Nissly et al. 1981, Polson 1972, Shanmugasundaram 1981). However, when successive stages of reproductive ontogeny are included as criteria for photoperiod-insensitivity, it seems that few genotypes are completely insensitive: Fruit-set, seed filling, and the intensity of reproductive development (the relative numbers of vegetative and reproductive nodes and the ratios between these values) seem to be regulated by photoperiod (Shanmugasundaram 1979b, Summerfield and Roberts 1985). Relatively little is known about these responses or their significance agriculturally (Thomas et al. 1981) or in terms of cultivar adaptation (Summerfield and Wien 1980), or about the interacting effects of temperature on photoperiodic responses at successive stages of development (Thomas and Raper 1977 and 1981), or the importance of plant age in terms of responsiveness to photo-thermal conditions (Fisher 1955, Patterson et al. 1977).

How Dark Is Dark

Photoperiod-sensitive plants must discriminate between day and night (illuminance detected as darkness), measure the duration of one or both, and, in response, control processes such as flowering (Salisbury 1963).

A "threshold illuminance" between 5 and 11 lux is needed to delay flowering in cultivar Biloxi (Borthwick and Parker 1938), but cultivars differ in sensitivity (Major and Johnson 1974), depending on whether or not they are tested in locations to which they are well-adapted (when 2.7 lux was the average value required for a 5-day delay in the appearance of open flowers) or are 'relatively poorly adapted' (when the valve was 6 lux). Modern cultivars respond in a quantitative manner to illuminance (Major and Johnson 1974, Takimoto and Ikeda 1961, Yoshida 1952), at least over the range of 2 to 100 lux. Furthermore, about 30 times more energy is required to inhibit flowering when blue (480 nm) rather than red (640 nm) light is used (Parker et al. 1946). Cultivars with the dominant gene E_3- experience delayed flowering if long (20 hr) days are imposed using cool-white fluorescent tubes, whereas those with e_3e_3 require additional far-red light (from tungsten filament lamps) to evoke the same response (Buzzell 1971, Kilen and Hartwig 1971).

Bearing in mind that response rates of many photo-biological processes are approximately proportional to the logarithm of incident illuminance (Withrow 1959), rather than to illuminance per se, and that photoperiodic phenomena are related more simply to the reciprocal of the time taken to flower (i.e. rate of progress towards flowering [1/f]) than to time to flowering (f) per se (Hadley et al. 1983a), therefore it seems sensible to express current data in these terms in

order to expose the relationship between illuminance and flowering in the clearest way. We consider in Fig. 1 the relationship between the rates of progress towards flowering (1/f) and the log illuminance that might be anticipated when plants with inherent photoperiod sensitivity differences are grown in experiments in which short natural days are extended by light of different illuminance.

Fig. 1a shows the responses predicted for quantitative long-day and quantitative short-day species (e.g. chickpea [Cicer arietinum] and soybean, respectively); for simplicity they are assumed to have the same threshold (T) and saturation (S) illuminance values, respectively. In quantitative long-day species, time to flowering is "reduced" when relatively short, natural days are extended by artificial illumination. Conversely, in quantitative short-day plants flowering is "delayed" when relatively short natural days are extended. The illuminance needed to saturate the photoperiodic response (S) can be defined as that illuminance above which there is no significant decrease (in long-day species) or increase (in short-day species) in the time taken to flower. Threshold illuminance (T) is defined as that illuminance below which there is no further significant delay (in long-day species) or hastening (in short-day species) in time to flowering.

For species endowed with an obligate response to photoperiod (Fig. 1b), and providing the supplementary illumination extends the daylength beyond the critical photoperiod, then once saturation illuminance has been reached flowering will be delayed indefinitely in short-day species (1/f = 0), whereas in long-day species, flowering occurs after an irreducible minimum time (1/f = a maximum but finite value). Conversely, below the threshold of illuminance, the flowering of an obligate long-day species is delayed indefinitely (1/f = 0), whereas in short-day species (assuming the natural photoperiod is shorter than the critical value) flowering will occur at an irreducible minimum duration (1/f = a maximum but finite value).

Thus, these relationships predict a change in slope for both short- and long-day species at saturation illuminance; the direction of such changes will

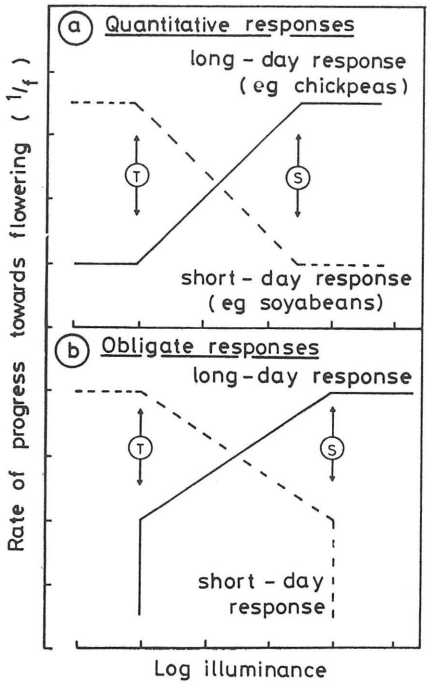

Fig. 1.
The relationship between log illuminance and rates of progress towards flowering (1/f) predicted for (a) quantitative long- (——) or short (-----) -day species and (b) obligate long- (——) or short- (-----) day species, in experiments in which relatively short days are extended by supplementary illumination of various illuminance values. T and S denote threshold and saturation illuminance values, respectively (see text).

depend upon whether the species are quantitative or obligate short-day plants, but will always be in the same direction for both obligate and quantitative long-day species. The converse applies at the threshold illuminance.

Re-examination of data published for chickpea (original data of N. P. Saxena et al., personal communication) and soybean (Major and Johnson 1974) reveals trends similar to those predicted for quantitative long- and short-day species, respectively (Fig. 2).

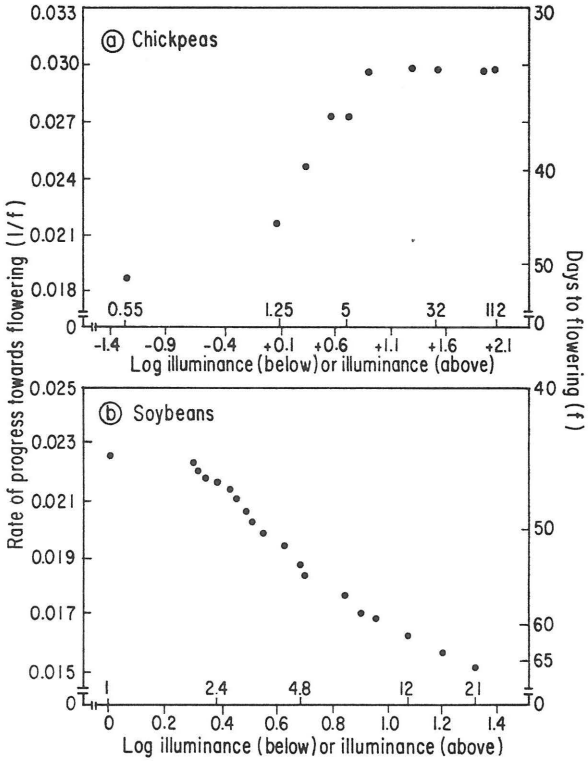

Fig. 2.
Relationship between log illuminance of supplementary light extending natural photoperiods to 24 hr and rate of progress towards flowering (1/f) in chickpea and soybean: (a) combined results for four chickpea cultivars (calculated and redrawn from N. P. Saxena, L. Krishnamurthy and A. R. Sheldrake (personal communication) and (b) combined results for ten commercial soybean cultivars (calculated from Major and Johnson 1974).

The exact threshold and saturation illuminance values of these species cannot be determined from available data. Nevertheless, it seems that the threshold illuminance in both cases is about 1 to 2 lux. Threshold illuminance values for the inhibition or promotion of flowering in short- and long-day species vary widely (by 2 or 3 orders of magnitude), although between 1 and 50 lux from tungsten lamps is sufficient to counteract the effect of darkness in many species (Vince-Prue 1975 and 1983).

Irrespective of the true threshold and saturating illuminance values for any species, the very rapid changes in illuminance during periods of twilight (Withrow 1959) mean that threshold values as small as 1 lux are likely to be exceeded from about 30 min before sunrise until 30 min after sunset and that saturation values, even as high as 1000 lux, would probably be achieved within 10 min after sunrise (first appearance of solar disc) and, on clear days, be maintained until 10 min before sunset (Salisbury 1963). The regulatory significance of such rapid changes in illuminance for reproductive development in plants seems difficult to envisage.

Figure 3 considers an alternative hypothesis which follows from this discussion to explain the seemingly different responses of soybean cultivars to dim light (Summerfield et al. 1984). Fig. 3a shows the times taken for soybean

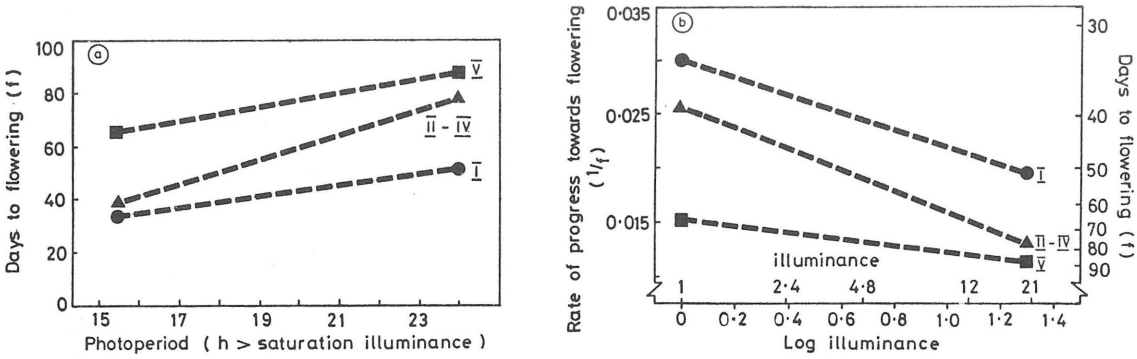

Fig. 3. Relationship between (a) photoperiod (hr > saturation illuminance) and days to flowering for soybean cultivars of different Maturity Groups (USA classification; Scott and Aldrich 1970) and (b) log illuminance and rate of progress towards flowering (1/f) for the same groups of cultivars grown along an illuminance gradient that extended natural days of about 15 hr 30 min duration to 24 hr (recalculated from Major and Johnson, 1974). Circles, triangles, and squares denote average responses of 2, 6, and 2 cultivars from USA Maturity Groups I, II-IV, and V, respectively.

genotypes of different USA Maturity Groups (MG) to flower when sown in May in Columbia, Missouri (39°N), where natural daylengths are close to 15 hr 30 min (Francis 1972), and when grown in 24 hr days in the same location with artificial light (20 lux) (data calculated from Major and Johnson 1974). Cultivars recognized as adapted to the region (MG II-IV) are more sensitive to photoperiod than those from areas further north (MG I) or further south (MG V). When cultivars that differ in this way are grown along an illuminance gradient (Figure 3b), and when all have similar respective threshold and saturation illuminance values, the relationship between the illuminance of supplementary light and days to flowering will be different; less photoperiod-sensitive cultivars will have the smaller gradients.

This alternative explanation is conceptually simpler than one which involves responsiveness to dim light per se. Consider, even for extreme values of threshold and saturation illuminance (e.g. 1 and 1000 lux, respectively) the duration during twilight when illuminance falls within this range is only about 40 min (Salisbury 1963; Withrow 1959). Thus, although plants may somehow integrate time and illuminance during this period, the duration is so short, and illuminance is changing so rapidly, that the effect on reproductive development seems unlikely to affect the overall precision of photoperiodic regulation of flowering. Therefore, sensitivity to photoperiod per se will represent greater surety for the regulation of reproductive development, because seasonal changes in this factor (climate) are less sensitive to environmental noise (weather) during twilight (Salisbury 1981).

A second point that merits emphasis is the practical implications of these data for the artificial manipulation of photoperiod, either in controlled environments or in the field. Breeders may want their parental lines to flower sequentially when planted on the same date in one location in order to spread the burden of effecting crosses and to facilitate crosses between early and late flowering parents. Seeding plants along an illuminance gradient may be one way to achieve this objective.

Critical Daylength

The critical daylength (the duration above which flowering is delayed or prevented) differs widely between cultivars; it varies from about 13 hr for

genotypes adapted to the tropics to 18 to 24 hr for cultivars grown at more extreme latitudes (Major 1980, Shibles et al. 1975). Three major genes which influence flowering and the timing of crop maturity have been identified (Bernard 1971, Bernard and Weiss 1973). Soybeans with e_1e_1 have long (17 to 22 hr) critical daylengths in the field (Guthrie 1972), whereas genotypes with E_1 have shorter critical photoperiods, and so the plants flower relatively late. Genotypes with e_3e_3 have longer critical photoperiods than those with E_3. Isolines carrying the recessive gene also mature earlier (Kilen and Hartwig 1971), which indicates the quantitative effect of photoinduction. The three E genes are simply inherited (two alleles at each locus), but additional genes with more complex inheritance, and with a spectrum of regulation that varies between environments, are probably involved in photoperiodic responses as well (Byth 1968). Fractional induction (i.e. the summation of non-consecutive inductive photoperiods to achieve an eventual threshold stimulus leading to initiation) seems impossible to achieve with soybean; subcritical inductive treatments are apparently never summated (Bernier et al. 1981a,b; Hamner 1969). This is not to say, however, that the effects of consecutive photoperiods are not summated.

Recent research (Hadley et al. 1984) does not support the generalization that critical day-night length (the maximum daylength or minimum night length that permits flowering) remains relatively resistant to changing temperatures (Salisbury 1981).

Juvenility

Some cultivars have a short ($\leq$9 days) juvenile phase (or basic vegetative period) during which they do not respond (or only weakly) to daylength. This probably occurs because the first trifoliolate leaf must be fully expanded to perceive the photoperiodic stimulus (Borthwick and Parker 1938, Shanmugasundaram and Tsou 1978). Leaves, especially those which have just fully-expanded, are the primary receptors of the photoperiodic stimulus in photoperiod-sensitive genotypes (Bernier et al. 1981a,b). A single trifoliolate leaf provides ample area to perceive the flowering stimulus, irrespective of its position on the plant, and is as effective as if all of the leaves were functioning simultaneously (Borthwick and Parker 1940). However, daylength-insensitive genotypes can be induced to flower when only cotyledons or the first pair of unifoliolate leaves are left intact (Shanmugasundaram and Lee 1981). A decapitation technique (Shanmugasundaram and Wang 1977, Shanmugasundaram et al. 1979) has been developed in which two axillary branches are allowed to develop from the unifoliolate leaf nodes of plants decapitated just above that node. One branch is exposed to long days, the other to short days; flowers appear simultaneously on both branches only on those genotypes that are more or less insensitive to daylength. With photoperiod sensitive cultivars, the receptor branch flowers only when it has no leaves or only two trifoliolate leaves (Shanmugasundaram et al. 1979).

Photo-Thermal Regulation of Flowering

Before considering the effects of photoperiod (daylength) and air temperature on reproductive development, it is pertinent to make a few general statements about these factors and to give some indication of their respective temporal and regional variations. We have relied heavily on the recent review by Dennett (1984).

Daylength: Daylength is defined as the time from sunrise to sunset, i.e. when the upper edge of the sun appears or disappears over the horizon. This is purely a geometric factor and can be calculated precisely from latitude and day of the year (see List 1958, Berry 1964, and Francis 1972). At the equator, daylength remains constant (12 hr 6 min) throughout the year; seasonal variations in the

tropics are relatively small compared with those at more extreme latitudes. For example, daylength changes from about 10 hr 54 min to 13 hr 18 min at 20°, whereas the range is from about 8 hr 6 min to 16 hr 24 min at 50°.

Air Temperature: Air temperature in the tropics is controlled mainly by radiation; differences in the temperature of air masses are usually of minor importance. This has two consequences. First the tropics have been defined climatologically as being that area where diurnal temperature variations exceed annual variations (Nieuwolt 1977) and, second, temperature - like solar radiation - tends to be relatively uniform over large areas. Altitude disturbs this thermal uniformity so that mean temperatures decrease with height (average rate of about 0.6°C/100 m) (Lockwood 1974), although local and regional differences exist (Brown and Cocheme 1973).

In lowland equatorial regions, mean temperatures are usually within the 25° to 30°C range, and diurnal variations depend mainly on cloudiness, distance from the sea, and elevation. For example, at Singapore (1.5°N, 8m), the diurnal range is 8°C in January and 6°C in July. At Mombassa, on the Indian Ocean coast of Kenya (4°S, 16m), the diurnal range is less than 7°C, but at Nairobi (1°S, 1820m) the range can be as large as 14°C (with an annual mean of 17°C at this altitude).

Maximum temperatures increase and minima decrease with distance from the equator to the geographical limits of the tropics at about 22.5° N or S. In seasonally-arid climates, monthly mean maxima exceeding 35° or even 40°C are common in the dry season. Minimum temperatures, depending on local features such as topography and exposure, can fall below 13°C (at 11°N at Samaru, Nigeria) or even 7°C (near the equator in Uganda). The risk of frost increases considerably at elevations greater than 2000 m.

These thermal conditions contrast with those in temperate regions, not only in diurnal amplitude and relative seasonality, but also in absolute range per se. Extrapolations from temperate climates (where so much of the research on soybeans has been done) to tropical regions are unlikely to prove reliable (e.g. Summerfield and Wien 1980).

Photo-Thermal Effects on Flowering: The country or latitude of origin of an accession has limited use in predicting adaptation to a specific environment [as might be expected if photoperiod responses were all-important (Byth 1968)], and the effects of temperature on photoperiod insensitive genotypes can be so pronounced that their supposedly broad-adaptation to a wide range of latitudes is open to question (Tanner and Hume 1976).

Differences in photoperiod, temperature, and the relative sensitivity of different genotypes to these factors dictate the rates and durations of phenological development in soybean crops, whether they are grown at temperate latitudes or in the tropics (see Shanmugasundaram et al. 1980 and citations in Summerfield and Roberts 1985).

Early maturing, indeterminate types with an optimum daylength (for flowering) of about 16 hr are grown in the northern states and Canada (USA maturity groups 00 and 0), whereas later-maturing, determinate types (Group X), with an optimum daylength close to 14 hr, are grown in the south (Weber 1968). In general, cultivars adapted to more northerly latitudes are said (Tanner and Hume 1976) to flower much later under cool days (16° cf 27°C) whereas those adapted to the south flower late if nights are cool (10° cf 21°C). Whether day, night, or average temperatures exert the major regulatory effect on flowering, combined photo-thermal responses are so dramatic and specific that cultivars within the USA are best adapted to zones equivalent to only about four degrees of latitude

(about 480 km). Outside this range, plants either fail to mature before the first frost (in the north) or flower and mature too early in the south. The American classification system is often unreliable in the tropics (Shanmugasundaram et al. 1980), and alternative systems have been proposed (Shanmugasundaram 1976).

Controlled environmental facilities, when operated properly (Summerfield 1980), can be a powerful adjunct to field research and have been used successfully to break the natural correlation between daylength and temperature (Summerfield and Minchin 1976), allowing accurate simulation of phenological development (Jones and Laing 1978). Temperature summation methods alone are not reliable predictors of phenological events in soybean (Major et al. 1975a and 1975b, Mota 1978). The alternative models predict phenological development more reliably within and between years at a particular site (see citations in Summerfield and Roberts 1985), even if they are less accurate when applied outside the regions for which they were developed (Jones and Laing 1978).

Notwithstanding the complexity of photoperiod x temperature x genotype responses and interactions, flowering responses to wide ranges of photoperiod and temperature are amenable to quantitative description (Hadley et al. 1983a,b, 1984). Results are summarized below.

Photoperiod-Insensitive Cultivar: Only cultivar Fiskeby 5, of the 9 cultivars tested, was completely insensitive to photoperiod, but differences in air temperature influenced the duration of the pre-flowering period (Fig. 4). Plants flowered soonest (after 29 days) in the warmest regime and latest (59 days) in the coolest regime. When the times from sowing to the appearance of first flowers are plotted against the mean diurnal temperature of each photothermal regime, it is clear that the reciprocal of the time to first flower (1/f) is a linear function of mean temperature ($\bar{t}$), so that the flowering response of this cultivar in all photo-thermal environments can be described by the following equation: $1/f = a + b\bar{t}$ (equation 1). Letter f denotes the number of days from sowing to the onset of flowering; a and b are constants.

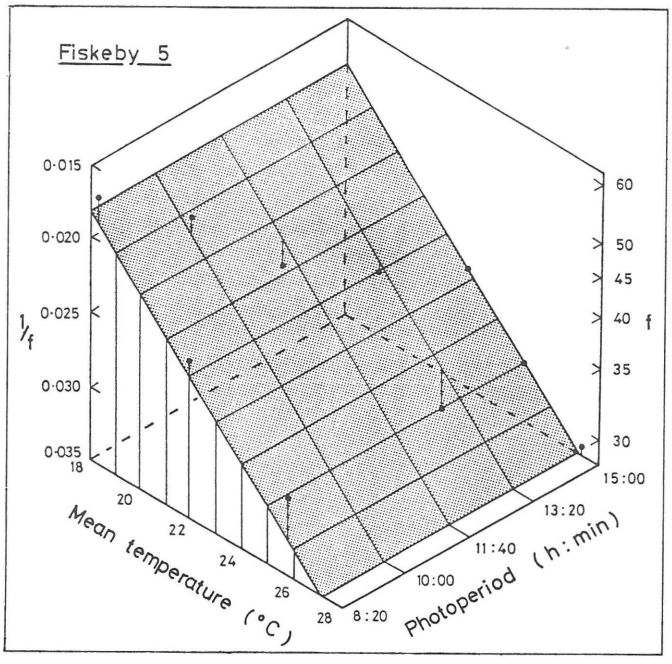

Fig. 4.
Effects of photoperiod (hr) and mean diurnal temperature (°C) on rate of progress towards flowering ($1/\bar{f}$) and days to flowering ($\bar{f}$) in soybean cv. Fiskeby 5 (left and right hand ordinates, respectively). Circles denote the experimental mean values in each of 10 environments.

Thus, as reported already for photoperiod-insensitive genotypes of cowpea (Hadley et al., 1983a), the reciprocal of time to flowering (rate of progress towards flowering) of Fiskeby 5 is also a simple function of mean diurnal temperature. As discussed elsewhere (e.g. Monteith 1977, Hadley et al. 1983a,b), equation 1 represents a thermal sum relation, in that it infers that flowering will occur in any photo-thermal environment after a constant number of thermal units, T_f, (in day-degrees above a base temperature of t_o) have accumulated after sowing. The value of the base temperature can be calculated from the constants of the regression (equation 1) using the expression: $t_o = -a/b$ (equation 2). Furthermore, the thermal sum required for flowering is given by: $T_f = 1/b$ (equation 3).

Photoperiod-Sensitive Genotypes: Among photoperiod sensitive genotypes, some - typified by TGm 39 (Fig. 5a) - were moderately sensitive, whereas others - typified by TGm 685 - were acutely sensitive (Fig. 5b). In photoperiods shorter than the critical daylength these cultivars are not affected by photoperiod, and flowering shows a basic temperature response typical of photoperiod-insensitive cultivars (as described in equation 1). However, a second response, superimposed on the temperature response surface, describes the delay in flowering due to long photoperiods; viz rates of progress towards flowering (1/f) are a linear function of photoperiod (p). However, in contrast to the model previously described for cowpea (Vigna unguiculata) (Hadley et al. 1983a,b), where the response to photoperiod was completely independent of temperature, this was not true for soybean. Thus, in any given photoperiod longer than the critical photoperiod the rate of progress towards flowering is a linear function of temperature (albeit a different function from that describing the temperature response in inductive photoperiods). When photoperiod delays flowering, there is no interaction between photoperiod and temperature, and so the response in these photo-thermal regimes can be described by equation 4: $1/f = a' + b't + c'p$ (a', b', and c' are constants).

Our results also suggest that there is a minimum rate of progress towards flowering which is not exceeded, irrespective of photo-thermal environment; i. e. for each cultivar, long photoperiods cannot delay flowering beyond a given maximum number of days (Fig. 5a, 5b).

The critical photoperiod (p_c) may be defined as that photoperiod in any thermal regime, which, if exceeded, causes flowering to be delayed. For photoperiod-sensitive soybeans this occurs at the intersection of the two response surfaces representing the photoperiod-insensitive flowering response described in equation 1 and the photoperiod-temperature response described in equation 4. In contrast with the response of cowpea (Hadley et al. 1983a,b), where the duration of the critical photoperiod decreased in warmer average temperatures, the critical photoperiod for soybean increased as temperatures became warmer (Fig. 5a, 5b). This is an inevitable consequence of the geometry of the overall response surfaces. In general, the critical photoperiod increased by some 100 to 120 min over the 18° to 27°C range of the mean temperatures tested (about 11 min $°C^{-1}$). The critical photoperiod for each of these photoperiod-sensitive soybeans can be estimated for any photo-thermal regime by inserting the calculated values of the constants derived from equations 1 and 4 into the following equation (5):

$$p_c = \frac{a - a' + \bar{t}(b-b')}{c'}$$

In photoperiod-sensitive cowpea accessions grown in photoperiods longer than the critical value, the times to first flower increased as an inverse function of increasing photoperiod. In soybeans, however, the delay in flowering increases not only as a function of increasing photoperiod but also as a function of decreasing temperature. Thus, the photoperiod equation derived for cowpea can

now be considered to be a special case of equation 4, but where the value of the temperature coefficient (b') is zero. A consequence of this in cowpea was that the equation which defined the critical photoperiod could omit the term b', and thus it was given as: $p_c = (a - a' + b\bar{t})/c'$, where a and b, and a' and c' are constants derived from equations 1 and 4, respectively. This relationship demands that the critical photoperiod decreases linearly with increases in temperature. However, in soybean, because there is a temperature effect in non-inductive photoperiods, and because the slope constants that define this effect are greater than those that define the effect of temperature in inductive photoperiods, it is inevitable that when these are applied in equation 5, the critical photoperiod increases with increasing temperature.

One minor additional complication in soybean is that there is a maximum period to flowering for some accessions that is never exceeded in any photothermal regime. However, it should be pointed out that in the more photoperiodically-sensitive accessions (e.g. Fig. 5b), the experiments were not continued for long enough to be certain that this constraint generally applies.

Re-examination of other work describing the effects of thermal environment on photoperiod-sensitive and insensitive soybean genotypes (Inouye et al. 1979, Shibles et al. 1975, Tanner and Hume 1976) indicates that these data also fit the model proposed here, in that - at a constant photoperiod or with photoperiod-insensitive genotypes in varying photoperiods - the rate of progress towards flowering is a linear function of average temperature. Our own and other work on

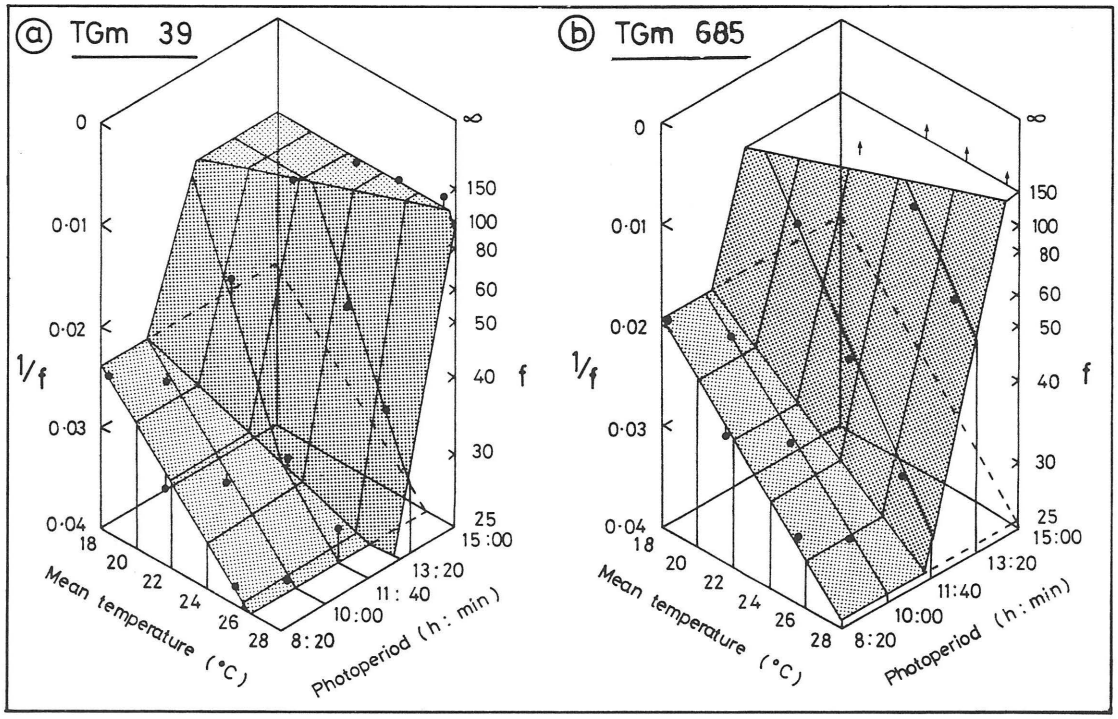

Fig. 5. Effects of photoperiod (hr) and mean diurnal temperature (°C) on rates of progress towards flowering ($1/\underline{f}$) and days to flowering ($\underline{f}$) in soybean accessions (a) TGm 39 and (b) TGm 685 (genotypes moderately and acutely sensitive to photoperiod, respectively). Circles denote the experimental mean values in each of 15 environments. The vertical arrows in (b) denote that plants in these environments failed to flower when the experiment was terminated 150 days after sowing.

photo-thermal effects on flowering in soybean have emphasized the importance of night (mean minimum) temperatures (see Summerfield and Roberts 1985). While this emphasis seemed justified for the small range of photo-thermal environments tested in our earlier experiments, it is now clear that genotypes are sensitive to mean diurnal temperatures rather than to night temperatures per se. Tanner and Hume (1976) also concluded that night temperatures had an overriding effect on days from planting to flowering for 12 soybean cultivars, but we suggest that this conclusion may have resulted from the use of an environmental regime (26.7°C day, 10°C night) that was stressful to several of the cultivars tested, and so delayed their flowering more than that predicted by mean temperature alone. When the data for their four other experiments are re-plotted, the relationship between the inverse of days to flowering and mean temperature appears virtually linear, but the data for their 26.7°C day/10°C night combination are clearly aberrant for those cultivars that apparently showed the most marked effect of night temperature per se.

Screening Germplasm

An objective of many research programs, including our own, is to develop techniques for screening large numbers of genotypes that are more or less sensitive to photoperiod and temperature, and are therefore likely to be well adapted either to a relatively few or to a wide range of environments, respectively.

It is clear from our latest findings (Hadley et al. 1984) that the strategy advocated for screening cowpeas will not be appropriate for soybeans. In order to develop appropriate techniques it is important first to consider the range of natural climates in which the crop is typically cultivated. The range of soybean extends from the tropics, where daylengths (including civil twilight) vary from about 11 to 14 h, to more temperate latitudes where the crop is grown during spring and summer months experiencing daylengths longer than 14 hr. It is clear from Fig. 5a and 5b that the crop will almost always experience photoperiods longer than the critical value.

It follows that the environments chosen for the screen should be in locations defined by the photo-thermal response surface, i.e. in photoperiods longer than the critical value. Since the slope of this plane is defined by temperature and photoperiod, the minimum number of environments required to establish the slope of the plane is three (including two photoperiods and two temperatures). Results obtained from these environments would establish the sensitivity of both the photoperiodic and temperature response of photoperiodically-sensitive accessions, and, for photoperiod-insensitive accessions, the data would determine the basic temperature response, and so allow calculation of the base temperature and thermal sum - a concept that can be immediately applied to varying diurnal and seasonal thermal environments in the field.

Examination of data for all eight photoperiod-sensitive genotypes suggests three environments that meet the necessary criteria: 21°C/12 hr, 25°C/12 hr, and 25°C/14 hr (mean temperature/photoperiod). It would also be useful to include a fourth treatment that defines the maximum period to flowering. Our data suggests that an appropriate environment would be 21°C/14 hr. Thus, a simple 2 x 2 factorial experiment should establish the main features of the photo-thermal response of photoperiod-sensitive accessions and the thermal response of photoperiod-insensitive ones. This screen would most reliably be carried out in controlled temperature and daylength glasshouses (e.g. Summerfield et al. 1979).

Several authors have discussed the merits of using photoperiod insensitive cultivars, particularly in areas of the tropics and subtropics where more than one soybean crop can be grown per year (Hinson 1974, Shanmugasundaram 1981). Such genotypes are now available and could presumably be incorporated into

varietal improvement programs. Our results indicate that their rates of phenological development could be reliably predicted by thermal integration above a base temperature of 7.8°C. On the other hand, it has yet to be determined that truly photoperiod-insensitive soybean can also be late maturing, and so photoperiod-sensitive cultivars may still be important where longer duration types are required under conditions of a fixed growing period and where crop duration needs to match the time available for cultivation. There appears here to be an exact parallel with rice (Oryza sativa), where all photoperiod-insensitive cultivars are of relatively short duration; long duration can only be obtained by using photoperiod-sensitive cultivars (Vergara and Chang 1976).

Information from two areas is required before these concepts can be used to predict the phenological behavior of field-grown soybean to non-inductive photoperiods. Our model, which is accurate in constant environments, does not take into account the changes in relative photoperiod-sensitivity that may occur during development, and how the responses described here relate to seasonal changes in climate. This information might be provided in experiments where reciprocal transfers of plants between long and short photoperiods and warm and cool temperatures are made at regular intervals during the development of diverse soybean genotypes (Shanmugasundaram and Lee 1980). When these data are combined with current knowledge, they may lead to the development of basic and fundamental models that can reliably predict the phenological behavior of diverse soybean genotypes in widely different climatic regions and growing seasons.

Concluding Remarks

Throughout this review we have concentrated on the photo-thermal regulation of the discrete event of floral anthesis in soybean, most often observed as the time that the first open flower (corolla color visible) appears. We recognize that floral development includes the initiation of floral primordia and their subsequent period of expansion, culminating in anthesis (Guard 1931). Initiation and anthesis are regulated independently by photoperiod, and floral initiation of axillary racemes is independent of that at stem apices (Thomas and Raper 1983). Photo-thermal effects on carbon metabolism and nitrogen nutrition post anthesis (Cure et al. 1982) - as well as continued phenological progress towards maturity, senescence, and death - are likely to be significant aspects of adaptability to environment and cropping season duration. Our aim is to quantify the relative significance of each of these diverse facets among soybean germplasm and to incorporate the information into a reliable, predictive scheme that can be used by plant breeders. Progress in the last decade has been rapid and we expect equally rapid developments in the future. The shift in recent years from a myopic preoccupation with photoperiodic effects per se is reason for optimism.

Acknowledgements

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Photoperiod and Temperature Effects on the Growth and Reproductive Behavior of Less Photoperiod-Sensitive Soybean

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Introduction

Soybean (Glycine max) is generally classified as a short-day plant. According to Fukui and Yarimizu (1951,1952), the crop's blooming to pod ripening period is reduced when soybean is grown under short daylengths and high temperatures. The longer the pod ripening period of a cultivar, the greater the decrease will be in its blooming to pod ripening period. However, some researchers have identified photoperiod-insensitive cultivars (Yoshida 1952, Criswell and Hume 1972, Summerfield and Minchin 1976, Inouye et al. 1979, Shanmugasundaram 1981).

Early maturing cultivars initially identified as being less photoperiod-sensitive in a two-season trial at AVRDC were examined to determine the effect of photoperiod and temperature on flowering and podding. The experiment was conducted at the Institute of Tropical Agriculture, Kyushu University, Japan.

Materials and Methods

Forty-eight cultivars with photoperiod-sensitivity scores of "0" were studied; cultivar differences in terms of days to flowering between natural days and the 16 hr treatments were within a 4-day range (Shanmugasundaram 1981). Four seeds were sown in plastic pots (18 x 20 cm) filled with 4.5 kg sandy loam soil (plus 1 g ammonium sulphate, 5 g calcium superphosphate, 1 g potassium chloride, and 2 g lime). After emergence, two seedlings were removed from each pot. The experiment was conducted with either two or four replications.

PHOTOPERIOD EXPERIMENT

Pots representing each of the 48 cultivars were exposed to short-day (8 hr) or long-day (continuous lighting) conditions. In a separate experiment, five cultivars (PI Nos. 154190, 194631, 196529, 189952, and 248407) were grown under 8, 12, 16, 20, and 24 hr lighting conditions (8 hr natural sunlight and 16 hr supplementary light). The flux density of the supplemental lighting was approximately 200 lux. Mean temperature during the experiment was approximately 28°C.

TEMPERATURE EXPERIMENT

Pots were placed in 20, 25, 30, and 35°C, controlled temperature rooms. The experiment was conducted each year for five years (1976-80) with approximately fifteen cultivars per year. Two or more additional cultivars were included for purposes of comparison. Natural photoperiod was approximately 13 hr, 30 min to 14 hr, 20 min.

Results and Discussion

Photoperiod Experiment

Flowering: Days from emergence to first flower anthesis (days to flowering) varied from 9 to 26 days under the short-day treatments and from 20 to 47 days under the long-day treatments (Table 1). The difference in days to flowering between the short-day and long-day treatments was two days or less in 38 cultivars and 4 to 24 days in 10 cultivars. The first group may be regarded as photoperiod-insensitive cultivars and the latter as quantitative short-day cultivars. Under short-days, the average number of days to flowering was 22.3 days (±1.6) among the photoperiod-insensitive cultivars and 22.5 days (±1.51) among the quantitative short-day cultivars. Under long-days, the average value was 22.7 (±1.8) in the former and 37.5 (±6.5) in the latter.

Initial screening (48 cultivars) was conducted under 10 hr and 16 hr photoperiods, mainly because maximum photoperiods in tropical and subtropical regions do not exceed 14 hr (Shanmugasundaram 1981). Although some entries were insensitive to photoperiod (8 to 20 hr), days to flowering was distinct between plants grown under 20 hr and 24 hr photoperiods in the two quantitative short-day cultivars tested (Table 2).

Days from first flower anthesis to terminal flower anthesis (flowering duration) in the 38 photoperiod-insensitive cultivars varied from 1 to 20 days under short-day conditions and from 1 to 19 days under long-day conditions. In more than 50% of the photoperiod-insensitive cultivars, first to terminal flower anthesis was 5 days or less under both photoperiods (Table 3). The flowering duration in the 10 quantitative short-day cultivars was 2 to 23 days under short photoperiods and from 8 to 26 days under long photoperiods. Therefore, flowering duration in some of the quantitative short-day cultivars appeared to be longer than in the photoperiod-insensitive cultivars.

Number of Nodes: Increased node number after first flower anthesis on the main stem varied from 0 to 10 nodes under both photoperiods with the photoperiod-insensitive cultivars, while the quantitative short-day cultivars varied from 0 to 11 nodes under short-days and from 5 to 12 nodes under long-days (Table 4). Highly significant positive correlations were observed between flowering duration and increased node number under short-days ($r = 0.9153^{***}$) and under long-days ($r = 0.9423^{***}$).

When the experiment was terminated, the difference in final node number on the main stem - between short and long photoperiods - was three nodes or less in the photoperiod-insensitive cultivars, but ranged from 5 to 11 nodes in the quantitative short-day cultivars (Tables 5 and 6).

Nagata (1960) reported that leaf primordia initiation terminates soon after flower primordia initiation of determinate cultivars, while with indeterminate soybeans it continues even after flower primordia initiation. Consequently, flowering duration is shorter in determinate than in indeterminate cultivars. Determinate cultivars produce less nodes after first flower anthesis, or after flower primordia initiation, than indeterminate cultivars. Nagata also reported (1962) that the number of nodes on the main stem, under short-day conditions, was the most practical indicator of determinate and indeterminate growth habits.

According to Thseng and Hosokawa (1972), increases in node number after first flower anthesis is 0, 3 to 9, and 9 to 14 nodes in plants with determinate, intermediate, and indeterminate growth habits, respectively. In another experiment Jin et al. (1982) reported that increases in node number after first flower

anthesis is roughly three nodes in determinate types and nine or more in indeterminate cultivars.

Table 1. Association of days from emergence to first flower anthesis under short-day and long-day conditions among different cultivars.

Days to Flowering Under Long-Days	Days to Flowering Under Short Days								
	19	20	21	22	23	24	25	26	Total
20		2	1						3
21		1	2	3					6
22		1	2	6					9
23	1		1	8	2	1			13
24					1	2	1		4
25									
26								1	1
27							1	2	3
34-47				4	2	3			9
Total	1	4	6	21	5	6	2	3	48

Table 2. Days from emergence to first flower anthesis of selected cultivars grown under different photoperiods.

Cultivar	Photoperiods (hr)				
	8	12	16	20	24
Photoperiod-insensitive					
PI 154190	26	25	26	26	26
PI 194631	26	26	27	26	26
PI 196529	22	21	22	22	21
Quantitative short-day					
PI 189952	24	24	25	24	38
PI 248407	24	24	24	25	33

Table 3. Association of flowering duration among different cultivars grown under short and long photoperiods.

Flowering Duration Under Long-Days	Flowering Duration Under Short Days					
	1-5	6-10	11-15	16-20	21-25	Total
1-5	19	2				21
6-10	1 (1)	2	1	0 (1)		4 (2)
11-15		1 (1)	3	3	1 (1)	8 (2)
16-20			2 (1)	3 (2)	0 (1)	5 (4)
21-25					0 (1)	0 (1)
26				0 (1)		0 (1)
Total	20 (1)	5 (1)	6 (1)	6 (4)	1 (3)	38 (10)

( ): Number of the quantitative short-day cultivars

Table 4. Increase in node number on the main stem after first flower anthesis under short- and long-day conditions.

Type	Increase in Node Number After First Flower Anthesis													
	0	1	2	3	4	5	6	7	8	9	10	11	12	Total
Short-day														
Photoperiod-insensitive	15	1	5	4	3	3	1	1	4	0	1			38
Quantitative short-day	1	0	0	1	0	3	0	0	3	1	0	1		10
Long-day														
Photoperiod-insensitive	15	4	2	3	3	2	1	4	3	0	1			38
Quantitative short-day						1	1	3	1	1	0	0	3	10

The increase in node number after first flower anthesis differed only slightly under short-day and long-day conditions (Table 4). With photoperiod-insensitive cultivars - both under short-days and long-days - the increase in node number was 3 nodes in 24 cultivars, 4 to 8 nodes in 13 cultivars, and 10 nodes in 1 cultivar. The first group may be regarded as determinate growth types, the second as intermediate types, and the last as an indeterminate type. None of the quantitative short-day cultivars can be classified as determinate based on the increase in node number after first flower anthesis under either photoperiodic regime.

Based on the increase in node number after first flower anthesis, the 38 photoperiod-insensitive cultivars tested were classified as follows:

Determinate growth types (24): PI Nos. 81035, 132203, 132214, 153203, 153210, 153211, 153212, 153216, 153218, 153219, 153222, 153303, 154190, 154197, 154198, 154200, 196501, 196525, 196528, 196529, 196530, Fiskeby 4, Fiskeby 5, and Shinsei.

Intermediate growth types (13): PI Nos. 82263-3 828, 154190, 180499, 180509, 180516, 180532-2, 194631, 194646, 194656, 194681, 321172, and Norman.

Indeterminate growth type (1): PI No. 194647.

Quantitative short-day cultivars (10): PI Nos. 227213, 68421-1, 68484-1, 81767 777, 153234, 161431-B, 180507, 189861, 189952, and 248407.

Nagata (1962) reported that determinate and indeterminate plants can be distinguished by leaf transformation type and by the shape of the terminal raceme. In this experiment, however, the relationship between growth type - based on the increase in node number after first flower anthesis and morphological characteristics - differed occasionally using Nagata's (1962) classification method.

Maturity and Yield: Days from first flower anthesis to maturity was similar among photoperiod-insensitive cultivars and quantitative short-day cultivars grown under short- and long-day photoperiods (Table 7).

Pod number/plant and grain yield were higher under long-day conditions than under short-day conditions in all cultivars (Table 8 and 9). Yield differences as a function of short-days or long-days were smallest among the determinate growth types, somewhat higher among intermediate photoperiod-insensitive cultivars, and highest in the quantitative short-day cultivars. Plant yield was highest in the quantitative short-day cultivars and lowest in the determinate photoperiod-insensitive cultivars under both photoperiodic conditions.

Of the 38 photoperiod-insensitive cultivars tested, highly positive correlations were observed between the final node number on the main stem and number of pods/plant ($r=0.6358^{**}$, $r=0.6144^{**}$) or grain yield per plant ($r=0.6358^{**}$, $r=0.5735^{**}$). Therefore, as suggested by Shanmugasundaram (1981), photoperiod-insensitive cultivars that are intermediate or indeterminate growth types may have higher yield potential than determinate types. If photoperiod-insensitive determinate cultivars are selected, the best way to increase yields would be to raise plant population densities since pod number/plant will be lower on photoperiod-insensitive intermediate and indeterminate cultivars and quantitative short-day cultivars. Additional experiments are needed to test this hypothesis.

Table 5. Differences in the final node number on the main stem among different cultivars grown under long-and short-day conditions.

Type	Difference in Final Node Number											
	0	1	2	3	4	5	6	7	8	9	10	11	Total
Photoperiod-insensitive	10	23	3	2									38
Quantitative short-day						1	2	2	2	1	1	1	10

Table 6. Final node number on the main stem of cultivars grown under short- and long-day conditions.

Type	Number of Cultivars	Final Node Number	
		short-day	long-day
Photoperiod-insensitive			
Determinate	24	9.9 ±1.36	10.9 ±1.19
Intermediate[z]	14	15.9 ±2.03	16.7 ±2.32
Quantitative short-day	10	15.1 ±3.43	22.7 ±2.82

[z]Contains one indeterminate cultivar

Table 7. Days from first flower anthesis to maturity of cultivars grown under short- and long-day conditions.

Type	Number of Cultivars	Days From Flower Anthesis to Maturity	
		short-day	long-day
Photoperiod-insensitive			
Determinate	24	57.7 ±5.45	59.7 ±5.45
Intermediate[z]	14	63.4 ±6.46	64.4 ±5.42
Quantitative short-day	10	63.3 ±11.04	61.7 ±7.37

[z]Including one indeterminate cultivar

Table 8. Number of pods per plant of cultivar types grown under short-day and long-day conditions.

Type	Number of Cultivars	Number of Pods per Plant	
		short-day	long-day
Photoperiod-insensitive			
Determinate	24	25.2 ±5.51	33.9 ±7.15
Intermediate[z]	14	33.4 ±6.75	49.4 ±9.34
Quantitative short-day	10	35.7 ±10.76	83.4 ±15.65

[z]Includes one indeterminate cultivar

Table 9. Grain yield per plant of cultivar types grown under short-day and long-day conditions.

Type	Number of Cultivars	Grain Yield per Plant (g)	
		short-day	long-day
Photoperiod-insensitive			
Determinate	24	7.1 ±1.67	8.1 ±1.88
Intermediate[z]	14	10.2 ±1.34	11.6 ±2.16
Quantitative short-day	10	8.1 ±2.71	19.9 ±5.13

[z]Includes one indeterminate cultivar

Temperature Experiment

Flowering: With most cultivars, days to flowering was shortest at 30°C, followed by an increase in days to flowering at 25°, 35°, and 20°C (Table 10). At 20°C, all plants showed cleistogamy; at 35°C most cultivars aborted their flowers.

Number of Nodes: The final node number on the main stem was almost the same in the photoperiod-insensitive determinate cultivars, regardless of the temperature treatment, whereas node number increased at higher temperatures with the photoperiod-insensitive intermediate and indeterminate cultivars and with the quantitative short-day cultivars.

Environmental factors, especially temperature, greatly influence photoperiodic response (Hillman 1962, Salisbury 1963). Low temperatures are known to reduce the critical photoperiod for flowering in long-day plants and increase it in short-day plants (Kimura 1966, Lang and Melchers 1943, Roberts and Struckmeyer 1937).

With the photoperiod-insensitive intermediate and indeterminate cultivars, even though the maximum photoperiod was shorter than 15 hr, final node number on the main stem (at 35°C) was higher than under continuous lighting conditions in the photoperiod experiment (Tables 6 and 11). Therefore, photoperiod-insensitive cultivars can be divided into two categories according to their temperature responses and final node number: 1) the final node number is similar regardless of temperature and 2) the node number increases at higher temperatures.

Maturity: Only a few plants produced pods and small seeds at 35°C. At 30°C, about one-third produced a few seeds, but no relationship was observed between growth type and podding. To clarify the effect of temperature on maturity, additional experiments should be conducted under alternating temperature conditions.

Summary

According to photoperiodic and temperature responses, the 48 test cultivars can be classified as follows:

Stable Determinate Growth Types (Sd types): These lines are photoperiod insensitive. Under short-day and long-day conditions, days to flowering is almost same, flowering period is short, and the increase in node number after first flower anthesis is insignificant. Final node number is similar, regardless of temperature and photoperiod.

Unstable Determinate (Intermediate) Growth Type (Ud type): These materials are also photoperiod insensitive. Days to flowering is almost the same under both photoperiods, but flowering periods are fairly long and the increase in node number is rather large. Number of nodes is slightly higher under long-day conditions than under short-day conditions; node number is higher at lower temperatures.

Quantitative Short-Day Cultivars: Plants can initiate flowers and produce pods under both photoperiods, but number of days to flowering and the resulting number of nodes are greater under long-day conditions than under short-day conditions. The number of nodes is also greater at higher temperatures.

Unstable, determinate, photoperiod-insensitive cultivars have higher yield potentials than stable, determinate growth types that require high plant population densities to produce high yields.

Table 10. Effect of temperature on the days from emergence to first flower anthesis.

Type	Number of Cultivars	Days to Flowering 20°	25°	30°	35°
Photoperiod-insensitive					
Determinate	24	30.8 ±1.80	23.6 ±1.77	10.7 ±1.08	28.4 ±4.47
Intermediate[z]	14	33.2 ±1.58	27.4 ±1.93	23.4 ±1.50	30.3 ±3.48
Quantitative short-day	10	32.7 ±1.13	25.8 ±0.92	23.9 ±0.88	30.7 ±2.06

[z]Includes one indeterminate cultivar

Table 11. Effect of temperature on final node number on the main stem.

Type	Number of Cultivars	Final Node Number 20°	25°	30°	35°
Photoperiod-insensitive					
Determinate	24	9.7 ±0.86	9.8 ±0.80	10.5 ±1.38	10.8 ±1.69
Intermediate[z]	14	12.2 ±1.57	13.1 ±1.73	17.0 ±2.35	23.1 ±3.00
Quantitative short-day	10	11.1 ±1.10	11.7 ±1.49	16.5 ±1.85	22.7 ±2.54

[z]Includes one indeterminate cultivar

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Adaptation of Soybean to Subtropical and Tropical Environments in Australia

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Introduction

Soybean (Glycine max) production in Australia began, in a limited way, in the late 1960s in southeastern Queensland (Fig. 1). Subsequent expansion took place in southern Queensland, and later in New South Wales. Small areas of soybean are presently grown in central Queensland, in the Ord River region of northwest Australia, and in the Douglas/Daly area of the Northern Territory.

Queensland and New South Wales are the dominant production areas (Table 1). About two-thirds of the country's soybean is produced in the subtropics of southeastern Queensland at latitudes of 26 to 29°S (Fig. 1). About 1,500 ha is planted annually in the tropics of Queensland, mainly at Emerald (22.5°S) and in the Burdekin region (20°S). In 1982-83, 700 ha were grown in the Ord River area (15°S) and 350 ha at Douglas/Daly (14°S). About one-third of the total production area is located at latitudes higher than 29°S, mainly on the northwest slopes and plains and in the northern coastal region of New South Wales.

This paper presents a brief overview of the major climatic constraints that influence the soybean industry in Australia and an analysis of the consequences of genotype x climate interactions for varietal improvement and the development of cropping strategies.

A general understanding of the climatic factors that influence growth and development, as well as the genetic differences involved in these responses, is relevant to soybean improvement in the tropics and subtropics of Australia which are geographically and climatically diverse. Soybean improvement research in Australia is quite limited, and is located primarily on the subtropical and warm temperate zones. Research and selection results must therefore be extrapolated to other environments. As such, many aspects of the Australian research experience may be relevant to soybean improvement in other parts of the tropics.

Climatic Constraints

Temperature and water constraints significantly affect soybean production in Australia (Nix et al. 1977, Chapman 1981). The likelihood of frost generally precludes winter production in the subtropics (Fig. 2b), although an occasional winter crop has been grown at fortuitously frost-free sites in several coastal and subcoastal areas of southeastern Queensland. In some elevated areas west of the Great Dividing Range, the possibility of autumn frosts restricts late sowing (post-December). In the tropics, except in some inland and elevated areas, frost is less of a problem, and, in the absence of other constraints, both summer and winter cropping can be carried out (Fig. 2b).

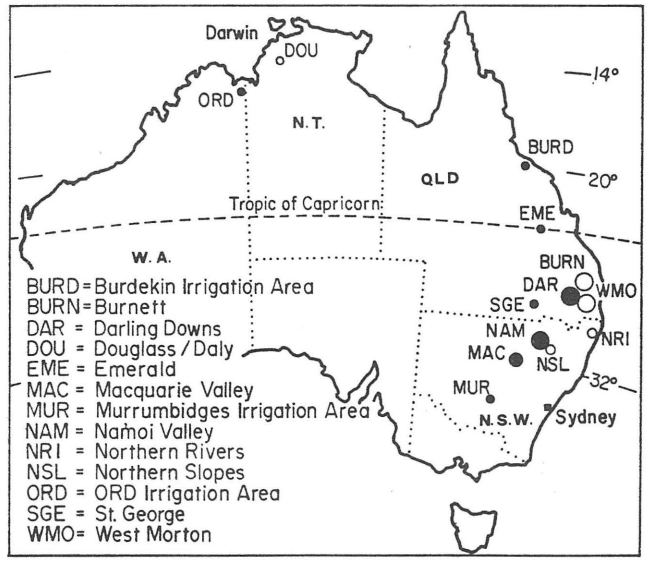
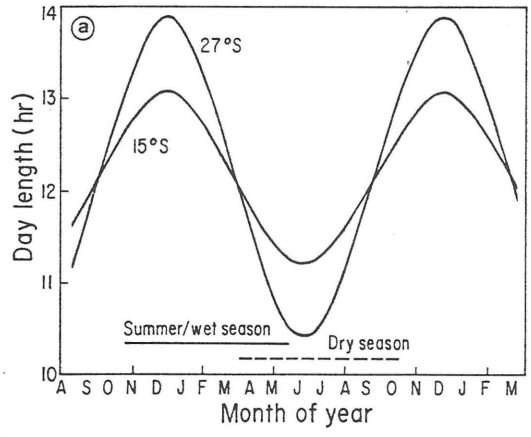


Fig. 1. (right)
Major soybean-producing areas in Australia (closed circles indicate predominantly irrigated production).



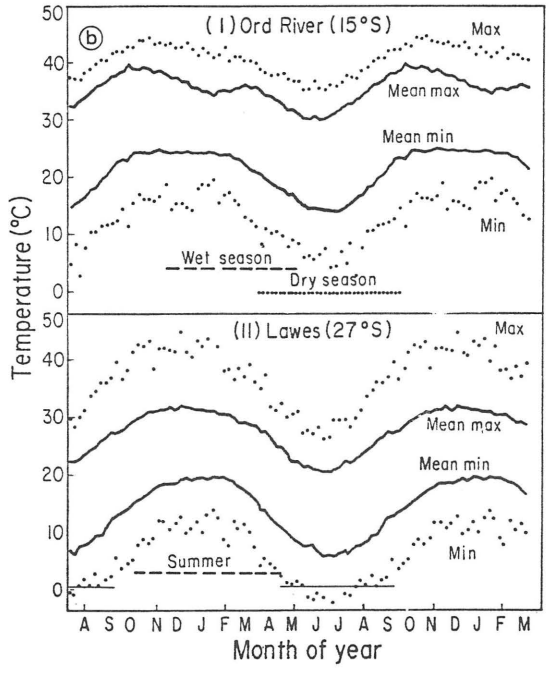


Fig. 2. (a, below; b, right)
(a) Seasonal profiles of daylength at 15°S and 27°S; (b) seasonal profiles (weekly means and extremes) of temperature at (i) the Ord River area, a tropical site (15°S) in the northwest and (ii) Lawes, a subtropical site (27°S) in the major soybean-producing area in southeastern Queensland.

Rainfall in the Australian tropics is distinctly seasonal; a variable summer wet season usually extends from December to March, followed by an essentially rain-free dry season. The duration of the monsoon and the timing and amount of rainfall vary (Hammer 1983, Williams et al. 1983), but the duration of the wet season and total rainfall generally decrease, and variability in the amount and time of rainfall increases with distance from the coast. Rainfed or irrigated cropping is possible during the wet season in the tropics, but irrigation is required in the dry season (Garside et al. 1983).

Given current constraints on knowledge of soybean adaptation, it is difficult to assess the areas potentially suitable for soybean in the Australian

Table 1. Areas sown and average yields of soybean in Queensland and New South Wales.

Year	Area Sown (10^3 ha)	Yield (t/ha)	Area Sown (10^3 ha)	Yield (t/ha)
1975-76	19.55	1.70	6.70	1.69
1976-77	26.03	1.57	8.52	1.69
1977-78	36.71	1.40	13.12	1.91
1978-79	36.43	1.79	17.08	1.95
1979-80	34.50	1.21	21.71	1.84
1980-81	29.32	1.80	10.08	1.98
1981-82	26.10	1.92	14.00	1.88

Source: Australian Bureau of Statistics

tropics (Chapman 1981). More than 1 million ha in Queensland are potentially suitable, although with current technology much of this area is either nct permanently arable or could be sown to more profitable crops (Weston et al. 1981). On the other hand, wet soil culture (see Troedson et al., eds.) may permit cultivation in areas with seasonally-waterlogged soils that are now considered non-arable (Chapman 1981). The potential for dry season cropping is largely restricted to Ord and Burdekin River irrigation projects (Fig. 1).

Rainfall in the eastern subtropics is bimodal, with summer and winter peaks. The importance of the summer component, both in absolute terms and as a proportion of the annual total, declines from north to south (Nix et al. 1977, Hammer 1983). Rainfall also declines rapidly with distance from the coast, particularly west of the ranges. Rainfall variability is high, and increases with distance inland. In southeastern Queensland and in northern New South Wales, rainfed cropping is therefore concentrated in the wetter ($\geq$500 mm summer rainfall) coastal, subcoastal, and eastern plain areas, while most production to the west is irrigated (Fig. 1). In western New South Wales, particularly in the central and southern regions, summer rainfall is inadequate for rainfed cropping, and production is largely irrigated.

Because much of the soybean crop in the subtropics is wholly or partly rainfed, production is variable, as indicated by yield comparisons from Queensland and New South Wales (Table 1). Areas sown in Queensland vary, depending on the adequacy of sowing rains, while yields depend on the adequacy of follow-up growing rains. An estimated 750,000 ha is potentially suitable for soybean in the subtropics of Queensland, although much of this area is either currently sown to other crops or may be in the future (Weston et al. 1981).

Genotype X Climate Interactions

Differential genotypic response to three climatic variables - daylength, temperature, and water availability - are the major components of genotype x climate interactions in soybean studies conducted in tropical and subtropical Australia.

Daylength and Temperature

Differential developmental response to daylength among cultivars was identified as a major factor governing soybean adaptation to latitude and sowing date (Byth 1968, Lawn and Byth 1973, 1974). In southeastern Queensland, sowing date studies in the summer showed that genetic lateness of maturity was associated with responsiveness to sowing date. The earliest maturing genotypes were insensitive to the range of daylengths in the test environment. In contrast, the latest maturing lines were sufficiently sensitive to prevailing midsummer

daylengths that flowering was delayed until the occurrence of shorter days in February/March when the lines were planted prior to the summer solstice. Mid-season lines were intermediate in response: flowering was mostly delayed for lines planted just prior to the summer solstice (Fig. 3).

Regression analyses showed that most of the variation in time to flowering over sowing date could be accounted for by daylength alone (Table 2). Only in the earlier-flowering lines, which were relatively non-responsive to sowing date, did temperature account for any substantial proportion of that variation (albeit small) which occurred. It was concluded that growing the same set of lines at latitudes different from those found in southeast Queensland would result either in later maturity and greater responsiveness to sowing date (higher latitudes) or earlier maturity and less responsiveness (lower latitudes); with the exception that in low temperature areas the magnitude of temperature effects would be expected to increase (Lawn and Byth 1973).

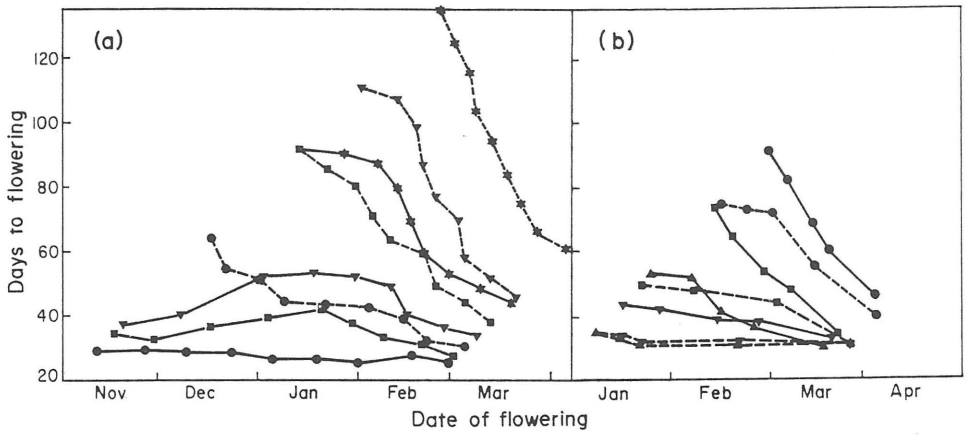


Fig. 3. Comparison of days to flowering as a function of date of flowering for (a) four lines sown at two weekly intervals in southeast Queensland (solid lines) and at 32°S near Perth (broken lines). Circles, squares, triangles and stars indicate accessions CPI 26673, Lee, Semstar, and Gilbert, respectively, and (b) four lines sown at various intervals between early December and late February at 27°S (solid lines) and at 15°S in the Ord River area (broken lines). Inverted triangles, normal triangles, squares, and circles represent accessions Hill, Semstar, Gilbert, and K8, respectively. (Data from 27°S from Lawn and Byth 1973; Perth data courtesy of P. J. Farrington (unpublished); Ord data from Beech et al. (unpublished).

Table 2. Rate of development (r) as a function of mean daily photoperiod (P) and mean daily maximum (T) or minimum (t) temperatures for wet season soybean at 27°S. The relative contributions of the climatic factors (as indicated by standard partial regression coefficients) are shown in parentheses.

	Sowing to Flowering		
	Days	Regressions	R^2
CPI 26671	30.6 (28-35)	r=0.026 +0.0016T-0.0024P (.65) (.35)	.81**
Semstar	43.6 (30-55)	r=0.190+0.0005t -0.0117P (.10) (.90)	.95**
Gilbert	67.5 (35-94)	r=0.109+0.0024t -0.0091P (.29) (.71)	.97**
K8	84.3 (45-129)	r=0.118+0.0021t -0.0096P (.20) (.80)	.99**

Subsequent studies showed that prediction to be substantively correct. Serial sowings at Perth (~32°S) produced later flowering and a greater response to sowing date than at Redland Bay (Fig. 3a). Conversely, in the Ord River area (15°S), lines were earlier flowering and less responsive (Fig. 3b). Thus, mid-season cultivar Semstar, which is phenologically well adapted in southeastern Queensland (~ USA maturity group VIII), together with most other lines adapted to subtropical and/or higher latitudes, are early flowering and non-responsive in the tropics. Quantitative analysis of the response of lines grown in the summer in southeastern Queensland and in the Ord River area indicated that differences in flowering response can be accounted for almost entirely by daylength response (I.M. Wood, personal communication).

While extrapolation of developmental response over latitude is useful for summer crops, direct extrapolation of wet season to dry season performance in the tropics is not possible for several reasons. Seasonal profiles of variations in daylength and temperature for dry season crops are a "mirror image" of those experienced in the wet season. Dry season crops are sown under declining daylengths in April and May (Fig. 2a), flower in late June/July - when days are shortest - and proceed to set pods and mature under lengthening days. Similarly, temperatures are warmer at the beginning and at the end of the dry season (Fig. 2b), and are coolest in July and early August when the crop is in the flowering and early pod filling stages.

Daylengths during most of the dry season in the Australian tropics are short relative to those experienced by summer crops at any latitude. However, daylengths around the time of maturity are longer than those experienced by most summer-grown crops at the same stage of development. For example, daylengths in mid-September (dry season) approach 12 hr, whereas summer-grown crops (which usually mature in late April/May, after the autumn equinox), are exposed to 11.5 hr-days (15°S) and 11 hr-days (27°S) at maturity (Fig. 2a).

Recent studies in northern Australia have indicated a substantial interaction between genotype and sowing date, location, and year (Mayers et al. 1982, J. D. Mayers unpublished data). These interactions are typified by the responses of three lines - CPI 70242 (a late flowering introduction from Indonesia), Buchanan (a locally bred line adapted to the wet season), and Fiskeby V - in three serial sowing studies in northern Australia (Fig. 4). Planting was carried out at weekly intervals from April to mid-July at the Ord River in 1981, and between the autumn and spring equinoxes in 1982 at both the Ord River and at Walkamin (17°S) in northern Queensland.

All lines were generally later flowering in 1981, and later at Walkamin than at the Ord River. Further, differences between sowing dates and between lines were greater in 1982 than in 1981, and greater at Walkamin than at the Ord. Many of the variations within lines due to site, year, and sowing date can be explained in terms of temperature. The dry season was generally cooler in 1982 than in 1981, and the Walkamin site (600 m elevation) is cooler than the Ord (Table 3). In addition, flowering was most delayed for the sowings in June and early-July, immediately prior to the coolest months of the year. For Fiskeby V, most of the site, year, and sowing date effects were accounted for by variations in mean temperature alone (Fig. 5). However, multiple linear regressions of the rate of development (1/days) prior to flowering against the means of prevailing climatic variables suggest that the later-flowering lines responded to both daylength and temperature (Table 4). For Buchanan, most of the variations in time to flowering could be accounted for by variations in minimum temperature and daylength. However, a comparison of the standard partial regression coefficients (Table 4) suggests that minimum temperature was more than ten times as important to variations in flowering as was daylength. Much of the daylength contribution occurred in the August and September sowings toward the end of the dry season (J. D. Mayers, unpublished data).

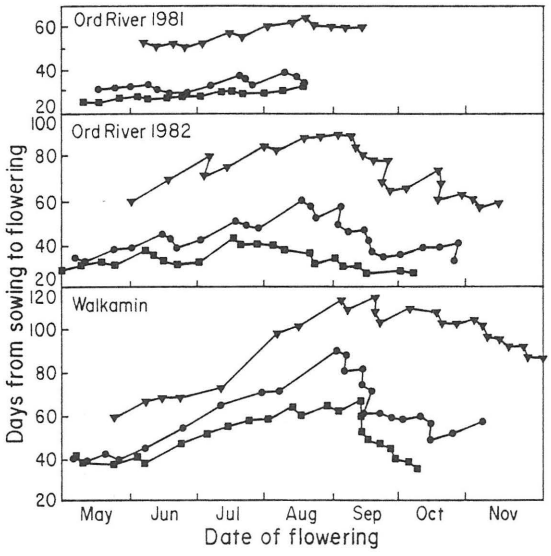


Fig. 4.
Days to flowering as a function of date of flowering in three lines sown at weekly intervals in 1981-82 during the dry season at 15°S in the Ord River area, and in 1982 at 17°S at Walkaman in northern Queensland. Squares, circles and inverted triangles represent Fiskeby V, Buchanan, and CPI 70242, respectively.

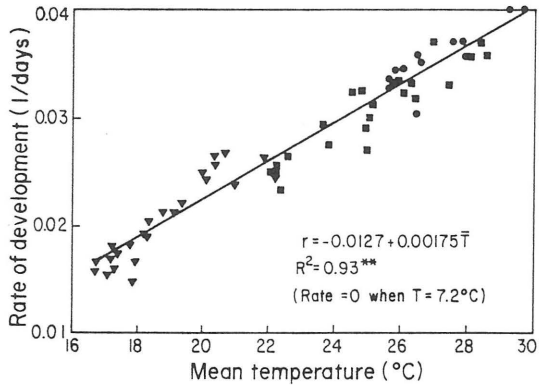


Fig. 5.
Rate of development (1/days sowing to flowering) as a function of mean temperature during the pre-flowering period for dry season sowings of Fiskeby V shown in Fig. 4. Circles, squares, and inverted triangles represent Ord River 1981, Ord River 1982, and Walkamin, respectively.

Table 3. Mean monthly maximum (T) and minimum (t) temperatures for three dry season studies (Fig. 4).

		Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
Ord River 1981	T	37.7	33.4	32.6	31.8	35.6	37.2	39.0	35.8
	t	21.3	20.6	17.6	17.2	19.3	23.4	22.0	24.6
Ord River 1982	T	34.6	32.2	30.7	29.3	32.5	35.2	38.0	38.0
	t	19.9	17.4	14.8	13.6	16.8	19.0	19.8	24.6
Walkamin 1982	T	24.6	24.2	22.9	22.3	21.3	26.9	29.3	29.7
	t	18.2	15.0	11.9	11.0	13.9	13.8	13.9	17.2

Table 4. Rate of development to flowering (r) as a function of mean daily photoperiod (P) and temperature (Tm) and of mean daily maximum (T) or minimum (t) temperature for dry season soybeans at 15-17°S. The relative contributions of these various climatic factors are indicated in parenthesis by standard partial regression coefficients.

	Sowing to Flowering		
	days	regressions	R^2
Fiskeby V	38.8 (25-67)	r = 0.013 + 0.0018Tm	.87**
Buchanan	47.5 (28-91)	r = 0.007 + 0.0022t - 0.0016P (.91) (.09)	.91**
Jupiter	68.0 (43-104)	r = 0.031 + 0.0018t - 0.0003T - 0.0030P (.67) (.18) (.15)	.91**
CPI 70242	77.8 (50-115)	r = 0.012 + 0.0016t - 0.0003T - 0.0014P (.71) (.02) (.09)	.94**

With CPI 70242, a late-flowering line, the rate of development prior to flowering was also negatively associated with maximum temperature (Table 4). Much of this effect appeared to be due to extremely high maximum temperatures (often >40°C) in September, October, and November in the Ord River area (cf. Fig. 2b). These effects will likely be observed only in the late dry season plantings. Similar responses in time to flowering were observed in lines intermediate to Buchanan and CPI 70242 (e.g. Jupiter, Bossier Late, and UFV-72-1).

While daylength during the dry season appears to have only a minor effect on development prior to flowering, after the beginning of flowering its influence is substantial, particularly in later-flowering lines (Table 5). Daylength effects on post-flowering development are most apparent for sowings after early-June. Pod maturity is delayed, and in many instances leaves remain green long after the pods mature. Analogous responses were reported for spring sowings in the subtropics (Lawn and Byth 1973).

Evidence from both field and controlled environmental studies shows that the range of temperatures experienced during the dry season in areas such as the Ord River (cf. Fig. 2b) may also have substantial differential effects on growth and seed yield (J. D. Mayers, unpublished data, Lawn 1983). For example, pod set is more sensitive to cool temperatures in CPI 70242, Bossier Late, Jupiter, and Indonesian line No. 29 than in temperate cultivars such as Fiskeby V, Salut, and Williams. With No. 29 and CPI 70242, pod set was completely inhibited at night temperatures of 12°C and below because of pollen viability problems, even when it was grown under day temperatures of 30°C (Lawn 1983, R. J. Lawn and D. J. Hume, unpublished data).

Table 5. Rate of development after flowering (rr) as a function of mean daily photoperiod (P) and mean daily temperature (Tm), or mean daily maximum temperature (T) for dry season soybeans at 15-17°S. The relative contributions of these various climatic factors are indicated in parentheses by standard partial regression coefficients.

	Flowering to Maturity		
	days	regressions	R^2
Fiskeby V	51.5 (36-82)	rr = 0.011 + 0.0004Tm	.17**
Buchanan	73.1 (53-127)	rr = 0.030 + 0.0004T - 0.0022P (.56) (.44)	.43**
Jupiter	76.1 (53-109)	rr = 0.036 + 0.0003T - 0.0025P (.43) (.57)	.59**
CPI 70242	69.4 (48-100)	rr = 0.023 + 0.0005T - 0.0019P (.64) (.36)	.64**

Water

The physiological/genetic basis of differential genotypic response to water availability in the Australian subtropics and tropics is poorly understood. It has received less research emphasis than daylength and temperature because the soybean industry was initially located in irrigated and higher rainfall areas, and partly because seasonal and regional variations in daylength and temperature are more predictable than rainfall variations.

The interaction between water deficits and phenology has received the most attention. In dryland environments where summer rainfall is variable and soil water-holding capacity is limited, shorter duration lines are usually higher yielding, even though yield potential under irrigation may be higher in longer-duration lines (Williamson 1974, Lawn et al. 1977, Rose 1983). This is exemplified by comparisons of the yield/phenology relationships of ten elite lines grown in the tropics under both irrigated and rainfed conditions in a year when the wet season ended in early March (Fig. 6).

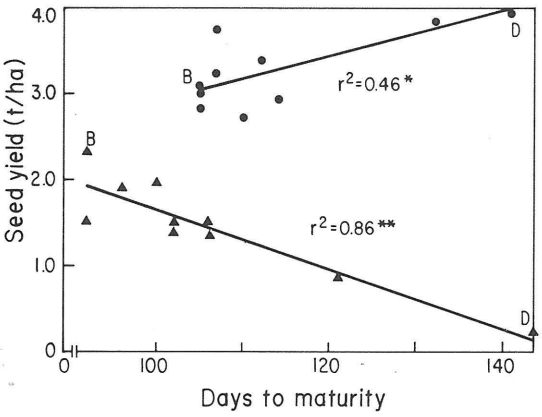


Fig. 6.
Yield as a function of crop duration for ten elite selections from the University of Queensland's breeding program under irrigation at 15°S in the Ord River area (circles) and under rainfed conditions at 14°S in the Douglas/Daly region (triangle). B and D represent cultivars Buchanan and Durack (unpublished data of A. L. Garside).

In dryland environments where extended periods of drought during the summer are common, as in Australia's subtropical soybean area, the coincidence of periods of severe water deficit with particularly sensitive stages of development (eg. flowering and early pod filling) can confound (Williamson 1974) and even reverse (Lawn et al. 1977) this general yield/phenology relationship.

Recent studies have focused on understanding the physiological mechanisms involved in response to water deficits (Turner et al. 1978, Lawn 1982a, Ludlow and Flower 1982, Rose et al. 1983). Soybean appears to tolerate lower tissue water potentials than cowpea (Vigna unguiculata), black gram (V mungo), or green gram (V. radiata). Stomatal regulation of water conductance from soybean leaves is less sensitive to declining leaf water potentials than the Vigna species (Lawn 1982a). Presumably as a consequence, rates of soil water use and growth, at least in the initial stages of a drought period, are higher in soybean (Lawn 1982b). Phenological adjustment in response to water deficits is small in soybean relative to Vigna crops (Lawn 1982a), but there is genotypic variation for this trait (Rose et al. 1983). Ludlow and Flower (1982) and Rose et al. (1983) reported significant levels of turgor maintenance through osmotic adjustment in soybean, although none was found by Turner et al. (1978). Rose et al. (1983) also reported genotypic variation for this trait. Progress has also been made in developing an understanding of the physiological basis of differential genotypic response to saturated soil conditions (see Troedson et al., eds.).

Soybean Improvement in Australia

The occurrence of large genotype x climate interactions has substantially influenced the development of mechanized soybean production in tropical and subtropical Australia. Some of the more important implications are discussed below in relation to the effects on both varietal improvement and agronomic management practices.

Subtropics

The soybean industry in southeastern Queensland was initially established with cultivars and selections from the southern USA (Byth 1976) and locally bred lines were initially derived from similar parentage (Rose and Williamson 1974). In rainfed areas, sowing date depends on the timing of the first substantial summer rains (usually in mid-November/December, but occasionally in early January), which is somewhat later than analogous sowings in the southern USA (Hartwig 1954). Because of later sowing, and because the material was grown at lower latitudes than its area of origin, crop durations were generally shorter than those recorded in the USA (Lawn and Byth 1973). Optimum row spacings were therefore narrower, and optimum plant population densities higher (Lawn et al. 1977) than for the full-season, spring crops characteristic of the southern USA.

In irrigated areas where October and early November sowings were feasible, spring daylengths in southeast Queensland were short enough that rapid flowering occurs, leading to lower yield potentials, relative to later sowings (Lawn and Byth 1973, 1974).

Conversely, when the cultivars were planted after the summer solstice, yield potentials were progressively reduced because of more rapid initiation of reproductive growth as a consequence of photoperiodic response. To maximize seed yield, narrower row spacings and higher plant densities were also required for late plantings (Lawn et al. 1977). Optimum spatial arrangement was also found to vary with cultivar duration.

Because of this cultivar x sowing date x spatial arrangement interaction, agronomic recommendations are complex (eg. Douglas 1981), but permit the flexibility in sowing date that is essential in an environment characterized by variable rainfall. This flexibility is also helpful in scheduling crop rotations. In areas of subtropical Australia where rainfall is adequate, soybean is often double-cropped with winter barley (Hordeum vulgare) or wheat (Triticum aestivum). Flexible agronomic practice has also allowed a wider range of adaptation of soybean cultivars in terms of regions and cropping systems.

Soybean breeders have sought to broaden the genetic base of material in southeast Queensland by incorporating material from various African and Asian countries into their programs. However, they have continued to develop cultivars suited to early/mid-summer planting rather than opt for full-season lines suited to earlier sowings and wider spacings. Apart from being better suited to rainfed culture and offering greater flexibility, shorter duration crops can produce high yields by combining an inherently higher harvest index (Lawn and Byth 1974) with the high biomass achieved by higher density sowing. Shorter duration crops also require fewer applications of irrigation and pesticides.

In the higher latitude irrigation areas of New South Wales, it was possible to directly transfer both cultivars and production technologies from the southern USA (Carter 1974, Laing 1974). Much of the production is still based on long duration (~160 day) crops sown in wide rows (~1 m) in November. More recent studies in the Namoi Valley, however, suggest that greater flexibility in sowing date is possible and that December sowings would be as high or higher yielding, with less dependence on irrigation and crop protection practices (Constable 1977). One consequence of the long duration, wide-row model used in higher latitude areas is a reduction in the latitudinal range over which individual cultivars are well-adapted (cf. I.A. Rose 1983).

To date, cultivars have not been specifically bred for adaptation to dryland environments, and to improve performance breeders have relied on short-duration lines and ameliorative agronomic practices such as fallowing and the manipulation of sowing dates and spatial arrangements (eg. Williamson 1974, Lawn et al. 1977). However, a breeding program for the dryland environments in northern New South Wales has been initiated (Rose et al. 1983). Significant progress has been reported using selection against phenological adjustment, which, in turn, seems to be related to the absence of osmotic adjustment.

Tropics

Wet Season: With appropriate agronomic adjustments, some of the lines used in southeast Queensland can be grown in the Emerald irrigation area (Douglas 1981). None of the subtropical materials, however, are suited to mechanized production at lower latitudes. All of these lines flower early (eg. Fig. 3b), and produce short-statured plants with pods set close to the ground. Late flowering, tropical lines have been identified (Byth 1968), but lateness was usually associated

with undesirable agronomic traits, i.e. twining or a decumbent habit (unsuitable for mechanized harvesting), small seed size, black or speckled seed color, and susceptibility to shattering.

A series of elite selections that combined desirable agronomic traits with good phenological adaptation to the wet season of the tropics were bred in a program based in the subtropics at the University of Queensland (Byth 1976). Single seed descent was combined with early generation selection (glasshouse and field) to identify appropriate photoperiodic responses (Byth and Lawn 1971). Three lines were released (Gilbert, Ross, and Daintree) following regional tests. Another selection was released in Zambia (A. J. Prior, personal communication).

Subsequent breeding cycles involving crosses of these materials and other high yielding subtropical lines have succeeded in raising yield potential while maintaining appropriate phenological and agronomic performance. Following regional tests of elite lines, two other cultivars (Buchanan and Durack) were released in 1979 for use in the wet season in the lower latitudes of the tropics.

Buchanan is a high-yielding (cf. Fig. 6), large-seeded, early maturing line (105 to 115 days) suitable for double-cropping in the Ord River area with a dry season crop such as sorghum (Sorghum vulgare) or sunflower (Helianthus annuus) (Anon. 1983). Yields of 3.0 t/ha have been recorded in farmers' fields, and experimental data suggest the possibility of on-farm yields of 4 t/ha (with irrigation). Because of its early maturity, Buchanan is also suitable for rainfed production in the Douglas/Daly region (Garside et al. 1983). Average yields were 1.5 t/ha in 1983, the first commercial season in Douglas/Daly.

Durack is a high-yielding, long-duration line (135 to 145 days; Fig. 6), that is suitable for irrigated cropping in the Ord River area (Anon. 1983). Its long duration, however, makes it unsuitable as a rainfed crop or for double-cropping with a dry season crop. Another line, which is slightly earlier maturing than Buchanan, was released under the name Fitzroy for commercial production in central and northern Queensland. Cannapolis, a recent introduction from Brazil, has also been approved for use in this area.

These releases will provide a short-term, but adequate basis for the establishment of mechanized soybean production in the wet season of the Australian tropics. If production is to expand and full advantage is to be taken of specific genotype x environment interactions, a broader range of cultivars will be needed. It is likely that a range of cultivars suited to rainfed culture will be needed to closely match cultivar duration with regional variation in duration of the wet season.

While cultivars adapted to the subtropics are generally unsuitable for mechanized production in the tropics, it has been possible to transfer some subtropical agronomic principles. Cultivar x sowing date x spatial arrangement interactions must be accommodated (Beech et al. 1982), but there are difficulties associated with the timing of sowing and establishment in an environment where early rainfall occurs as isolated storms of variable timing and intensity (Garside et al. 1983).

Dry Season: Some 570 accessions from various sources (including Brazil, Thailand, the USA, Zimbabwe, AVRDC, and IITA) have been tested in the dry season in the Ord River area, but none are suitable for mechanized production. Many of these cultivars, particularly those with desirable agronomic traits such as erect habit, shatter resistance, and good seed quality, are too short-statured for mechanized production (Mayers et al. 1982). Materials are available that are better adapted phenologically to the dry season, but these lines are usually associated with such undesirable traits such as small seed size, twining growth habits, and susceptibility to shattering. They also tend to be more sensitive to

the range of minimum temperatures in the dry season in terms of development and growth (Lawn 1983, J. D. Mayers unpublished data).

Studies on the genetic control of phenology have been initiated (B. C. Imrie, personal communication), but breeding for adaptation to the dry season is not yet underway.

Acknowledgements

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Effect of Water Stress on Soybean Metabolism

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Introduction

Water deficits have a profound affect on plant metabolism (Hsiao 1973). Photosynthesis is inhibited and photosynthate levels and N metabolism are altered (Lawlor and Fock 1977).

Attention has recently been directed to changes in amino acid metabolism, especially the accumulation of proline as a function of drought resistance (Singh et al. 1973). When ten barley (Hordeum vulgare) cultivars were subjected to the same degree of water stress, the amount of accumulated proline was positively correlated with yield stability over a range of environments (Singh et al. 1972). Palfi et al. (1978) reported that "higher" plants can be classified as proline-accumulating and non-proline-accumulating. This differentiation was based on the plants' ability to accumulate free proline under severe water stress to a concentration greater than 1% of dry weight.

Proline accumulation, as a response to water stress, was found to be a function of synthesis stimulation from glutamate (Barnett and Naylor 1966) and the inhibition of oxidation (Sells and Koeppe 1981). However, many phenomena concerning the physiological and biochemical mechanisms of proline accumulation, as well as the N sources of proline, require examination.

In the present study, changes in the concentration of carbohydrates were determined and a correlation was established between proline accumulation and protein metabolism under water stress conditions.

Materials and Methods

Plant Materials and Growth Conditions

Experiment 1: Sterilized soybean seed (Glycine max) washed with 70% ethanol and 5% calcium hypochloride was germinated on moist filter papers placed in petri dishes. Seedlings were grown in vermiculite for one week, and were then planted in 31 freely-draining pots containing a 1:1 (v/v) mixture of sand and vermiculite. The soil surface was covered with a layer of sand. The pots were watered twice a day for four weeks with a 1/4-strength nutrient solution (Downs and Hellmers 1975) containing ^{15}N-nitrate (10.8 atom %) as the sole N source. Plants were grown in a biotron (natural light, 25°C, 75% RH).

Twenty-four hours before water stress was induced, the pots were washed with 10 times their volume of water until no nitrate was detected. They were then washed with a 1/2-strength nutrient solution containing ^{14}N-nitrate. After replacing the soil ^{15}N with ^{14}N for 24 hr, the pots were irrigated with a 1/2-strength nutrient solution. Water stress was imposed by withholding irrigation for 9 days.

Experiment 2: Seedlings were planted in 15 l freely draining pots. Water stress was imposed after five weeks of growth by withholding irrigation for 10 days.

Sampling and Determination of Leaf Water Potential

Plant sampling and the determination of leaf water potential were carried out between 13:00 and 14:00 hours. Leaf water potential was measured using the pressure chamber technique (Scholander et al. 1965). Plant materials were immersed in liquid N, and the frozen material was freeze-dried for chemical analysis.

Analytical Procedures

Sugars and Nitrogenous Compounds: Total N was determined by modified reductive Kjeldahl digestion (salicylic acid and sodium thiosulfate). Free amino acids were extracted from the freeze-dried samples in a mixture of methanol, chloroform, and water (MCW, 12:5:3); protein was extracted from the MCW-insoluble residue in hot, 88% formic acid. The dry extract was taken up in a small volume of water and passed through a Dowex 50W x 8 (H^+) column and an Amberlite IRA 45 (OH^-) column. Amino acids were eluted from the cation-exchange resin column with 2 N NH_4OH. Free amino acid concentration was determined with an amino acid analyzer (JLC 6AH). Protein-N content was determined by the Kjeldahl procedure.

The concentration of soluble sugars from neutral fractions was assessed by a modification of the three-step anthrone method (Jones et al. 1980). Insoluble sugars were extracted with cold perchloric acid from ethanol-insoluble residue and were analyzed by anthrone reaction at 90°C (glucose standard).

^{15}N Analysis of Nitrogen Compounds: Ammonium in reductive Kjeldahl digestion solution was absorbed into 0.1 N HCl by air distillation. A part of the reabsorbed ammonium solution was put in a capillary tube and dried.

Aliquots of each protein and free amino acid fraction, corresponding to approximately 2 µg N, were converted directly to N_2 gas by the modified Dumas method.

Amino acids were developed by silica gel thin-layer chromatography using two solvent systems: Phenol/water (3:1, v/v) and butanol/acetic acid/water (4:1:1, v/v/v). A thin-layer was sprayed after development with ninhydrin solution and heated at 100°C. Each amino acid colored spot was collected, eluted in a Pyrex glass (using 100 µl of 50% of ethanol evaporated to dryness), and converted directly to N_2 gas by the modified Dumas method.

Measurement of ^{15}N isotope abundance in the N samples was determined by emission spectroscopy.

Results

Carbohydrate Metabolism

Figure 1A shows the content change of the insoluble sugars that contained starch. Insoluble sugar content decreased rapidly as leaf water potential declined, and reached a constant level (35% of the irrigated control plants) when the leaf water potential was -2.5 MPa. Total soluble sugars nearly doubled at -2.5 MPa (Fig. 1B). Sucrose, a minor component of soluble sugars, increased five times more than the control plants at -2.5 MPa. Glucose and fructose, major component of the soluble sugars, increased to a lesser extent.

Leaf Water Potential and Plant Growth

After four days of water stress, leaf water potential rapidly decreased with concomitant suppression of plant growth and the emergence of new leaves (Fig. 2A,B,C).

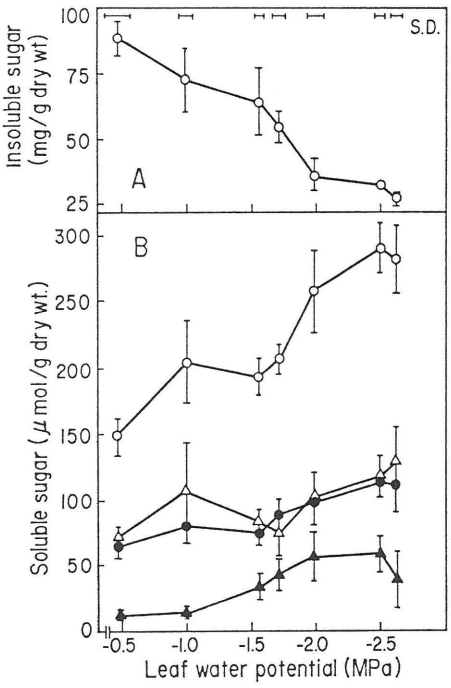


Fig. 1. (left)
Changes in the carbohydrate content of young, fully expanded leaves: A = insoluble sugars; B = soluble sugars; open circles = total soluble sugars; open triangles = glucose; solid circles = fructose; solid triangles = sucrose. Vertical and horizontal bars indicate the standard deviations of the means.

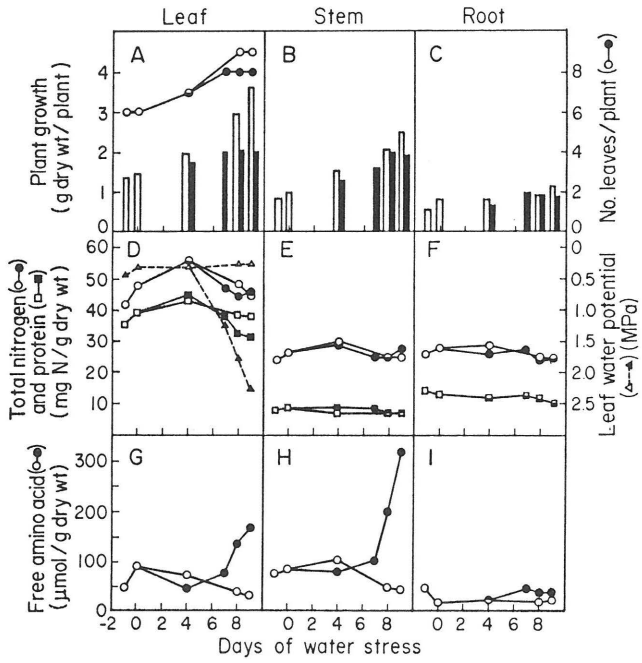


Fig. 2. (right)
Plant growth and nitrogenous compound content. Open and solid symbols are non-stressed and water-stressed plants, respectively.

Total-N, Protein, and Free Amino Acid Content

The procedures used to rinse out ^{15}N in soils with ^{14}N-nitrate solution for 24 hr and excess irrigation of ^{14}N-nitrate solution at the time just prior to the imposition of water stress (washing treatment procedure) induced an increase in total N and protein during the first four days, and then decreased in the leaves (Fig. 2D). Slight increases in total N occurred in the stems and in the roots during the first four days (Fig. 2E,F). Nitrogen content was unchanged by water stress (Fig. 2D,E,F). Water stress resulted in the loss of some protein in the leaves after four days of stress, but protein content in the stems and in the roots were unchanged (Fig. 2D,E,F).

Free amino acids increased in the leaves and stems as a result of the washing treatment (Fig. 2G,H). Changes in free amino acids are shown in Tables 1 and 2. The washing treatment induced an increase of aspartic acid, serine, asparagine, glutamic acid, glutamine, and alanine in the leaves and stems by days 0 and 4. There were significant changes in the free amino acid contents of the water-stressed plant tissues. After four days of stress, free amino acid also

increased in the leaves and stems, but little increase was found in the roots (Fig. 2G,H,I). Water stress induced an increase in tryptophan, histidine, threonine, valine, isoleucine, leucine, tyrosine, and phenylalanine in the leaves, and tryptophan, histidine, threonine, serine, valine, isoleucine, leucine and phenylalanine in the stems. Particularly high accumulations of proline and asparagine were found in the leaves and stems (Tables 1 and 2). Water stress induced a slight proline increase in the roots (Table 2). The free amino acid in the upper leaves (green) of severely-stressed plants at day 9 was more than that found in the lower leaves (wilted) (Table 1). In the lower leaves, lysine, histidine, aspartic acid, threonine, serine, asparagine, glutamic acid, glutamine, glycine, and proline were found in lower quantities than in the upper leaves. Low ammonia levels were maintained throughout the stress period in all tissues except the wilted lower leaves. (Tables 1 and 2 on page 380)

Nitrate Absorption

Nitrate absorption decreased when leaf water potential remained unchanged, but was greatly suppressed with the development of water stress (Fig. 3). ^{14}N flow into the leaves ceased under severe stress conditions, although ^{14}N accumulated in the stems.

Changes in ^{15}N

The washing treatment resulted in significant decreases in ^{15}N free amino acid and soluble-N fractions in the leaves, but only slight decreases in protein (Fig. 4D,G,J). In the stems, ^{15}N abundance of all fractions decreased slightly (Fig. 4E,H,K). In the roots, the ^{15}N of soluble-N decreased rapidly, but protein and free amino acids decreased only slightly (Fig. 4F,I,L). Significant decreases in ^{15}N abundance of free amino acids in the leaves were attributed to a significant decrease in aspartic acid, serine, glutamic acid, and alanine (data not shown). Small decreases in the ^{15}N of free amino acids in the stems were due to a small decrease in all free amino acids (data not shown).

The ^{15}N abundance of protein from all tissues remained at 6.0 atom % excess after 4 days of stress (Fig. 4D,E,F); soluble-N fractions and free amino acids increased during the latter stress periods (Fig. 4G,H,I,J,K,L).

^{15}N Content of Leaf Protein and Free Amino Acids

After day 4, leaf protein ^{15}N content decreased substantially, with concomitant increases in free amino acids; 35% of the leaf protein loss was compensated for by the increase in free amino acids, especially proline and asparagine (Fig. 5). After day 7 the ratio of proline to asparagine increased.

Proline Content

The pattern of proline accumulation in young expanded leaves (experiment 2) during the stress period is shown in Fig. 6. Free proline levels were relatively constant until stress became severe (below -1.5MPa), and were 0.86% of the dry weight of the control at a leaf water potential of -2.6 MPa. Protein-bound proline gradually decreased during the stress period. Total proline (protein-bound + free) first decreased with mild to moderate stress, and then increased under severe stress (-2.6 MPa), attaining a level of 130% of the control plants.

Fig. 7 shows the changes in ^{15}N proline during the water stress period. The increase in ^{15}N free proline was three times greater than the decrease in protein-bound proline from the leaves.

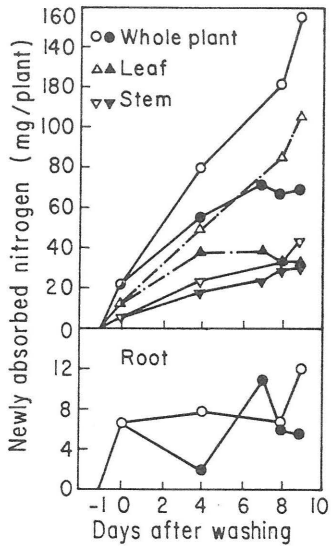


Fig. 3. (left)
Amount of newly absorbed N during water stress. Amount of newly absorbed N was calculated from Figs. 4 and 2 as follows: Newly absorbed N (mg)/plant = An - A_{-1} where n = days after washing treatment; A: ^{14}N content/plant (mg).

$$A = \frac{100 - B_n}{100} \times \text{total N content/plant (mg)}$$

(where B_n is atom % excess of total N at day n).

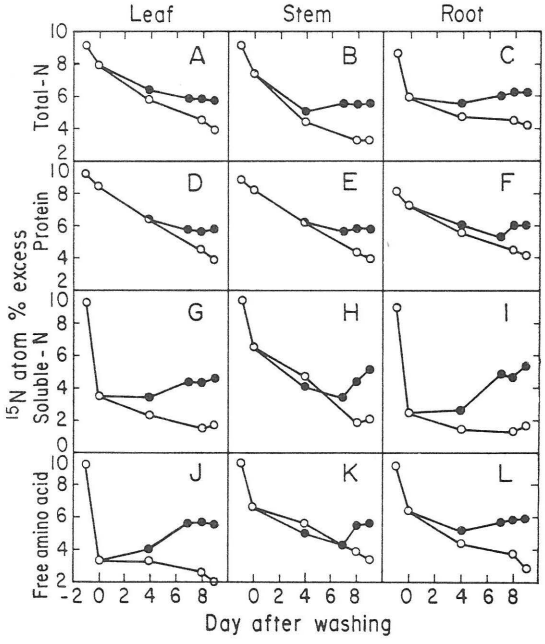
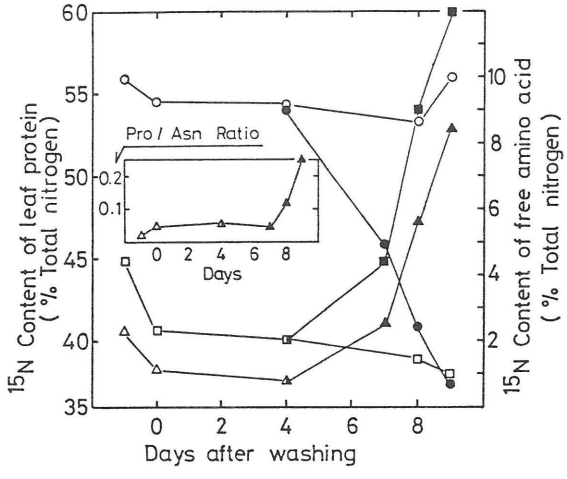


Fig. 4. (right)
^{15}N abundance of N compunds. Open and solid circles are non-stressed and water-stressed plants, respectively.

Fig. 5. (below)
^{15}N content of leaf protein and free amino acids. Open and solid symbols repesent stressed and non-stressed plants, respectively; circles = leaf protein, squares = total free amino acids/plant, triangles = proline + asparagine/plant, Pro = proline, Asn = asparagine.



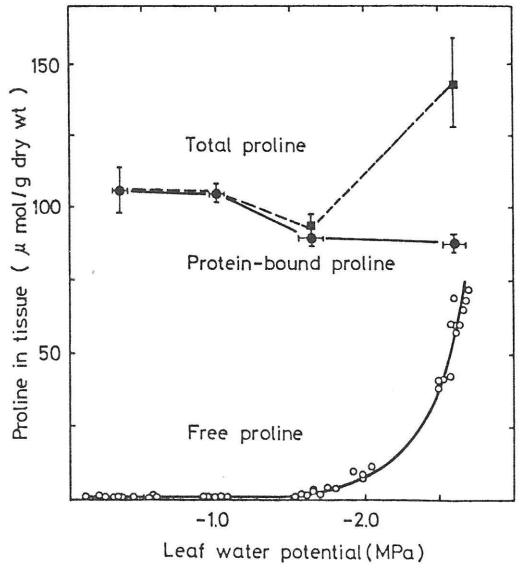


Fig. 6. (right)
Proline level in young, fully expanded leaves during water stress. Vertical and horizontal bars indicate standard deviations of the means.

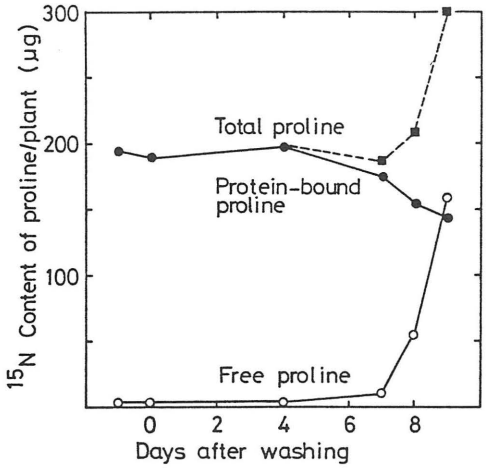


Fig. 7.
^{15}N content level of proline during water stress. Open and solid circles are non-stressed and water-stressed plants, respectively. ^{15}N content of the leaf-protein-bound proline was estimated on the assumption that leaf protein contains 4% proline-N.

Discussion

Carbohydrate Metabolism

A decrease in insoluble sugars (Fig. 1A) resulted in a reduction of photosynthesis, primarily because of stomatal closure in response to water stress (Hsiao 1973). The increase in soluble sugars because of water stress agrees with the results of other researchers (Munns et al. 1979, Jones et al. 1980, Ford and Wilson 1981). The increase in soluble sugars can be explained as follows:

1) The breakdown of insoluble sugars may have led to an increase in soluble sugar concentration (Hsiao 1973), and

2) Decreased translocation from the leaves to other organs (Hsiao 1973; Watson and Wardlaw 1981) and/or cessation of growth (Hsiao 1973) may have contributed to the increase.

Nitrogen Metabolism

Nitrate Absorption and Utilization: Frota and Tucker (1978) reported that polyethylene glycol-induced water stress inhibited the uptake of ammonia and nitrate in bean plants. In our experiment the absorption of nitrate decreased when the leaf water potential remained unchanged, but was greatly suppressed with the advent of water stress (Fig. 3). In particular, ^{14}N flow into the leaves ceased completely under severe stress conditions, indicating a cessation in metabolic nitrate flow into the leaves through the xylem. Shaner and Boyer (1976) argued that a reduction in leaf nitrate reductase activity in water-stressed corn (Zea mays) is principally caused by a decline in the flow of xylem nitrate reaching the small metabolic pool of the leaves, rather than an effect of low leaf water potential. High nitrate assimilation occurs in the soybean shoots (Hunter et al. 1982). Consequently, it can be assumed that the N source for active free amino acid synthesis under water stress changes from the nitrate that enters the metabolic pool of the leaves to reserved materials such as protein.

Protein Metabolism: Protein metabolism is affected by water stress. Net protein loss from the leaves under severe stress is attributable to both a decrease in synthetic protein activity and a stimulated degradation of protein (Fig. 4D,5). The protein loss found in water-stressed plants resulted from a disruption of

normal protein synthesis and degradation (Cooke et al. 1979, 1980; Dungey and Davies 1982).

Source of Proline N: Many investigators have noted that free proline accumulates under prolonged, severe water stress (Fig. 6). The main metabolic causes for proline accumulation may not only be due to a lower rate of degradation (Sells and Koeppe 1981), but to over-production (Fig. 6). However, the source of N for proline and the internal factors that stimulate proline synthesis are unknown.

Schobert (1977) found that diatom grown in an N-free culture solution accumulated little free proline under high salinity conditions, but that the addition of increasing concentrations of nitrate and ammonium resulted in proline accumulation. Furthermore, proline accumulation did not occur in water- and N-stressed cotton (Gossypium hirsutum) seedlings (Elmore and McMichael 1981). These results suggest a close relationship between water-stress induced proline accumulation and N status in plant tissues.

It seems reasonable to assume that leaf protein is a source of N for proline because nitrate absorption and assimilation are greatly decreased and because the degradation of protein is enhanced by water stress (Fig. 3, 5). Singh et al. (1973), however, reported that net protein synthesis continued slowly even as proline accumulated in barley (Hordeum vulgare) plants under polyethylene glycol-induced water stress, suggesting that pre-existing protein is not the major source of proline. It has also been reported that proline accumulation in detached tobacco (Nicotiana tabacum) leaves under water stress is not associated with protein metabolism (Tyankova 1981). However, there are several reports in which protein metabolism and proline accumulation were closely linked (Goring and Thien 1978, Tan and Halloran 1982). Tan and Halloran (1982), found a positive correlation between the capacity of 14 wheat (Triticum aestivum) cultivars to accumulate proline and an increase in total catabolic amino acids. This suggests that leaf protein may be a source of N for proline.

In this study, the behavior of labeled ^{15}N leaf protein was traced. It was found that water stress induced degradation of the leaf protein and that 35% of the N loss was compensated for by a nitrogen gain in the free amino acids. This indicates that high accumulations of free amino acids is attributable to the degradation of leaf proteins (Fig. 5). Furthermore, it was found that high accumulations of free proline under severe stress conditions are caused by free proline over-production connected with the degradation of leaf protein (Fig. 7).

It has been reported that proline does not play a role in NH_4^+ detoxification during water stress because the blades of wilted barley plants fed with $^{13}NH_4^+$ incorporated ^{13}N mainly into glutamate and glutamine, not into proline (after 30 min) (Hanson and Tully 1979). Kato (1980), however, reported that slightly wilted leaves of citrus trees that were fed with $^{15}NH_4^+$ incorporated ^{15}N into proline after 2 hr.

There is a close relationship between proline accumulation and protein degradation under water stress conditions; concentration of NH_4^+ did not increase markedly during the stress period despite extensive protein degradation. Therefore, it is possibile that proline plays a supplemental role in NH_4^+ detoxification during periods of water stress.

Table 1. Change in free amino acids in soybean leaves (μmole/g dry weight) during water stress

Amino Acid	Control					Days	Water Stress				
	-1	0	4	8	9		4	7	8	9	
										upper (green)	lower (wilting)
Tryptophan	0.7	0.8	0.3	0.3	0.3		0.3	3.0	6.1	6.5	5.1
Lysine	0.2	0.2	0.3	0.2	0.1		0.4	1.0	0.9	1.5	0.1
Histidine	0.5	0.5	1.1	0.4	0.2		1.0	2.3	3.1	3.8	0.2
Arginine	8.8	3.2	3.3	1.0	0.4		2.5	2.8	3.5	4.6	3.4
Aspartic acid	4.8	9.2	8.9	2.6	3.6		8.2	5.0	3.6	5.7	0.8
Threonine	0.6	1.5	1.4	1.1	0.9		1.2	3.7	5.9	7.6	2.9
Serine	4.9	9.7	6.7	5.0	4.5		3.6	4.6	6.4	8.9	1.6
Asparagine	8.6	14.1	16.1	5.4	2.6		7.9	12.3	31.9	31.7	14.0
Glutamic acid	10.0	21.3	16.2	7.0	8.8		12.4	8.9	5.3	8.0	1.0
Glutamine	1.3	2.1	4.6	3.5	1.8		2.5	1.9	6.4	3.3	0.6
Proline	0.8	1.2	0.8	0.8	0.6		0.8	3.5	13.5	65.9	8.5
Glycine	1.0	1.4	0.5	0.9	0.8		0.4	0.7	0.8	0.9	0.1
Alanine	4.2	11.4	9.6	8.5	6.8		5.6	6.1	6.7	8.1	4.2
Valine	0.8	1.9	0.8	0.7	0.6		0.7	4.6	9.1	13.2	8.6
Isoleucine	0.5	1.0	0.4	0.4	0.3		0.5	4.0	8.2	11.5	8.1
Leucine	0.5	0.9	0.5	0.5	0.3		0.5	4.6	9.7	14.0	11.1
Tyrosine	0.7	0.7	0.3	0.3	0.1		0.3	3.9	5.5	6.4	3.5
Phenylalanine	4.4	5.6	1.2	1.2	1.0		0.8	4.8	9.1	14.3	7.6
Total	53.3	86.4	73.0	39.8	33.7		49.6	77.7	135.0	215.0	81.4
Ammonia	2.3	4.7	3.2	1.4	2.7		2.8	3.3	2.0	4.9	121.0

Table 2. Change in free amino acids in the stems and roots of soybean plants (μmole/g dry weight) during water stress.

Amino Acid	Control					Days	Water Stress			
	-1	0	4	8	9		4	7	8	9
	stems									
Tryptophan	0.9	1.8	1.8	1.7	0.7		0.8	0.7	3.5	3.0
Lysine	1.8	2.3	2.8	1.7	1.4		2.0	2.6	1.4	1.2
Histidine	0.6	0.6	1.3	0.7	0.4		0.8	1.0	3.4	4.4
Arginine	3.3	2.1	2.9	1.6	1.5		2.3	2.9	1.3	1.8
Aspartic acid	3.0	4.1	6.7	4.2	4.1		6.0	7.2	6.5	8.2
Threonine	2.0	2.7	3.4	2.0	1.8		2.8	3.0	7.2	8.2
Serine	3.4	4.7	5.1	3.0	2.8		4.0	4.8	8.3	12.0
Asparagine	42.5	44.0	50.1	17.4	15.3		31.6	50.7	92.0	158.0
Glutamic acid	0.6	0.6	0.9	0.6	0.6		0.9	1.0	0.8	0.8
Glutamine	2.1	3.5	2.5	1.2	1.9		3.1	3.7	6.1	2.5
Proline	2.5	3.0	3.8	2.2	2.1		3.3	3.3	16.4	44.9
Glycine	0.7	0.8	1.3	0.8	0.7		1.0	1.3	1.2	2.7
Alanine	3.6	4.9	6.4	4.0	3.6		4.9	5.4	7.7	8.6
Valine	2.6	3.1	4.2	2.4	2.3		4.1	4.2	16.5	22.4
Isoleucine	1.5	2.0	2.8	1.5	1.4		2.6	2.6	11.5	13.6
Leucine	3.5	4.3	5.3	3.0	3.0		4.5	4.8	10.6	10.1
Tyrosine	1.5	1.6	2.0	1.2	1.3		1.8	2.0	2.3	1.9
Phenylalanine	1.7	2.5	2.7	1.5	1.4		2.0	2.2	3.8	5.3
Total	77.8	80.6	106.0	50.7	46.3		78.4	103.0	200.0	309.0
Ammonia	3.8	3.3	8.9	2.4	2.8		4.2	5.8	4.3	6.6
	roots									
Proline	0.1	0.2	0.7	0.6	0.9		0.5	3.7	7.1	11.0
Total	57.9	16.4	25.2	20.5	26.4		18.1	50.6	40.2	40.6
Ammonia	2.2	3.0	2.9	2.0	2.7		1.8	3.2	1.2	2.1

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Yield Response of Selected Soybean Cultivars to Water Stress During Different Reproductive Growth Periods

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Introduction

Several researchers have reported the adverse effects of water stress on soybean (Glycine max) (Shaw and Laing 1966, Doss et al. 1974, Momen et al. 1979, and Wein et al. 1979). Others have found significant cultivar x water stress interactions (Mederski et al. 1973, Sammons et al. 1981). Field trials in northeastern Thailand (Laosuwan et al. 1977) have indicated significant potential for cultivar SJ 4 when growing conditions are favorable. However, under erratic climatic conditions, earlier maturing cultivars usually outyield SJ 4.

The purpose of this study was to investigate the response of SJ 4 and three early maturing cultivars to water stress during different growth stages.

Materials and Methods

SJ 4 and three early maturing cultivars (Evans, Maple Arrow, and Geiso) were sown in a mixture of Opiki silt loam and sand (70:30) in 4.5 l pots. The plants were grown in controlled environment rooms at the Plant Physiology Division Climate Laboratory, Department of Scientific and Industrial Research, New Zealand. Environmental conditions were as follows: Temperature 31/23°C (day/night ±0.5°C), humidity 70/90% RH (day/night ±5%), photoperiod 14 hr, light intensity 153 wm^2 (photosynthetically active radiation in the 400 to 700 nm waveband), carbon dioxide 349 ppm (±30), air flow 0.3 to 0.5 m/sec. Each cultivar had 13 pots/treatment/replication (one plant/pot) arranged in randomized complete blocks with four replications. The experiment was analyzed according to a 4 x 4 factorial design, with four cultivars and four water treatments, respectively.

Fehr's growth stage system was used in the experiment (Fehr and Caviness 1977). Water treatments included: T_1 = (control) well-watered throughout the entire experiment, T_2 = stress imposed from R_1 to R_4, T_3 = stress imposed from R_4 to R_7, and T_4 = stress imposed from R_1 to R_7.

The plants received modified Hoagland's A mineral nutrient solution four times/day at a rate of approximately 120 ml/pot/application. In the stress treatments, when the plants reached the defined growth stage, nutrient application was withheld until the upper leaves of the plants reached a relative leaf water content (RLWC) of approximately 60%. Each pot was then given 80 ml of nutrient solution daily; pot weight was also measured on a daily basis. The nutrient solution maintained the initial weight of the plant during the stress period. It was thus possible to maintain the RLWC of stressed plants within a range of 62 to 75%; the RLWC for well-watered plants was 87 to 96%.

When the grain matured each treatment was harvested to determine total seed yield and main stem seed yield (pod number, seed/pod, seed weight, number of nodes with pods, number of pods/node, and number of nodes/plant. Main effects were compared and treatment interaction examined using a fixed effect model for analysis of variance; least significant difference was used to compare the means.

Main stem seed yield, yield components, and selected plant characteristics were used in a step-wise multiple regression with seed yield as the dependent variable to determine variations in yield (coefficient of determination increments) and functional relationships (standardized regression coefficient between yield and other characteristics).

Results and Discussion

Because the magnitude of response to water stress - in terms of yield and its components - was related to four different control values, the results are presented as a percentage relative to the individual controls as well as actual seed yield per plant. Water stress had a significant effect on soybean yield (Table 1). In general, stress during the latter part of the reproductive period, T_3 (R_4-R_7), affected soybean yield more than stress during the earlier reproductive period, T_2 (R_1-R_4) (Doss et al. 1974, Sionit and Kramer 1977).

Trial results also indicated differences between cultivars in their reaction to water stress. For example, in the absence of water stress, SJ 4 proved to be the most productive of all the cultivars. However, when stress occurred over the entire reproductive period, SJ 4 appeared to suffer more than any other cultivar. This phenomenon can be seen when one compares the relative yield reductions of each cultivar with the non-stressed controls. Laosuwan et al. (1977) also found that SJ 4 was one of the best cultivars in Northeastern Thailand when grown under favorable conditions, but that early maturing cultivars KS 473 and Jupiter produced higher yield under adverse conditions.

When water stress was applied in the early reproductive period, Geiso was the least affected cultivar; all other cultivars showed a similar reduction in seed yield. However, because of SJ 4's high productivity under non-stressed conditions, the seed yield reductions of this late maturing cultivar, due to early stress, still enabled it to produce relatively high yields. When water was applied late in the reproductive period, SJ 4 and Geiso showed a marked reduction in seed yield, both in relative and absolute terms, with the result that there were few yield differences between cultivars.

The main stem yield components, which are presented in Table 2 as a percentage relative to the individual controls, show that pod number was affected by stress treatments more than other components. This supports the findings of Shaw and Laing (1966), Momen et al. (1979), and Sammons et al. (1981). When water stress was imposed during the early reproductive period (T_2), it had little effect on the seed weight of any of the test cultivars (Table 2). Seeds/pod seemed to be the least sensitive of the three components measured, particularly with cultivar Maple Arrow. Under the longest stress period (T_4), all three SJ 4 components were affected more than those of the other cultivars.

The relative importance of yield components in determining seed yield (pooled over cultivars) showed that in most of the water treatments, yield was mainly due to variation in pod number, except in T_2 (Table 3). In T_2, after a brief period of stress, the potential sites for dry matter storage (pod number) were reduced to about the same level, and therefore the ability to translocate more photosyntates into these sites, rather than the number of sites, became the major determinant of yield variation.

These results show that SJ 4 cannot be regarded as a truly drought-tolerant cultivar. Furthermore, in environments where water stress is common, especially towards the latter part of the growing season, some early maturing cultivars may be more suitable. Under good growing conditions, however, late maturing cultivars such as SJ 4 can produce higher yields than early maturing cultivars. In addition, the possibility of increasing the seed yield of early maturing cultivars by increasing plant population densities should not be overlooked.

Table 1. Total seed yield (gm/plant) and % to control of four soybean cultivars under different levels of water stress.

Treatment	Evans		Maple Arrow		Geiso		SJ 4		Mean %
	yield	% control	yield	% control	yield	% control	yield	% control	to control
T_1	24.2	100.0 a[z]	29.8	100.0 a	26.5	100.0 a	57.4	100.0 a	100.0 a[y]
T_2	11.9	49.1 c	13.0	43.5 cd	19.2	72.3 b	24.2	42.1 cd	51.8 b
T_3	6.7	27.5 de	12.2	40.7 cd	4.6	17.5 efg	9.9	17.2 efg	25.7 c
T_4	4.2	17.4 efg	7.0	23.5 ef	2.6	9.9 fg	0.8	1.4 g	13.0 d

Seed yield LSD 5% = 7.19

[z]% control of all cultivars sharing the same letter are not significantly different at the 5% level
[y]means sharing the same letter are not significantly different at the 5% level

Table 2. Main stem yield components of four soybean cultivars grown under different water treatments (% control).

Component	Treatment	Cultivar				Mean
		Evans	Maple Arrow	Geiso	SJ 4	
Pod number	T_1	100.0	100.0	100.0	100.0	100.0 a[z]
	T_2	66.4	41.7	61.5	100.0	67.4 b
	T_3	64.1	64.5	32.6	22.9	46.0 c
	T_4	45.8	30.3	31.8	3.4	27.8 d
	LDS 5% = 27.5					
Seed weight	T_1	100.0	100.0	100.0	100.0	100.0 a
	T_2	80.6	112.2	99.8	86.3	94.7 a
	T_3	50.8	63.7	53.8	90.3	64.6 b
	T_4	51.9	67.2	66.8	35.9	55.5 b
	LSD 5% = 24.1					
Seeds/pod	T_1	100.0	100.0	100.0	100.0	100.0 a
	T_2	76.7	91.8	104.0	102.7	93.8 ab
	T_3	84.4	86.0	96.0	74.3	85.2 b
	T_4	74.4	94.2	66.7	31.1	66.6 c
	LSD 5% = 21.3					

[z]means of the same component sharing the same letter are not significantly different at the 5% level

Table 3. Increment in R^2 and standardized regression coefficient of three yield components from multiple regression analyses for four water treatments.

Water Treatment	Yield Component	Increment in R^2	Standardized Regression Coefficient
T_1	pod number	0.618	0.681
	seeds/pod	0.084	0.326
	seed weight	0.285	0.515
T_2	pod number	0.341	-0.250
	seeds/pod	0.082	0.284
	seed weight	0.531	0.822
T_3	pod number	0.947	1.563
	seeds/pod	0.004	0.167
	seed weight	0.010	0.163
T_4	pod number	0.833	1.955
	seeds/pod	0.008	0.531
	seed weight	0.025	0.403

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Physiological Requirements of Soybean in Tropical Cropping Systems

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Photoperiod, Growth, and Yield

Because soybean (Glycine max) is a short-day plant, photoperiod strongly influences its phenological and physiological development (Shanmugasundaram et al. 1980). In Thailand, relatively short photoperiods in the dry season result in early flowering (see Lawn et al., eds.). In the rainy season, an increase in vegetative growth results in larger plant size, increases in leaf area and node number, and higher yields (Hartwig 1970, Pookpakdi 1977, and Siriprasert 1981).

The days to flowering and days to maturity of different cultivars planted in the rainy and dry seasons are shown in Table 1. The delay in flowering in the rainy season increased vegetative growth as indicated by increases in plant height. Soybean cultivars from US maturity groups VII, VIII, IX, and X flower and mature somewhat later than Williams (group III), but their vegetative growth and yields are higher.

Pookpakdi (1977) reported that soybeans from maturity groups III and IV (Williams and Clark 63) are not suitable for the lowland tropics. When exposed to the shorter photoperiods found in the tropics, these cultivars flowered early, had short vegetative periods, and yielded poorly. Soybeans from group VIII, IX, and X were found to be more suitable.

Dry Matter Accumulation

Soybean dry matter production is higher in the rainy season than in the dry season, mainly because of longer photoperiods and higher levels of soil moisture. Dry matter production for different cultivars and seasons are presented in Table 2. Other studies have shown that high dry matter production is correlated with higher seed yield (Veerawudh 1974, Pookpakdi 1977).

Plant Populations

Rainy Season

Soybean yield increases in direct proportion to plant population density (Buttery 1969 a and b, Pookpakdi 1977, Shibles and Weber 1965, Siriprasert 1981, and Veerawudh 1974). Shibles and Weber (1965) demonstrated the effect of plant population on the leaf area index (LAI) and total dry matter production in critical LAI-type cultivars. Increases in LAI brought about by higher plant population densities increased dry matter production.

A plant population experiment conducted at AVRDC in 1976 confirmed the relationship between population density, LAI, and dry matter production. It was shown that increased LAI usually accompanies an increase in total dry matter per area (Table 3). Because soybean growth varies according to season and environ-

ment, different plant population densities are required to obtain a specific LAI level. For example, rainy season soybean requires lower plant population densities than dry season soybean due to its superior vegetative growth.

Using a between-row distance of 75 cm, and by varying the distance between plants from 5 to 20 cm, Veerawudh (1974) found that the crop growth rate and LAI of five soybean cultivars increased as spacings between plants increased (Table 4). Furthermore, the yield of all cultivars tested was highly correlated with LAI and crop growth rate (CGR) (Table 5). This study also showed a significant relationship between plant density, total dry matter, and yield.

Table 1. Days to flowering and maturity of different soybean cultivars in Thailand according to season.

Cultivar	Maturity Group	Days to Flowering		Days to Maturity		Plant Height (cm)	
		rainy	dry	rainy	dry	rainy	dry
William	III	30	30	98	93	20	19
Tunia	VII	37	35	108	107	31	28
Improved Pelican	VIII	43	37	98	96	37	26
Jupiter	IX	45	37	113	104	41	32
Alamo	X	44	41	110	104	31	23
SJ 2[z]	-	39	37	110	104	41	29

[z]Recommended cultivar

Table 2. Total dry matter production[z] of soybean planted in the rainy and dry seasons in farmers' fields in central Thailand.

Cultivar	Rainy Season (g/plant)	Dry Season (g/plant)
SJ 1	13.47	3.54
SJ 2	11.37	3.74
SJ 4	13.54	2.84
SJ 5	13.75	2.64
Clark 63	12.17	3.51
William	5.71	2.12

[z]49 days after planting

Table 3. Effect of plant population on total dry matter (t/ha) and leaf area index (LAI) of cv. Williams planted at six population densities.

Treatment No.	Plant Population (plant/ha)	Summer		Fall	
		dry matter	LAI	dry matter	LAI
1	7,500	0.6	0.13	0.1	0.01
2	22,498	1.4	0.55	0.4	0.07
3	38,968	2.5	0.94	0.7	0.22
4	67,492	3.9	1.54	1.0	0.50
5	202,464	7.2	3.13	2.8	1.17
6	607,355	8.0	4.39	4.2	3.30

Total Dry Matter	LSD 0.05
Between plant populations	1.2
Between seasons	1.0
LAI	
Between plant populations	0.9
Between seasons	0.7

Although increases in plant population density often increase seed yield due to high dry matter production, equidistant plant spacing also promotes growth and yield (Safo-Kantanka and Lawson 1980, Siriprasert 1981).

Other Physiological Parameters

Growth analysis is frequently used to measure the physiological parameters of soybean. Veerawudh (1974) reported that the net assimilation rate (NAR) of different soybean cultivars ranged from only 68 to 73 g/m^2/week, 25 to 42 days after planting (DAP). Between 42 and 68 DAP, NAR dropped slightly in all cultivars tested (Table 6). A significant decrease in NAR was observed 68 DAP. The reduction of NAR at the reproductive stage indicated a decrease in the photosynthetic ability of the leaves, a phenomenon partly due to the senescence of the lower leaves.

Table 4. Leaf area index and crop growth rate (49 days after emergence) of five soybean cultivars grown in the rainy season in central Thailand[z].

Spacing Between Plants (50 cm rows)	LAI	Crop Growth Rate (g/m^2/week)
5	3.59	119.80
10	1.93	82.41
15	1.40	68.43
20	1.29	68.00
Mean	2.06	84.66
LSD 0.05	0.25	NS

[z]Figures shown are averages of five cultivars: Semmes, Dare, Hill, Improved Pelican, and Lee

Table 5. Correlation between yield, LAI, and crop growth rate of five soybean cultivars grown in the rainy season in central Thailand.

Cultivar	LAI	Crop Growth Rate
Semmes	0.835**	0.683*
Dare	0.883**	0.811**
Hill	0.963**	0.791**
Improved Pelican	0.835**	0.844**
Lee	0.843**	0.594*

* Significant at 0.05
** Significant at 0.01

Table 6. Physiological parameters of rainy season soybean (49 DAP).

Distance Between[z] Hills (cm)	Leaf Area/ Plant	Sp. Leaf Area	Sp. Leaf[z] Wt.	NAR[z] g/m^2/ week	LAR[z]
5 cm	1077	1.68	0.59	40.69	0.78
10 cm	1158	1.60	0.62	43.00	0.74
15 cm	1260	1.52	0.66	47.74	0.70
20 cm	1548	1.56	0.64	59.53	0.72
Mean	1260	1.59	0.63	47.74	0.74

[z]60 cm rows
Source: Veerawudh (1974)

NAR was also found to be related to plant population density increases. AVRDC (1978) reported correlation coefficients of SLW (specific leaf weight) and yield to be highly significant and negative. In our experiments, correlations between yield, SLW, and NAR were insignificant in rainy season population density trials.

The seed dry matter accumulation rate and the duration of effective seed filling is also related to yield (Egli and Leggett 1976). In two experiments conducted on farmers' fields, we found that the accumulation rate of seed dry matter in cultivar SJ 4 were 13.7 and 9.39/g/m^2/day in the rainy and dry seasons, respectively. The effective seed filling period ranged from 25 to 30 days. Seed dry matter accumulation was found to be highly correlated with moisture availability. There was also a highly significant correlation between yield, seed size, and the rate of seed filling.

Soybean Intercropping

In Thailand, soybean intercropping with cotton (Gossypium hirsutum) appears to have some potential as a pest control practice. The chemical control requirements for cotton and soybean are similar. The relationship between the two crops reduces insect infestation by creating a complex environment and by stimulating the growth of natural enemies (Tawornsuk, personal communication).

Theoretically, intercropping results in competition between the component crops for nutrients, light, and moisture. With careful management, however, intercropping can increase dry matter production by improving light interception, increasing N efficiency (Palada and Harwood 1974), and maintaining soil fertility (Finlay 1974). Intercropping can also increase productivity if the crops complement one another (Herrera and Harwood 1973).

A corn (Zea mays) -soybean intercropping experiment in Thailand showed that total dry matter accumulation (85 DAP) was 6.8 t/ha, while corn and soybean alone produced 4.6 and 3.6 t/ha of dry matter without fertilizer. If 180 kg N/ha was applied, the dry matter yield was not higher than that of the corn monoculture. N application stimulated the growth of corn but not of soybean (it also resulted in the shading of the soybean crop).

Similar experiments conducted in the Philippines (Suryatna and Harwood 1976) showed advantages in terms of nutrient accumulation. Total nitrogen, phosphorus, and potassium accumulations were high in a corn-soybean intercrop when N was not applied, compared with soybean or corn monocrops. Thus corn-soybean intercropping may benefit the farmer when cash inputs are limited (Table 7).

Table 7. Total nitrogen, phosphorus, and potassium accumulation in above ground plant parts 85 DAP[z].

Crop	0 kg N/ha			180 kg N/ha		
	N	P[y]	K[y]	N	P[y]	K[y]
Rice	28.38 hb	11.44 p	43.13 m	75.79 i	30.61 f	133.71 b
Corn	32.40 p	12.99 p	45.71 m	90.31 f	35.50 cde	102.30 d
Soybean	74.87 ij	16.83 no	34.89 n	82.53 h	24.80 ghi	35.04 n
Corn + rice	41.23 o	18.66 n	50.14 l	126.41 c	48.00 a	143.43 a
Corn + soybean	104.16 e	21.12 jklm	74.14 h	148.25 a	37.01 c	100.09 a

[z]Means followed by common a letter are not significantly different at 5% level of probability according to Duncan's Multiple Range Test

[y]Phosphorus and potassium fertilizer were applied before planting at the rate of 60 kg/ha as P_2O_5 and 60 kg/ha as K_2O

Source: Suryatna and Harwood (1976)

Anwarhan et al. (1977) reported that percent light interception in soybean planted as a monocrop increased from 39.7 to 45.7 when plant population increased from 200,000 to 400,000 plants/ha. Light interception increases slightly with an increase in soybean plant population density (intercropped with corn). In this experiment there was a tendency for the percent light interception to increase when high rates of N fertilizer were applied. Dry matter and leaf area index were significantly correlated with mean light interception ($r = 0.72$ and $r = 0.75$, respectively); correlations between light interception and grain yield were insignificant ($r = 0.53$ NS).

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Discussion Section VI

Question: In your recommendation that basal application of 20 to 30 kg N per ha will enhance nitrogen fixation, did you take into consideration the inherent nitrogen content of the soil?

Tanaka: If soil testing is conducted, then the recommendation should vary according to soil fertility.

Question: Under a constant photoperiod did the time of flowering depend on heat-unit accumulated by the plant? Second, is the heat required for flowering constant?

Summerfield: We have presented information elsewhere (Hadley, P., Roberts, E. H., Summerfield, R. J. and Minchin, F.R., 1984, Annals Botany 52 [in press]) describing the relation between photo-thermal combination, genotype, and thermal sums (heat-units) for flowering. The relations between rates of progress towards flowering and thermal sum can become unreliable (i.e. they break down) if temperature exceeds the optimum value for 1/f for a substantial period of the time over which it is integrated.

Question: Is there any objective measures for photosensitivity of soybeans?

Sundar: The objective measure might be judging the cultivar's sensitivity relative to the difference between 10- and 16-hour photoperiods during different seasons when temperatures vary.

Section VII

Economics

The Economics of Small- and Large-Scale Soybean Production in the Philippines

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Introduction

The Philippines imports large quantities of soybean (Glycine max) and soybean meal. To meet increasing requirements, government is encouraging the expansion of local soybean production. In doing so, a number of farm production models have been employed. This paper reviews the economic potential of the various models.

Soybean Production in the Philippines

For the purpose of discussion, soybean farms in the Philippines have been classified into four categories: Ordinary farms, demonstration or seed farms, financed farms, and cooperative farms.

Ordinary farms are usually small, fragmented, lowland holdings that are managed by self-reliant rice farmers who lack access to credit. Most farming operations are carried out by hand and without regard to recommended cultural practices. Soybean is grown for animal feed or for use as a coffee substitute. Ordinary farms are usually found in central Luzon.

Demonstration or seed breeding farms are most often managed by private companies under government supervision. Financed farms are required to plant soybean in contiguous areas and to follow a specific technology package. Soybean is usually grown after rice (Oryza sativa) or corn (Zea mays).

Cooperative farms involve large numbers of farmers who grow soybean as a main crop on a contiguous upland farm that has been divided into separately owned and managed parcels of 2 ha or more. A cooperative farm is similar to a large farm with unitary management. Large-scale farming practices are followed, including the use of tractors for cooperative land preparation. In many cases, seed companies lend seed to the farmers. Technical packages are followed under the supervision of seed company technicians. The farmer shoulders all labor and non-seed input costs. The seed company buys the crop at US $0.40/kg for resale.

Labor Use

Labor use varies among the different farm types. The amount of labor used on cooperative farms is about 40 days less than on ordinary farms, mostly because tractors are used for primary tillage. Financed farms and demonstration farms employ 80 labor days/ha and 74 labor days/ha, respectively (Table 1). Animals are used only for traction.

Land Preparation, Planting, and Cultivation

Land preparation on ordinary farms is performed mostly with draft animals, whereas mechanical power is used on cooperative farms. In dry areas with heavy soils, plowing and harrowing is carried out three or more times to pulverize the

soils, while on the light soils in Cotabato Province tractor harrowing is practiced.

Seeds are sown on hills (3 to 4 cm deep) to achieve uniform emergence. Seed broadcasting is not commonly practiced because of weed problems. Drilling and basal application of fertilizer are usually carried out at the same time. Seeds are tested for germination on demonstration and cooperative farms.

To speed operations, cooperative farms use contractual labor for furrowing, cultivation, and hilling-up. This shortens the period between crops, and enables farmers to grow soybeans three times per year. An animal-drawn soybean furrower with three 4- to 6-inch teeth is used to make furrows and place seeds at a uniform depth.

Intertillage and Pest Control

Intertillage is practiced more on cooperative and demonstration farms than on ordinary and financed farms. Cooperative farmers use an animal-drawn cultivator 10 to 15 days after seedling emergence; a second cultivation (with blade) follows 25 to 30 days after seedling emergence. Spot weeding within rows is also practiced. Pesticide application is similar for all farm types.

Harvesting, Threshing, and Drying

Soybean is harvested manually by cutting the plant at the base. On ordinary farms the crop is thoroughly sun-dried, spread on a cement floor or other hard surface, and then beaten. On cooperative and demonstration farms soybean seeds are threshed 24 hours after drying to prevent mold formation and excessive moisture absorption. The beans are dried in oil-fired dryers (40 to 45°C for seed and 45 to 50°C for food or feed).

Mechanical threshers are used on cooperative and demonstration farms. In most cases ordinary rice or sorghum (sorghum vulgare) threshers are modified to prevent damage to the soybean seed.

Inputs

Cooperative, demonstration, and financed farms apply more inputs than ordinary farms. Private companies often lend non-certified seed to cooperative farmers (cultivars Orba and SJ-2). Ordinary farmers save seed from the previous harvest or purchase it from the Bureau of Plant Industry. Financed farms use certified seed (cultivars BPI-SY2 and UPL-SY2) and follow the recommendations used on demonstration farms. About 50 to 60 kg/ha are sown in the dry season compared with 40 to 50 kg/ha in the wet season. All farm types use inoculants, but only demonstration and cooperative farms use seed fungicides. Herbicides are not used on any farm type.

Fertilizer is applied basally and as a sidedressing. More fertilizer is applied on cooperative farms than on ordinary farms.

Costs and Returns

A summary of the costs and returns of the different farm types is shown in Table 2 (details are presented in Tables 3, 4, 5 and 6). Labor costs, especially for land preparation and harvesting are higher for ordinary farms, while material costs are usually lower. Labor costs are valued at US $2.5/person-animal day and US $1.5/animal day for ordinary, financed, and demonstration farms. Labor on cooperative farms is performed on a contractual basis at US $3 to $4 per person-animal day.

Average yields on cooperative and demonstration farms is about 2.0 t/ha, while average yields on ordinary and financed farms are about 1.0 and 1.5 t/ha, respectively. The higher yields obtained on demonstration and cooperative farms can be attributed to the use of better cultural practices and intensive management techniques, as well as to favorable conditions in the areas where the farms are located. Based on the National Food Authority's support price for soybean (US $0.40/kg), gross returns and net returns on cooperative and demonstration farms are higher than on financed and ordinary farms. Benefit-cost ratios show higher returns to investments on cooperative and demonstration farms, indicating that group/joint cultivation is economically more attractive than production on small, scattered plots. On cooperative farms, soybean is produced as a main crop, and can be grown two to three times per year. Thus, large-scale soybean production in Mindanao can be very profitable. However, soybean production in this area is risky because of weather conditions and disease and pest problems. To reduce the risk, soybean can be profitably intercropped with corn (Table 7).

Marketing and Prices

Ordinary farms usually have problems marketing soybean because of difficulties in meeting quality standards and because of low-volume production and sales. In Southern Mindanao, however, small farmers can sell their crops to a variety of buyers, but prices vary. The highest retail price for high quality seed is US $0.85/kg. Variations in average annual soybean prices are shown in Table 8.(p. 398)

Profitability

Soybean is produced on ordinary farms in small, dispersed plots (0.1 to 0.3 ha), usually in sequence with non-rice crops. Financed, demonstration, and cooperative farms produce soybean on contiguous land areas of a hectare or more. Cost comparisons of ordinary farms with those of the other farm types show that ordinary farms are at a disadvantage.

Labor costs on ordinary farms are US $34/ha higher, but ordinary farmers use fewer material inputs (-US $25/ha). It is not possible to determine the substitution rates of material inputs for labor, therefore total variable costs must be considered. Ordinary farms, on balance, require $11/ha more to operate than other farm types (Table 9).(p. 398)

When farm management is augmented by the more constant supervision and instruction available on demonstration and cooperative farms, an additional yield gain of 0.5 t/ha can be achieved (attributed to better technology application).

In summary, the gains experienced by financed farmers are due to technology access, whereas those of cooperative farmers results from expert technology application. The profit gap between ordinary farms and cooperative farms is US $406/ha. Three percent of that amount is due to cost advantages of scale, 49% is due to yield advantages from technology access, and another 49% is due to expert technology application.

Yield Advantages of Scale

While approximately 97% of the yield advantage of larger plots, compared with smaller plots, is attributed to access to and application of technology, these advantages may also be due to an advanatage of scale. A public investment is made by government or financial institutions to provide financed farmers with technology. The conditions of this financing require that the farmers cultivate soybean on large, contiguous plots, and that a large number of farmers in close proximity join the scheme. This makes the government's investment worthwhile.

In a sense, the technological gains experienced by financed farmers is due to their larger and less dispersed production structures. Hence, gains can be attributed to scale, but they also accrue through the use of technology.

Similarly, the greater supervision and instruction available to cooperative farms is due to their more compact production structure. Farmers' contiguous 2 ha plots offer higher economies of scale in terms of supervision. There are also scales in economy that cannot be distinguished from the gains derived from technology.

Cost advantages of scale accrue through farm operations, and are achieved as a result of individual farmer responses. They are small compared to yield advantages of scale. The latter accrue through the overall production structure across farms, and are achieved through responses of the non-farm public and the agri-business sector.

Table 1. Labor use on Philippine soybean farms.

Farm Operation	Ordinary (LD[z]/ha)	Demonstration (LD/ha)	Financed (LD/ha)	Cooperative (LD/ha)
Land preparation	21	8	12	2[y]
Furrowing	3	1	2	2
Inoculation/drilling/ fertilization	7	9	7	8
Cultivation	6	4	2	5
Hand weeding	10	24	9	15
Pest/disease control	6	6	6	6
Harvesting/cutting/hauling	10	8	12	10
Drying	10	2	10	2
Threshing/cleaning/bagging	20	12	20	2
Total	93	74	80	52

[z]LD = Labor days
[y]Associated with two tractor days; traction power on other farm types and for other operations supplied by draft animals

(Tables 2-7 are on pp 399-402)

Table 8. Soybean prices in the Philippines, 1976-1981 (US $/kg).

Year	Farm[z]	Wholesale[y]	Retail[x]
1976	0.33	0.27	0.36
1977	0.34	0.29	0.44
1978	0.38	0.32	0.41
1979	0.42	0.31	0.52
1980	0.47	0.37	0.71
1981	0.30	0.49	0.45

[z] Bureau of Agricultural Economics, Philippines
[y] Ministry of Agriculture, Philippines
[z] Based on Manila prices, Ministry of Agriculture

Table 9. Profit differences between farm types (US $/ha).

Minimum profit	121	Profit on ordinary farm
Cost advantage	11	Ordinary vs. financed, demonstration, and cooperative farms
Yield advantage	198	Ordinary vs. financed farm
Yield advantage	197	Financed vs. demonstration farm
Maximum profit	527	Demonstration and cooperative farms

Table 2. Comparison of yield, labor costs, and returns of soybeans on different farm types.

Items	Farm Type			
	ordinary	demonstration	financed	cooperative
Avg. yield (t/ha)	1.0	2.0	1.5	2.0
Workdays				
Tractor	-	-	-	2
Animal	27	13	16	7
Human	93	74	80	52
Costs (US $/ha)				
Material costs	104	128	127	128
Seed	37	34	42	25
Fertilizer	35	37	37	61
Chemicals	32	57	48	42
Labor costs	170	134	136	135
Land preparation	60	23	35	30
Planting and crop maintenance	50	69	38	62
Harvesting/threshing/ others	60	42	63	43
Total variable costs (US $)	274	262	263	263
Gross returns (US $)	395	790	593	790
Net returns (US $)	121	528	330	527
B/C ratio	1.5	3.0	2.3	3.0

Table 3. Costs and returns of soybean production on ordinary farms.

	Labor Days	US $/ha
Labor costs[z]		
First plowing (animal)	8	20.00
Second plowing (animal)	7	17.00
Harrowing (2x; animal)	6	15.00
Furrowing	3	8.00
Inoculation/drilling/fertilization	7	11.00
Cultivation (animal)	6	15.00
Hand weeding	10	15.00
Pest/disease control	6	9.00
Harvesting/cutting/hauling	10	15.00
Drying	10	15.00
Threshing/cleaning/bagging	20	30.00
Sub-total	93	170.00
Material costs		
Seed (50 kg)		37.00
Fertilizer (14-14-14 [3 bags])		34.00
Inoculant (200 g)		5.00
Insecticides (3 l)		21.00
Fungicides (200 g)		10.00
Sub-total		104.00
Total variable costs		
Gross returns at 1 t/ha ($0.40/kg)		395.00
Net returns		121.00

[z]Value at US $2.50/person-animal day, $1.50/person day
Source: Ministry of Agriculture

Table 4. Costs and returns of soybean production on financed farms.

	Labor Days	US $/ha
Labor costs[z]		
Plowing (2x) animal	8	20.00
Harrowing (2x) animal	4	10.00
Furrowing (animal)	2	5.00
Drilling/fertilization	7	11.00
Insecticide application (3x)	6	9.00
Weeding	9	14.00
Hilling-up (animal)	2	5.00
Harvesting/hauling	12	18.00
Threshing (manual)	15	22.00
Drying/cleaning/bagging	10	15.00
Storage and handling	5	7.00
Sub-total	80	136.00
Material costs		
Seed (50 kg)		43.00
Fertilizer:		
16-20-0 (2 bags)		25.00
0-0-60 (1 bag)		11.00
Inoculant (100 g)		1.00
Bifolan 2 (1 l)		9.00
Insecticides:		
Endosulfan (1 l)		7.00
Methomyle (2 qt)		16.00
Furadan (12.5 kg)		15.00
Sub-total		127.00
Total variable costs		263.00
Gross returns at 1.5 t/ha ($0.40/kg)		593.00
Net returns		330.00

Source: Ministry of Agriculture, Davao del Sur

Table 5. Costs and returns of soybean production on demonstration farms.

	Labor Days	US $/ha
Labor costs		
Plowing (animal)	7	18.00
Harrowing (animal)	1	3.00
Furrowing (animal)	1	3.00
Inoculation/drilling/fertilization	9	13.00
Handweeding	24	36.00
Cultivation (animal)	4	10.00
Pest/disease control	6	9.00
Harvesting/cutting/hauling	8	12.00
Drying/cleaning	2	3.00
Threshing (manual)	4	6.00
(machine)	-	10.00
Grading/packaging	8	12.00
Sub-total	74	135.00
Material costs		
Seed (40 kg)		34.00
Fertilizer:		
12-20-0 (2 bags)		25.00
0-0-60 (1 bag)		12.00
Inoculant (350 g)		1.00
Agraspin (1/3 l)		11.00
Chemicals: Furadan (1 bag)		16.00
Azodrin (2 l)		15.00
Lannate (1 l)		8.00
Thiodan (1 l)		6.00
Sub-total		128.00
Total variable costs		263.00
Gross returns at 2.0 t/ha ($0.40/kg)		790.00
Net returns		527.00

Source: Botanique, Philippines

Table 6. Costs and returns of soybean production on cooperative farms.

	Labor Days	US $/ha
Labor costs		
Harrowing (2x) tractor[z]	2	24.00
Furrowing (soybean furrower, animal)	2	6.00
Inoculation/drilling/basal/fertilizing	4	6.00
Cultivation		
Without blade[y]	1	4.00
With blade (animal)[x]	2	6.00
Fertilization (sidedressing)	4	6.00
Hilling-up (animal-drawn double-blade plow)	2	6.00
Spot weeding (manual) (3x)	15	24.00
Pest and disease control (4x)	6	10.00
Harvesting (cutting method)	10	16.00
Binding and hauling to thresher	2	3.00
Threshing and cleaning (40 bags at $5.00/bag)		20.00
Sun drying and packing	2	3.00
Sub-total	52	134.00
Material costs		
Seed (50 kg)		25.00
Inoculant (100 g pack)		1.00
Fertilizer:		
16-20-0 (2 bags)		25.00
0-0-60 (2 bags)		23.00
46-0-0 (1 bag)		12.00
Insecticides:		
contact (2 qt)		10.00
systemic (1 qt)		8.00
Carbofuran (1 bag)		16.00
Fungicide:		
copper fungicide (500 g)		8.00
Sub-total		128.00
Total variable costs		262.00
Gross returns at 1.5 t/ha ($0.40/kg)		790.00
Net returns		528.00
Return rate on variable cost		

[z] $ 12/ha tractor rental rate
[y] Contractual labor at $4/ha
[x] Contractual labor at $6/ha
All costs and returns exclude fixed costs such as depreciation, interest on loans, land rent, taxes, etc

Table 7. Costs and returns analysis of soybean-hybrid corn intercropping, Davao del Sur, 1983.

Item	Qty/Unit Labor days	Soybean $/ha	Corn $/ha
Labor cost			
Land preparation			
Plowing (2x)	6	30.00	30.00
Harrowing (2x)	3	15.00	
Planting and care			
Furrowing	2	5.00	
Planting/basal	11	15.00	3.00
Sidedressing	4	4.00	2.00
Cultivation (2x)	3	10.00	5.00
Insecticide application	7	10.00	4.00
Weeding	20	25.00	5.00
Harvesting and processing			
Harvesting/handling	24	25.00	11.00
Threshing			
Mechanical - 7% of the threshed		40.00	
Husking and shelling 7% of shelled			23.00
Drying and cleaning		8.00	50.00
Grading and packaging		6.00	3.00
Sub-total		193.00	64.00
Material cost			
Seed			
corn (7 kg)			12.00
soybean (40 kg)		30.00	
Fertilizer			
16-20-0 (2 bags)		23.00	
14-14-14 (1 bag)			12.00
21-0-0 (2 bags)		89.00	9.00
Insecticides			
Carbofuran (1 qt)		10.00	8.00
Endosulfan (2 qt)		12.00	
Methomyl (2 qt)			12.00
Inoculant (200 g)		1.00	
		0.85	0.53
Total cost		278.00	117.00
Returns			
Gross returns (estimated soybean yield of 1.5 t/ha; corn 2.5 t/ha)		743.00	325.00
Net income before deducting fixed costs (interest, depreciation, taxes, rental, etc.)		465.00	209.00

Source: Ministry of Agriculture, Region XI, Digos, Davao del Sur, 1983

The Economics of Soybean in Indonesia

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Introduction

This paper reviews the economics of soybean (Glycine max) production in Indonesia with regard to farm management, demand, marketing, and utilization. Supply is considered as a local production phenomenon, and does not include imported soybean. Marketing and demand are analyzed individually, taking into account domestic and industrial consumption.

Production Trends

The government of Indonesia recently completed its third five-year development plan (1979-1984). As with the 1969-73 and 1974-78 plans, the third plan emphasized agriculture for domestic consumption and as a foreign exchange earner.

The area planted to soybean and selected major food crops in Indonesia are compared in Table 1. Since 1955, rice (Oryza sativa) production has increased significantly because of government policies aimed at self-sufficiency. There has also been a small but steady rise in soybean and peanut (Arachis hypogea) production. Cassava (Manihot esculenta) and corn (Zea mays) production have remained stagnant, and sweet potato (Ipomoea batatas) production has declined.

Production and yield figures for soybean are presented in Table 2. Although average yields per hectare have increased, production levels are still quite low because of poor crop management practices and the absence of high yielding, disease resistant cultivars.

In the early 1970s more than 80% of Indonesia's soybean was grown in Java, and more than half of that amount was grown in East Java (Table 3). Annual production increased by 75,000 t between the first and second five-year plan periods and by 66,000 t between the second and third. In general, production grew more rapidly in areas outside of Java.

Economic Considerations

The production costs and net returns of selected crops grown in Java and Madura, two of Indonesia's soybean production areas, are shown in Table 4. Soybean production in 1979 was profitable if calculated on the basis of price and the rate of production. Considered independently of other crops, it was reasonable to expect that the area planted to soybean would expand. However, soybean profitability proved to be unfavorable compared with that of other crops.

Profitability is not the only factor that influences production decisions; price stability, price trends, and yields also play a role. Commodity price ratios, with the price of soybean used as a denominator, are shown in Table 5. A decline in price ratios over time indicates a rise in soybean prices faster than that of other crops; if the ratios increase the opposite is true. The data show that almost all crop price ratios declined, except that of peanut. This means that most price trends (apart from peanut) favor soybean. This is consistent

with Table 1 which shows that the increase in the area planted to soybean is higher than that of other crops (with the exception of peanut). Thus, if the farmers' decision is based only on price, there is an incentive to grow soybean.

Although production costs and profits are major factors in determining the crops that farmers grow, yield per hectare is equally important. Yield per hectare for several food crops (1969-1980) are shown in Table 6. Yields per hectare and increases in productivity for soybean (Table 2) were lower compared with other crops. Therefore, despite a favorable price trend for soybean, lower yields and a lower rate of increase in productivity mitigate against the farmers' decision to plant soybean.

Demand

Most of the soybean produced in Indonesia is consumed in Java, West Nusatenggara, or Sumatra. Most production is used for domestic purposes; only small amounts are exported or used as animal feed. However, there is an increasing tendency to use soybean as poultry feed. Processed soybean products include tempeh (fermented soybean cake), tofu (a protein extract), and soybean sprouts.

Average domestic consumption from 1968 to 1980 is shown in Table 7. Despite increases in production during this period, daily per capita consumption is still less than 15 g per day.

Marketing

Soybean is traded in Indonesia as shown in Fig 1.

A survey conducted by the Bogor Agricultural University indicated that farmers sell almost 75% their crop (Anon. 1976) and use the remainder for home consumption or seed.

The farm price, as a percentage of the retail price, varies from 47.3% in Bali to 80.9% in East Java (Table 8). Transportation costs and losses during shipping are the two largest cost components. High marketing margins indicate, to some extent, the high cost of transportation and marketing. Variations in prices between district market centers and rural markets in South Sulawesi - compared with those in East Java, for example - are basically due to high transportation costs (Table 9).

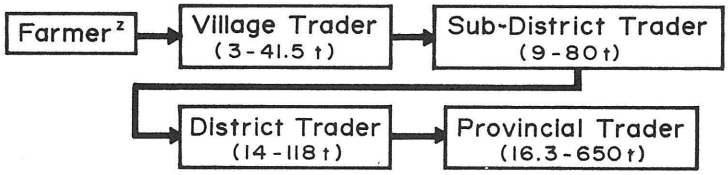

Fig. 1.
Trade route of soybean in Indonesia; ( ) values represent yearly volume; [z]at times, farmers deal directly with sub-district traders.

Conclusions

Potential exists for increasing soybean production in Indonesia. It hinges, however, on the development of improved market infrastructures, alterations in price and income relationships, and the development of consistent policies aimed at stimulating production. Infrastructural improvements alone will not significantly stimulate production because they apply equally to crops that are economically superior to soybean. Other factors that require attention include the lack

of high yielding cultivars, agricultural policies that emphasize rice, and the instability of soybean marketing structures.

Table 1. Food crop production hectarage in Indonesia, 1955-1980.

Year	Rice	Corn	Cassava	Sweet Potato	Peanut	Soybean
			(000 ha)			
1955-68	7132	2706	1431	421	355	584
1970	8135	2929	1398	358	380	695
1972	7898	2160	1468	338	354	698
Avg	8155	2719	1434	360	380	674
1974	8508	2669	1509	330	411	768
1976	8368	2095	1353	301	414	646
1978	8929	3025	1383	301	506	733
Avg	8532	2560	1404	314	463	709
1980	9018	2771	1414	287	507	732
1981	-	-	-	-	-	811
Avg	8910	2683	1427	287	490	758

Source: Central Bureau of Statistics, Indonesia

Table 2. Soybean production and yield in Indonesia, 1969-1981.

Year	Production (000 t)	Yield (t/ha)
1969	388.9	0.70
1971	515.6	0.76
1973	541.0	0.73
1975	589.8	0.79
1977	522.8	0.81
1979	679.8	0.87
1981	687.2	0.85

Source: Central Bureau of Statistics, Indonesia

Table 3. Soybean production area by region, Indonesia, 1969-80.

Region	Area (000 ha)	Percentage	Average Annual Production (000 t)		
			1969-73	1974-78	1979-82
East Java	370	52.7	292	302	346
Central Java	141	20.1	94	105	109
West Java	28	4.0	19	21	18
Yogyakarta	33	4.7	17	23	35
Java	572	81.4	422	452	508
Bali, Nusatenggara	62	8.8	39	51	48
Sumatera	50	7.1	25	52	56
Sulawesi	14	2.0	5	10	18
Others	4	0.6	2	3	4
Outside Java	130	18.5	71	116	126
Total	702	100.0	493	568	634

Source: Central Bureau of Statistics

Table 4. Farm price, cost of production, and net profit of selected crops, Java and Madura, 1979.

	Rice	Corn	Soybean	Peanut	Cassava	Sweet Potato
	(US $/ha)					
Farm price	503	192	365	490	457	418
Cost of production	148	42	48	73	20	42
Net profit	355	150	317	417	437	377

Source: Central Bureau of Statistics

Table 5. Commodity price ratios in rural markets of Java and Madura, 1969-80.

Year	Rice/ Soybean	Corn/ Soybean	Cassava/ Soybean	Sweet Potato/ Soybean	Peanut/ Soybean
1969	0.86	0.48	0.20	0.18	1.59
1970	0.81	0.37	0.15	0.16	1.59
1971	0.69	0.35	0.13	0.15	1.46
1972	0.76	0.42	0.15	0.16	1.67
1973	0.75	0.35	0.16	0.18	1.49
1974	0.64	0.36	0.11	0.12	1.84
1975	0.77	0.47	0.14	0.16	1.97
1976	0.80	0.44	0.16	0.17	1.67
1977	0.77	0.36	0.15	0.16	1.75
1978	0.76	0.36	0.13	0.15	1.70
1979	0.72	0.46	0.09	0.16	2.14
1980	0.72	0.38	0.12	0.16	2.14

Source: Central Bureau of Statistics

Table 6. Yield (t/ha) of selected food crops in Indonesia, 1969-80.

Year	Rice[z]	Corn (t/ha)	Cassava	Sweet Potato	Peanut
1969	3.3	0.9	7.4	6.1	0.7
1970	3.5	0.9	7.5	6.1	0.7
1971	3.5	1.0	7.6	6.2	0.8
1972	3.5	1.0	7.1	6.1	0.8
1973	3.7	1.1	7.8	6.3	0.7
Avg.	3.5	1.0	7.5	6.2	0.7
1974	3.8	1.1	8.6	7.5	0.7
1975	3.7	1.2	8.9	7.8	0.8
1976	4.0	1.2	9.0	7.9	0.8
1977	3.0	1.2	9.2	7.5	0.8
1978	3.1	1.3	9.3	6.9	0.9
Avg.	3.5	1.2	9.0	7.5	0.8
1979	3.2	1.4	9.6	7.6	0.9
1980	3.6	1.5	9.7	7.5	0.9
Avg.	3.4	1.4	9.6	7.6	0.9

[z]wetland paddy
Source: Central Bureau of Statistics

Table 7. Domestic soybean consumption in Indonesia, 1968-80.

Year	Total Consumption (000 t)	Average Consumption Per Capita			
		kg/year	g/day	calories/day	protein (g)/day
1968	365	3.2	8.9	30	3.4
1969	347	3.0	8.3	28	3.2
1970	441	3.8	10.4	35	4.0
1971	462	3.9	10.6	36	4.0
1972	462	3.8	10.4	35	3.9
1973	448	3.6	9.8	33	3.7
1974	520	4.0	11.1	37	4.2
1975	528	4.0	11.0	37	4.2
1976	629	4.7	12.9	52	4.5
1977	552	4.0	11.0	44	3.9
1978	679	4.8	13.3	53	4.7
1979	770	5.3	14.7	59	5.2
1980	684	4.6	12.8	51	4.5

Source: Central Bureau of Statistics

Table 8. Index of soybean prices and marketing costs in Java, Nusa Tenggara, and Lampung, 1976[z].

Cost	West Java	Central Java	East Java	Lampung	Bali	West Nusa Tenggara
Farm gate price	78.98	80.12	80.91	69.15	47.32	64.46
Transportation	0.28	0.33	0.55	2.39	0.38	0.70
Loading/unloading	-	0.30	0.14	0.68	-	-
Storage	-	0.50	-	-	-	-
Loss (1.5 %)	1.18	1.20	1.21	0.02	0.71	0.96
Packaging	-	-	-	0.68	-	-
Tax	-	-	-	1.02	-	-
Profit margin of village traders	4.28	0.47	5.11	2.22	18.55	6.56
Subdistrict buying price	84.72	82.62	87.92	77.18	66.88	72.68
Transportation	0.28	0.80	0.36	1.37	0.16	0.70
Loading/unloading	-	0.31	0.15	0.68	-	-
Loss (1.5%)	1.27	1.23	1.32	1.16	1.0	1.25
Packaging	-	-	-	0.68	-	-
Tax	-	-	-	0.12	-	-
Profit margin subdistrict traders	1.77	1.55	3.17	5.33	19.47	14.75
District buying price	88.09	86.47	93.18	86.52	-	-
Transportation	3.26	1.05	1.02	1.37	-	-
Loading/unloading	0.08	0.24	0.08	0.68	-	-
Storage	-	-	0.05	0.08	-	-
Loss (1%)	0.08	-	-	-	-	-
Profit margin district traders	1.44	3.01	0.11	0.60	-	-
Provincial price	93.42	90.37	94.45	89.24	93.75	89.38
Transportation	4.83	1.20	0.72	1.38	-	0.70
Loading/unloading	0.08	0.26	-	0.12	-	-
Loss (1%)	0.94	0.91	0.95	0.89	0.94	0.90
Profit margin provincial traders	0.74	7.26	3.78	8.69	5.31	8.75
Retail price	100	100	100		100	100

Source: Faculty of Agricultural Engineering, Bogor Agricultural University, 1976
[z]Costs calculated as perentage of soybean retail price in each province

Table 9. Soybean prices at rural and district markets centers, 1975-80.

year	East Java (US$/kg)			South Sulawesi (US$/kg)		
	rural market	district market center	margin	rural market	district market center	margin
1975	0.26	0.27	0.02	0.18	0.23	0.06
1976	0.25	0.28	0.03	0.22	0.32	0.10
1977	0.28	0.30	0.02	0.24	0.32	0.08
1978	0.29	0.32	0.03	0.26	0.37	0.11
1979	0.43	0.46	0.03	0.33	0.49	0.16
1980	0.52	0.53	Negligible	0.46	0.56	0.10

Source: Directorate General for Food Crops, 1980.

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The Development of Multi-Cropping Systems and Soybean Production in the Asian-Pacific Region

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The Development of Multi-Cropping Systems

The need to develop multi-cropping systems for Asian and Pacific countries is widely recognized. From a "macro" point of view the adoption of cash crops [high income elasticity crops that can be substituted for rice (Oryza sativa)] should be encouraged. Rice is the dominant crop in the region, and there may be a regional surplus by the late 1980s. Japan and Taiwan have already instituted rice reduction programs, and other countries are expected to follow suit. Until now many farmers have enjoyed the benefits of rice subsidies, but decreasing demand, combined with downward pressures on prices and increasing government deficits, all weigh heavily against rice support programs in the future.

An increase in the production of cash crops might also help to reduce the income gap between the urban and rural sectors. The region's high-growth economy, driven by rapid industrialization, has widened the urban-rural income gap. An increase in cash crop production would be particularly beneficial in countries where there are limited opportunities for increasing non-farm income.

There are also benefits that can result from multi-cropping at the micro-level. These include: 1) more efficient use of farm resources, particularly labor; 2) greater resource efficiency from farm wastes and by-products; 3) an increase in land utilization; 4) stabilization of farm incomes; and 5) risk minimization.

Soybean in Multi-Cropping Systems

Demand

Regional soybean (Glycine max) consumption increased significantly during the past decade because of population increases, higher incomes, and increases in consumer demand. There has also been a rise in the use of soybean as animal feed. Soybean consumption in Taiwan, Japan, and Korea increased from 4.3 million t in 1970 to 6.1 million t in 1980 (Table 1).

The income elasticity for soybean demand can be estimated according to the following equation:

$$\Delta D = \Delta P + \mu.\Delta I$$

ΔD: % increase in demand
ΔP: % increase in population
ΔI: % increase in real per capita income
μ : income elasticity of demand

A case study in Korea revealed that the income elasticity for soybean demand, including induced demand, was 1.2851, while the value in relation to soybean used for human consumption was 0.8418 (Anon. 1978). This means that a 10% increase in real per capita income will result in a 12.9% increase in aggregate soybean demand and an 8.4% increase in direct consumption.

Soybean Production in the Asian-Pacific Region

World soybean production increased by 5.7% per annum during the last decade, reaching 8.7 million t in 1981. Soybean production in the Asian and Pacific region, however, increased at a rate of only 4.8% during this period. Japan and Korea had small production increases, mainly because of higher yields. Production in Taiwan decreased from 65,000 t in 1970 to 26,000 t in 1980 (Table 2).

Table 1. Soybean consumption in Taiwan, Japan, and Korea, 1970-80.

Countries	Soybean Consumption (1000 t)			% Increase		
	1970	1975	1980	1970-1975	1975-1980	1970-1980
ROC	683	889	965	30.2	8.5	41.3
Japan	3,366	3,460	4,575	2.8	32.2	35.9
Korea	268	368	633	36.9	72.5	136.2
Total	4,317	4,716	6,141	9.2	30.2	42.3

Source: Anon. (1980), Anon. (1981), Anon. (1982b), Anon. (1982c)

Table 2. Soybean production area and yield, 1969-81.

Location	Harvested Area (1000 ha)			Yield (t/ha)			Production (1000 t)		
	1969-1971	1980	1981	1969-71	1980	1981	1969-1971	1980	1981
World total	29,289	51,831	50,229	1.5	1.6	1.7	43,552	80,896	87,957
Asian total	9,376	9,710	9,923	1.0	1.0	1.0	9,394	9,977	10,336
Taiwan	42	15	10	1.5	1.7	1.5	65	26	16
Japan	100	142	144	1.3	1.2	1.4	128	174	210
Korea	292	188	199	0.8	1.4	1.2	228	216	249

Source: Anon.(1981) and Anon. (1982)b

Production Stagnation

The objective of farm management is to maximize income by maintaining a sustained rate of growth from a limited resource base. Therefore, most farmers who practice "reasonable" farm management will choose their crops on the basis of potential profits. Profitability can be analyzed on the basis of relative price levels, relative yields, and relative production costs. An analysis of soybean's effect on an existing cropping system is also important because farmers, as farm managers, have an interest in total farm income rather than just income from a single crop.

Income Comparison: Income comparisons show that soybean is far less competitive than many of the crops presently grown in Taiwan, Japan, or Korea. Net income per hectare in Taiwan (1981) was estimated at US $63, which is far less than red bean (*Vigna angularis*) (US $242) or peanut (*Arachis hypogaea*) (US $329). In Japan, the net income per hectare of soybean (1980) was estimated at (-)US $100, which is higher than the income derived from red bean, (-)US $480 and rice, (-)US $460, but much less than the income that can be earned from vegetables. The net income from soybean farming per hectare in Korea (1976) was estimated at (-)US $200 (Table 3). Of course, income levels vary with changes in economic conditions. If relative prices increase, while other factors remain the same, income and yield levels would increase. However, income might decrease if the cost of production rose. Therefore, income levels in a specific year cannot be used in isolation to identify the reasons why soybean production in the region is stagnant. There should also be an attempt to analyze price trends, yields, and costs.

Prices: Judging only in terms of price, soybean production in the region is quite favorable to farmers. Its price has increased at a faster rate than average farm prices. However, this rate is lower than those of vegetables, peanuts, green beans (Phaseoulus vulgaris), and red beans, which are soybean's main competitors. This fact has two implications. First, although countries in the region have experienced a high increase in their demand for soybean (4.2% annual rate compared with 2.4% for total food demand), the relative price of soybean has not increased proportionally. Second, the price of competitive farm products is unfavorable to soybean. These factors can all be attributed to the importation of cheaper soybean from abroad.

Total imports to Taiwan, Japan, and Korea increased 47.7% during the past decade - from 3.9 million t in 1970 to 5.7 million t in 1980. This depressed the price of the local product despite government price subsidies.

Table 3. Comparison of crop income levels.

Location	Crop	Gross Revenue	Production Costs	Net Income
Taiwan (1981) (US$/ha)	Soybean	1,067	1,002	65
	Red bean	1,192	942	250
	Green bean	728	1,117	(-)389
	Sweet potato (autumn)	1,248	1,472	(-)224
	Corn (winter)	1,237	1,173	64
	Peanut (autumn)	2,221	1,880	341
	Rice (1st crop)	1,968	1,856	112
	(2nd crop)	1,773	1,774	(-) 1
Japan (1980) (US$/ha)	Soybean	2,150	2,250	(-)100
	Red bean	2,080	2,560	(-)480
	Cucumber	53,380	41,350	12,030
	Tomato	60,900	3,909	21,810
	Rice[z]	6,390	685	(-)460
Korea (1976) (US$/ha)	Soybean	380	580	(-)200
	Red bean	420	510	(-) 90
	Green bean	520	500	20
	Peanut	1,140	1,020	120
	Sweet potato	700	900	(-)200
	Pepper	4,260	2,040	2,220

[z] 1979

Source: Y.O. Chen, Chief, Economic Planning Division (CAPD); Japan - Anon. (1982a); Korea - Anon.(1976b)

Yields: There have been steady improvements in productivity during the past decade. While Taiwan experienced a 1.2% increase [lower than all competitive crops except corn (Zea mays)], Japan had a 13.4% increase (slightly higher than competitive crops). This seems to be one of the reasons why Japan has shown a sustained increase in production. Similarly, soybean yields in Korea increased 58.3%; however, this figure is lower than that of competitive crops (1970-80).

Costs: Labor is the most expensive soybean production input in Taiwan and Korea: 46% and 38%, respectively. The next costliest item, apart from interest for land capital, is fertilizer (8.9% in Taiwan and 11.4% in Korea). Fertilizer costs are lower for soybean than for competitive crops because of the nitrogen-fixing capacity of the plant. The next largest item is seed.

When we compare soybean labor costs with those of competitive crops (Table 4), the percentage of labor costs to total costs is rather high. In

Taiwan "paid" wages for hired labor are about 21% of all costs, which is higher than the ratio for competitive crops. Soybean is often cultivated in Taiwan during a period when family labor can be used for other productive work, mainly because small-scale soybean cultivation has relatively low labor requirements. In addition, the high labor costs for soybean, compared with competitive crops, might result in a production decline because wage costs, until recently, have risen faster than all other production costs. From 1976 through 1981, wages increased about 116% in Taiwan and 296% in Korea. In both cases labor costs rose at a far higher rate than all other production costs.

Table 4. Soybean production costs.

Location	Crop	Total Cost (A)	Wages (B)	B/A (%)
	Soybean	674	311	46.1
	Red bean	1,075	(140)[z]	(20.7)
	Green bean	379	225	20.9
Taiwan	White potato	1,726	221	58.0
			816	47.3
(US$)			(219)	(12.7)
	Sweet potato	913	449	49.2
			(5)	(0.6)
	Corn	862	304	35.2
	Peanuts	897	420	46.9
			(112)	(12.5)
	Soybean	38	22	38.7
			(2)	(4.0)
	Red bean	42	24	57.9
	Green bean	52	23	44.1
Korea	Peanuts	113	44	38.6
(US$)	Sweet potato	70	45	64.1
	White potato	143	38	26.2
	Peppers	426	113	26.6

[z] ( ) paid wages for hired labor
Source: Pan (1980), Anon. (1976b)

Cropping Systems: Soybean should be used primarily as a rotation crop in Asia and the Pacific. In southern Taiwan it is grown in the winter season after the harvest of the second rice crop. It was previously cultivated as a winter crop before the first rice crop. In this case, farmers planted early maturing cultivars. Recently, there has been a trend to substitute red bean for soybean due to its shorter growing period and more favorable price. After 1968 the total soybean area in southern Taiwan decreased from approximately 39,000 to 17,000 ha (Table 5). This occurred despite an increase in total cultivated land (+5,500 ha). In contrast, the area planted to vegetables and fruits showed a significant increase during the same period. Rice farming also increased, but the double-cropped rice area decreased; the increase in the total rice area (6,000 ha) was due to an increase in single-crop rice. As a result, rice production was replaced by an equivalent area of sugarcane (Saccharum officinarum), vegetables, or fallow. However, considering that rice reduction programs have been in effect since 1982, second-crop rice production will certainly decrease in the future because of relatively lower yields.

The next problem is to decide which crop should be substituted for rice. In this instance rice can be replaced by vegetables or soybean. The prices of vegetables over the noted period were higher than those for other winter crops

Table 5. Crop production areas in southern Taiwan (ha).

Crops	1978 (A)					1968 (B)				
	Tainan	Kaohsiung	Pingtung	Penghu	Total	Tainan	Kaohsiung	Pingtung	Penghu	Total
Rice	52,624	36,785	77,715		167,124	46,703	38,880	75,405		160,988
(single crop)	(14,158)	(15,789)	(37,768)		(67,715)	(3,964)	(15,741)	(35,582)		(55,287)
(double crop)	(38,466)	(20,996)	(39,947)		(99,409)	(42,793)	(23,139)	(39,823)		(105,805)
Sweet potato	12,654	7,829	7,212	1,803	29,498	43,463	15,963	15,245		74,671
Millet		154	785	21	960	1	289	1,481	28	1,799
Sorghum	161	10	12	933	1,116	160	38	21	2,247	2,466
Corn	5,413	2,438	1,607	100	9,560	1,910	1,204	532	121	3,767
Soybean	623	3,052	13,729		17,404	1,236	7,918	30,031		39,248
Red bean	9	969	18,423		19,401					
Green bean	2,140	35	8		2,183					
Tobacco	26	2,312	871		3,209	34	1,973	1,705		3,712
Sugarcane	27,678	11,247	12,622		51,547	25,652	12,118	10,472		48,242
Peanut	1,190	1,388	1,274	2,805	6,657	2,580	2,478	1,332	2,997	9,387
Sesame	1,502	147	14		1,663	3,285	539	33		3,857
Broad bean	248	143	752		1,143	5	75	2,042		2,122
Tapioca	1,805	3,718	3,171		8,757	5,631	4,759	1,963		12,353
Sisal			6,772		6,772		35	9,023		9,058
Vegetables	28,375	14,518	18,303	583	62,365	8,995	8,051	7,396	449	24,891
Fruits	16,971	10,570	9,817	7	37,365	8,185	11,318	13,648	7	33,158
Asparagas	2,043	255			2,298	1,418	430	31		1,879
Flowers	15	12	8		35					
Total	102,295	58,204	83,271	5,861	249,631	97,967	58,169	80,986	6,978	244,100

Source: Anon. (1976a)

(Table 6). On the other hand, the yield of winter soybean was also higher than those of summer and autumn crops (Table 7). It may therefore be desirable to replace the second rice crop with vegetables. Winter soybean might be increased by reducing the production of winter vegetables because of increased production in the autumn, i.e. rice + vegetable + soybean. In addition, several other intercropping systems might also be recommended: Rice and soybean, soybean and other cereals, and soybean and plantation crops.

Table 6. Seasonal price variations in Taiwan.

Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Soybean	95.5	101.3	100.1	97.6	97.8	97.3	98.5	99.4	99.4	100.5	103.3	109.5
Scallion	95.5	73.2	67.5	61.5	68.5	93.9	109.8	147.2	134.4	128.7	110.1	109.4
Chinese cabbage	52.5	46.3	64.1	55.4	83.8	140.1	127.9	216.5	151.8	87.3	85.4	89.5
Tomato	52.4	39.1	49.7	53.1	48.6	89.6	109.0	223.4	191.7	177.3	89.9	67.2
Green pepper	55.5	62.3	72.1	82.8	72.8	84.5	120.4	192.0	170.6	138.6	87.2	65.5

Note: 3-year average, 1980-82

Table 7. Comparison of soybean yields in Taiwan, 1981.

	Yields (t/ha)
Winter crop	1.7
1st crop	1.5
2nd crop	1.2

Source: Anon. (1982b)

Conclusions

The prospects for soybean production in Taiwan, Japan, and Korea are poor considering recent decreases in production and strong price supports for other crops. The ratio of the farm household sale price to the imported price (1981) in Taiwan, Japan, and Korea was 1.7, 3.7, and 3.1, respectively. This was primarily due to differences in production costs. For example, the production cost for 10 kg of soybean in the USA (1979) was estimated at US $1.34 (Pan 1980) compared with US $3.82 in Taiwan, and US $12.78 in Japan. A dramatic increase in soybean production in the region is therefore unlikely.

However, as long as there are idle resources that can be used for soybean production, and socio-economic factors that favor production, we should try to encourage soybean farming. Demand is increasing rapidly and the nutritional productivity per unit area of soybean is high. Considering the tendency towards decreased land utilization, which is one of the major constraints in increasing food production in the region, we should provide incentives for increasing production.

Productivity Increases

As mentioned, farmers tend to choose crops on the basis of potential earnings. Therefore, adequate incentives should be provided to increase production. Most governments in the region have already established strong price supports for soybean. A study of the response in soybean cultivation area to prices (Anon. 1983a) revealed that soybean's elasticity is only 0.34.

$$\log S'_{Bt} = \underset{(1.12)}{\log 0.23} - \underset{(0.15)}{0.25 \log X_1} + \underset{(0.08)}{0.34 \log X_2} + \underset{(0.03)}{1.33 \log X_3} - \underset{(0.03)}{0.05 \log X_4}$$

$R^2 = 0.979$; D-W ratio = 2.78

S_{B+} : soybean cultivation area at t year
X_1 : soybean cultivation area at t-1 year
X_2 : real soybean price at t-1 year (farm sale price)
X_3 : number of rural population at t-1 year
X_4 : amount of imported soybeans at t-1 year

Therefore, we should not expect a dramatic increase in soybean production as a result of price supports. Rather, effort should concentrate on increasing productivity. There are large differences between average regional yields and those of individual farm households. The development of high yielding cultivars and advanced technology should therefore be encouraged.

Research and Extension

To improve productivity, research and extension should be strengthened. The development of early maturing cultivars should be stressed because of the overlap of the soybean production period with those of other crops. The period available for soybean is short, and early maturity is desirable.

Labor Savings

Labor saving technology should be adopted. Farm mechanization for sowing and harvesting is badly needed. Group or cooperative farming should be encouraged to promote farm mechanization. Farms in the same village or region should adopt uniform soybean cultivation systems. This will provide farmers with marketing advantages as a result of increased production volume.

Price Incentives

The guaranteed price of soybean should be maintained or improved. The price elasticity in the Korean study was estimated at about 0.34. This means that if the real price of soybean was increased by 10%, the soybean cultivation area in Korea would increase by about 3.4%. Where farming is more extensive, price incentives will bring about even better results.

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Section VIII
Related Topics

Improved Soybean Cultivars in Tanzania

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Introduction

As early as 1955, soybean (Glycine max) was recognized in Tanzania as a useful crop. Although its full potential has yet to be realized (Ayiseni 1982), soybean is becoming increasingly attractive to farmers because of price incentives and improvements in the country's marketing system (Makena and Doto 1982).

Auckland (1970) noted that production is limited in Tanzania largely by a lack of adapted cultivars. Breeding work first began in the 1950s in the southern part of the country (Nachingwea) (Auckland 1966). Initial objectives were to produce 1) high yielding, non-shattering, lodging resistant cultivars suitable for mechanical harvesting, and 2) high yielding, non-shattering indeterminate lines that could be picked by hand. This program, which was concluded in 1963, was responsible for the development of several improved cultivars, including IH/192 - Tanzania's standard line - and 3H/1, 3H/101, and 7H/149/1.

In the years that followed, other research stations (Ilonga, Tengeru, and Morogoro) concentrated on evaluating the Nachingwea material and foreign germplasm imported mainly by INTSOY.

At Morogoro, a number of cultivars were evaluated either as monocrops or intercrops with cereals (Finlay 1975 and 1976, Semu and Jana 1975, Makena and Doto 1982). These studies showed that soybean cultivars developed under sole-crop conditions may not be suitable for intercropping (Finlay, 1976 and Makena and Doto 1982).

Since 1979, soybean research has also been conducted at the Morogoro Faculty of Agriculture, Forestry, and Veterinary Science. Current efforts are directed at identifying cultivars that combine the following features: High yield potential and the ability to nodulate with indigenous rhizobia (see Dashiell et al., eds), early to medium maturity with first pod height 13 cm above ground level, and high levels of disease and insect resistance.

The results of four experiments conducted at Morogoro are summarized below.

Materials and Methods

Experiment 1

Eleven soybean cultivars were evaluated at two planting dates (17 March and 1 April, 1982), with and without fertilizer (Ayiseni, 1982).

Experiment 2

The performance of 11 soybean cultivars was studied at four planting dates beginning at weekly intervals from 19 March, 1982 (Ayiseni 1982).

Experiment 3

Ten cultivars were evaluated in a randomized block design with four replications (Mkassa 1982). The materials were sown on 29 March, 1982.

Rows were spaced 60 cm apart in experiments 1, 2, and 3; within row spacing was 15 cm for experiments 1 and 2, and 10 cm for experiment 3. Fertilizer was applied before planting in all experiments (30 kg N/ha and 25 kg P/ha), except in the no-fertilizer plots in experiment 1.

Experiment 4

Forty-six F_6 lines (IH/192 x Bossier) that were thought to be capable of nodulating with indigenous rhizobia were grown from March to June 1982 in three non-replicated, double-rows. The performance of the F_6 lines was compared with those of their parents: IH/192 for high yield and promiscuous nodulation and Bossier for high yield and early maturity.

Rows were spaced 60 cm apart; within row spacing was 10 cm. Fertilizer (25 kg P/ha) was applied prior to sowing. Data were collected on yield per plant, plant height, N fixation, and protein and oil content.

Experiments 1, 2, and 3 were subjected to analysis of variance; experiment 4 was not.

Results and Discussion

Highly significant differences were observed between cultivars for both harvest index and grain yield in experiments 1 and 2 (Table 1). Variation in sowing date and fertilizer application rate had a significant effect on harvest index and grain yield. However, cultivar x sowing date and cultivar x fertilizer interactions were not significant. It may therefore be possible to carry out evaluation and selection work during the rainy season.

In experiments 1 and 2 the highest harvest indices were obtained from Orba, a line which also produced excellent yields in experiment 3 (Table 2). Cultivars Bossier and IH/192 performed poorly in the three experiments.

Caribe and Orba were also found to be superior in previous experiments at Morogoro (Makena and Doto 1982). While these cultivars may prove useful in and around Morogoro, there are indications that lines such as $L_{10}R_2P_2$ have greater yield potential and superior agronomic characteristics (Table 3). Lines $L_{13}R_2P_3$ and $L_{16}R_2P_1$ were found to have excellent nodulation and N activity.

Table 1. Mean squares for harvest index and yield/plant, experiments 1 and (2).

Source of Variation	d.f.	Harvest Index (M.S.)	Yield/Plant (M.S.)
Cultivar (C)	10	0.09***	69.1***
	(10)	(0.04***)	(127.9***)
Sowing dates (S)	1	0.09***	1027.3***
	(3)	(0.53**)	507.2***
Fertilizer (F)	1	0.03*	86.0*
C x S	10	0.007	34.4
	30	(0.005)	(17.3)
V x F	10	0.005	33.4
Error	129	0.005	21.4
	(85)[z]	(0.004)	(20.9)

[z]One d.f. less for missing plot

Future plans call for the testing of all Bossier x IH/192 crosses (F_7 and F_8) and other promising selections as monocrops and intercrops with cereals.

Table 2. Mean varietal harvest index and grain yield/plant, experiments 1, 2, and 3.

Cultivar	Harvest Index		Yield/Plant (g)		
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 3
Orba	0.47	0.46	17.9	17.2	10.3
TGM249-4-6	0.46	0.40	15.1	10.3	9.7
Bossier	0.46	0.40	13.3	8.4	11.2
245-4-OTRS	0.44	0.42	14.0	10.7	6.9
Calland	0.44	0.40	13.1	11.1	-
Tunia	0.43	0.40	15.9	15.1	11.4
Tracy	0.42	0.41	13.5	11.2	9.8
HardeeL.S.	0.40	0.35	17.9	15.9	11.2
Caribe	0.34	0.46	13.9	18.6	12.3
CS90	0.28	-	11.2	-	8.7
IH/192	0.25	0.26	13.2	14.8	-
Improved Pelican	-	0.42	-	12.1	-
CH-3	-	-	-	-	9.5

Table 3. Characteristics of selected F_6 lines and parents.

Line	Yield (g/plant)	Height (cm)	Total ARA[z] µmole/plant/hr	µMole C_2H_4 per g nodule	Protein (%)	Oil (%)
$L_{10}R_2P_2$	31.7	58.3	4.4	6.9	32.8	19.4
$L_5R_3P_1$	29.6	63.3	0.0	0.0	32.8	20.8
$L_{16}R_2P_1$	27.8	65.0	4.5	129.8	32.8	20.6
$L_{10}R_3P_2$	26.9	59.0	2.1	18.4	26.3	21.3
$L_{16}R_2P_1$	26.0	74.0	3.0	357.8	-	-
$L_1R_3P_2$	25.9	57.8	0.2	29.7	32.8	21.0
$L_{13}R_2P_3$	25.8	56.0	4.0	32.9	35.0	21.9
$L_{15}R_1P_1$	25.5	58.5	0.0	0.0	37.2	20.2
$L_3R_3P_1$	25.3	52.4	0.0	0.0	26.3	21.1
$L_3R_2P_2$	24.6	51.5	0.0	0.0	32.8	21.3
Bossier	21.9	44.3	0.1	7.3	35.0	22.0
IH/192	19.2	88.0	1.2	16.9	39.4	20.8

[z]Acetylene reduction activity

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Soybean in Burkina Faso — Agronomic Studies and Development Prospects

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Environmental Conditions

General

Burkina Faso (formerly Upper Volta) lies in the central part of Sahelian Africa. It is a flat country with a surface area of 274,000 km^2. Ninety percent of its 6,500,000 inhabitants live in scattered rural areas. The country's soils are fairly well-drained, particularly in the south. Water availability is seasonal.

Soils

Half of the surface area of the country is covered by sandy, lateritic soils that are low in calcium and phosphorus. The best land is composed of brown, eutrophic soils, but these are rare. There are also scattered patches of high-mineral vertisols that can be farmed with mechanized equipment.

Apart from a few strips of hydromorphic soil that border the main rivers, the remaining third of the country is covered with raw mineral soils, halomorphic soils, and immature eroded soils, most of which are unsuitable for agriculture.

Climate

There is a distinct dry season (mid-November to mid-April) and rainy season (mid-June to mid-September). Maximum rainfall takes place in August. Average precipitation varies from 1,200 mm (80 to 90 days) in the southwest to less than 500 mm (40 to 50 days) in the northeast.

Temperatures are low in the dry season (17 to 34°C) and in the middle of the rainy season, and peak just before and after the rainy season (39°C). Diurnal temperature variation is high during the dry season and somewhat lower during the rainy season.

Soybean Research

The IRHO introduced the country's first soybean cultivars in 1958 in an attempt to diversify traditional cropping patterns. Experiments were established at two research stations - one in the central part of the country (Saria, rainfall 800 mm) and one in the Southwest (Niangoloko, rainfall 1,200 mm).

Varietal Adaptation

Only three cultivars produced consistent yields of more than 1 t/ha. (Ilini, Santa Maria, and CES 1486). Ilini, which was introduced from Portugal, proved to be the best cultivar for the central zone, and Santa Maria (Venezuela) and CES 486 (Ivory Coast) were found to be suitable for the southern zone.

Other cultivars have since been introduced, and a collection of some 200 lines is being maintained. Several lines have shown good potential (>2.5 t/ha), and many are suited to mechanical harvesting. However, most of these materials, e.g. Jupiter, Alamo, and UFV 1, have poor germination rates (Table 1). For this reason, many of the cultivars first introduced in 1958 are still being recommended to farmers. While their yield potential is low, the seed stores well during the dry season, and shattering is not a problem if manual harvesting is used.

Cultivation

The influence of sowing date was studied in the central and the southern regions. Trial results showed that sowing should take place at the end of June in both areas.

Trials have also indicated that reducing the spacings between rows is preferable to growing the plants closer together within rows. The optimal distance between rows is 50 to 60 cm or 300,000 plants/ha (Table 2).

Table 1. Yield and germination of selected cultivars (INTSOY trial, Saria 1981)

Cultivar	Yield (t/ha)	% Germination 2 Months After Harvest
Illini (control)	1.2	93.5
Ecuador	1.6	40.0
Williams 79	1.6	48.5
UF V1	1.9*	29.3
Alamo	1.0	70.5
Foster	2.0*	60.5
Jupiter	2.2**	32.8
Bossier	1.5	51.5

*significantly different from the control at 0.05%
**significantly different from the control at 0.01%

Table 2. Plant population density and spacing trial, Sourou, 1982 (cv. Alamo)

Plant Population	Interrow Spacing	Within Row Spacing	Yield (t/ha)
200,000	57	9	2.4 b[z]
200,000	80	6	2.3 c
260,000	57	7	2.6 a
260,000	80	5	1.9 c
320,000	57	5	1.9 c
320,000	80	4	2.1 d

[z]Figures followed by a different letter are significantly different at 0.05%.

Fertilizer and Nutrition

Fertilizer experiments showed a strong response to nitrogen and phosphorus. Potassium had no effect on soybean. The economic threshold is between 50 and 60 kg/ha for nitrogen and 30 kg/ha for phosphorus (Table 3). Split applications of nitrogen did not improve yields.

Many inoculant strains have been tested, particularly those from the French National Institute for Agronomic Research. Natural strains exist but they are

not competitive with those introduced by means of artificial inoculation. Although inoculation is generally successful, water stress seems to interfere with N fixation.

Among the various products tested, Lipha and Nitragin proved to be the most effective. Significant yield increases were recorded in the inoculated treatments (Table 4).

Table 3. Results of fertilizer NP trial (kg/ha) at Banfora, 1977.

N	P			N Mean
	0	22	44	
0	1.0	2.0	2.2	1.7
40	2.1	2.4	2.4	2.3**
80	2.4	2.3	2.4	2.3**
P mean	1.8	2.2**	2.3**	

**significant at the 0.01% level

Table 4. Effect of inoculation on leaf N and soybean yield, Banfora, 1978 (Nitragin inoculum)

kg N/ha	%Leaf N	
	uninoculated	inoculated
20	3.128	3.771
60	3.202	3.975
100	3.500	4.315
Mean	3.277	4.020**
	mean yield t/ha	
	1.6	2.7**

Diseases and Insects

Soybean diseases are minor problems. The following diseases have been recorded:

Cercospora leaf spot is the most common soybean disease.

Yellow mosaic (BYMV) was observed in 1977 on Forrest (probably seed-borne), but has not reappeared.

Rust, Phakopsora pachyrhizi, was observed in one collection in 1980, but only on cultivars of Chinese origin.

The insect pests observed to date are leaf-eating caterpillars and green pod-sucking bugs. Nematodes are a problem in the south (Meloidogyne spp. and Asphamatylenchus strauturatus).

Extension and Development

General

The majority of arable land is planted to millet (Eleusine coracana) and sorghum (Sorghum vulgare). Most holdings are small, and commercial crops do not

occupy more than a quarter of all cultivated land; cotton (Gossypium hirsutum) is the main cash crop. Groundnut (Arachis hypogaea) was once an export crop, but is now limited to local consumption because of low prices, marketing policies, and the lack of extension.

The country has a deficit in cereals and fats; annual imports total about US $15 million. Some 5,000 t of donated soybean oil is also imported each year.

Introduction in Rural Areas

In the 1970s, following the successful extension of improved groundnut cultivars to small farmers in the vicinity of research stations, a similar attempt was made to popularize soybean.

Care was taken to limit the area grown by each farmer according to labor availability so that pod shattering problems could be avoided at harvest. Average yields were 1.0 to 1.5 t/ha.

The crop was gradually accepted by small landholders. "Nere" seeds (Parkia biglobosa) are used for making a fermented condiment known as "soumbala." The soybean cultivars that were distributed (black seed coats) looked much like nere, and could be prepared in the same way. This culinary use has become widespread, and some families prefer soybean to nere. The black seed coat is no longer a reason for preference; cream-colored seeds are equally acceptable.

Constraints

In 1975, the Regional Development Organization (RDO) in the eastern part of the country attempted to promote soybean. The RDO's intention was to train the farmers and then purchase their crops.

A total of 4.5 t of seed were distributed in 1976 and 25 t in 1977. The RDO, however, did not concern itself with the sale of the product, and in 1977 found that the farmers had produced about 200 t, most of which RDO could not purchase. The experiment was, of course, a disaster, and the following year soybean production dropped dramatically.

Farmers have no particular objections to soybean, since it presents no basic agronomic problems, but marketing is a major problem.

Taking into account the price of other crops, the price of soybean should be US $0.20/kg. Burkina Faso has an oil mill (capacity 45,000 t) which is mainly used for extracting cotton seed oil. The plant runs at only 50% of capacity, but it lacks equipment for soybean oil extraction. Although there would be no trouble finding a local market for soybean oil, the same would not be true for soybean cake. While cattle raising is an important part of the economy, its nomadic characteristics rule out the use of soybean as a cattle feed.

Future Development

Recent events provide some hope for soybean production. A pilot soybean milk manufacturing unit with a capacity of 200 l/hr should be operational by 1984. A factory with much greater capacity will be built if the first plant is successful.

In addition, a hydroponic center is now operational. From 1984 onwards it will require 250 t of soybean for use as fish food.

Elsewhere, a valley development project should open up 41,000 ha of new land, 24,000 of which will be irrigated. This project provides for the cultivation of several major crops, including soybean.

A preliminary study project has been set up on 210 ha, and thus far the results have been encouraging. For agro-industrial sites, the best crop rotation has proven to be wheat (Triticum aestivum) and soybean, (4.5 t wheat/ha and 2.4 t soybeans/ha). Wheat is grown during the cool, dry season under irrigation; soybean is grown during the rainy season.

Another development project is working with sweet sorghum. This crop will almost certainly be rotated with soybean.

Conclusions

Although climatic conditions in Burkina Faso are far from excellent, experiments show that considerable improvement in soybean production is possible. Difficulties stem mainly from agricultural policies. Soybean cultivation presents no basic problems, and could be extended to large areas of the country.

Soybean in the Ivory Coast

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Introduction

The policy of the government of the Ivory Coast is to improve soybean (Glycine max) production so as to: 1) diversify food crop production in the country's savannah zone; 2) increase farm incomes; 3) stimulate the settlement of itinerant farmers; 4) achieve national self-sufficiency in protein foods; and 5) provide a stable source of high protein feed for livestock.

To encourage soybean production, government - in cooperation with Brazilian experts - established a soybean production plan in 1978. The plan called for the creation of four 2000-ha mechanized seed farms. The government has also taken the responsibility for soybean research, production, and processing, and plays a role in input supply.

Government policy emphasizes manual production practices so as not to displace farmers from their land. The soybean production area in 1980-82 exceeded 2,000 ha; average yields were about 1.5 t/ha. The official price of soybean is US $150/t.

Varietal Adaptation

Soybean production in the Ivory Coast is principally located in the savannah zone, an area subject to approximately 1,200 mm of rainfall per year, most of which falls during the June-October rainy season.

The Ivory Coast Soybean Project is responsible for introducing and adapting high yielding cultivars. Cooperative projects have been carried out with the International Institute of Tropical Agriculture, the International Soybean Project, EMBRAPA, and the Asian Vegetable Research and Development Center. Thus far a number of useful cultivars have been identified. Their characteristics include: early flowering and maturity, resistance to shattering, resistance or tolerance to foliar diseases, synchronous maturity, good seed quality, good seed storage characteristics, and high rates of symbiotic nitrogen fixation. One of the most promising cultivars, IAC 8 from Brazil, has a yield potential in excess of 3 t/ha. Our present soybean collection consists of some 260 cultivars divided into four categories: Early (91 to 100 days); semi-early (101 to 110 days, resistant to lodging and suitable for mechanical cultivation); medium maturing (111 to 120 days, susceptible to lodging and diseases); and late maturing (more than 120 days).

Management Practices

Present recommendations call for planting soybean from mid-June to early August; harvesting is carried out in October/November. The seed should be planted at a depth of 3 to 5 cm. Recommended spacing is 0.5 m between rows and 5.0 cm between plants (400,000 seeds/ha; 60 to 80 kg/ha). Fertilizer should be applied at the rate of 30 kg N/ha, 50 kg P_2O_5/ha (single superphosphate), and 60 kg K_2O/ha.

On local savannah soils (pH 5.5) Brazilian inoculant, "Turfal Special," was superior to sterilized inoculant, "Turfal Standard". Nodulation took place 15 days after sowing.

IITA cultivars that nodulate with indigenous rhizobia also show promise (see Dashiell et al., eds.). The best lines are TGx 306-036 D, TGx 328-49 D, TGx 304-017, TGx 304 030 D, TGx 309-050 D, and TGx 605-020 D.

The country's most important soybean insect pests are listed in Table 1. Most damage takes place during the pod-filling stage. Recommended insecticides include Lorsban, Endosulfan, and Decis.

The following diseases have been observed in the field: Cercospora sojina, Xanthomonas sojensis, Pseudomonas gylcinea, Pseudomonas tabaci, Peronospora manshurica, Cercospora kikuchii, soybean mosaic, and cowpea mosaic.

Major weeds include: Rottboellia exaltata, Euphorbia heterophylla, Digitaria horizontalis, Brachiaria lata, Brachiaria deflexa, Physalis angulata, Borreria scabra, Bidens pilosa, and Paspalum orbiculare. Recommended herbicides are trifluralin, metribuzin, bentazon, and butralin.

Seed Production and Viability

The loss of seed viability is the most significant soybean production problem in the Ivory Coast. Several IITA lines have been identified with seed germination rates of more than 80% after eight months of storage (warehouse conditions) (Table 2).

Table 1. Soybean insect pests in the Ivory Coast.

Lepidoptera	Hemiptera - Heteroptera
Plusia spp.	Riptortus dentipes
Heliothis spp.	Riptortus spp.
Spodoptera littoralis	Mirperus jaculus
Hedylepta spp.	Nezara viridula
Cydia ptychora	Nezara spp.
Plodia spp.	Acrosternum spp.
Ephestia cautella	Piezodorus guildinii
	Aspavia armigera
Hemiptera - Homoptera	Dysdercus superstituosus
Empoasca spp.	Anoplocnemis curvipes
Bemisia tabaci	Helopelthis spp.
Coleoptera	Orthoptera
Milabris spp.	Zonocerus variegatus
Diabrotica spp.	
Epilachna similis	
Lagria villosa	

Table 2. Germination rate of selected cultivars after eight months of storage.

Cultivar	% Germination
TGx 340-295 D	94
TGm 737 P	93
TGx 342-35I D	90
TGx 342-375 D	89
TGx 533-43 C	82
TGx 252-7I C	80
TGx 262-2 C	77
TGx 542-2 C	67
TGx 533-65 C	65
TGx 297-I92 C	64
IAC 8	56
Tropical	48
PS I	48
IAC 5	29
IAC 9	37
IAC 2	23
Bossier	18

Irrigated Soybean Production in Egypt

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Introduction

Commercial soybean (Glycine max) production in Egypt began in the early 1970s. From 1979 to 1983 the production area increased from 1,200 ha to 64,000 ha, and average yields more than doubled (Table 1). A recent study by Quenemoen et al. (1981) showed that a soybean-berseem clover (Trifolium alexandrinum) annual rotation was US $850/ha more profitable than a comparable cotton (Gossypium barbadense) -clover system. Other studies have shown that net returns from soybean-berseem clover rotations compare favorably with traditional summer corn (Zea mays) rotations (Azziz et al. 1981).

Local soybean production meets only 30 to 40% of the country's requirements for oil and poultry feed. Government planners are promoting soybean production, and are calling for a 40% increase in the area under production by 1987.

Irrigated Soybean Management

Nearly all Egyptian soybean production takes place in the Delta and Middle Egypt regions (27 to 31°N). The crop is planted from mid-April until early May, and is harvested in late August or September. There is little, if any, rainfall during the cropping season. The Egyptian climate is remarkably consistent and varies little from year to year. During the summer cropping season average max/min temperatures range from 30 to 35/16 to 20°C in the Delta and from 33 to 30/16 to 20°C in Middle Egypt. The Delta region is under the Mediterranean influence and is more humid than Middle Egypt.

Soybean is grown in the Nile Valley on alluvial soils that range from heavy clays to medium textured clay loams. Seed beds are ridged at 60 to 75 cm interrow spacings to facilitate irrigation and drainage. Most farmers incorporate 35 kg P/ha before ridging; potassium is recommended in a few areas.

Two planting methods are used, depending upon the soil texture. To avoid poor stands on soils that are prone to crusting, farmers plant seven to ten days after the field has been irrigated, a period when soil moisture is conducive to germination. Hand hoes or dibble sticks are used to break up crusted soil. On dry soils, farmers sow directly (as described above), and irrigate immediately after planting. Seeds are planted on hills in both systems in the upper third of the ridge (80 to 95 kg seed/ha).

A plant density of 330,000/ha is recommended, but most farmers space hills 10 to 15 cm apart, sow three to five seeds per hill, and then thin to one or two plants per hill. Plant populations are usually 50 to 60% of the recommended density.

Rhizobium japonicum is not present in Egyptian soils, and inoculation is not practiced. Instead, recommendations call for N fertilizer at a rate of 180 kg N/ha in three equal split top dressings, but most farmers use even higher rates. A survey conducted in the Menia Governorate in 1982 showed that most farmers apply 215 to 300 kg N/ha (personal communication, R. Deuson).

Irrigation water is available throughout the growing season. Light irrigation is recommended seven to ten days after planting, followed by irrigation in 14- to 20-day cycles. Weeds are mostly controlled by hand. Although effective herbicides have been identified, and could be made available, farmers are not familiar with calibrated application methods, and they lack access to power sprayers.

The cotton leaf worm (Spodoptera littoralis) and the common red spider mite (Tetranychus telarius) cause economic losses. Effective insecticides are available for both pests, and farmers are well versed in their use. Insect pest populations are high in June and July, and control is difficult when local cultivars are sown later than early May. Soybean diseases do not cause economic losses.

The plants are cut or pulled from the ground at maturity, and are placed in bunches to dry. Motorized threshers are used by most farmers after four to seven days of drying.

Major Production Constraints and Research/Extension Efforts

Nodulation and Nitrogen Fixation

Inoculum use has been hindered by inconsistent trial results on farmers' fields and by the government's policy of subsidizing N fertilizer at about half the world market price.

Hamdi et al. (1981) reviewed the attempts made to achieve consistent nodulation with field-grown soybean. Both imported inocula (Nitragin and Legume-Aid) and inocula produced with locally available carriers proved ineffective.

The number of viable Rhizobium in the inocula was rarely measured during this 8-year program, which makes it difficult to accurately interpret the results. High soil temperature, soil desiccation in the seed zone, seed coat diffusates toxic to Rhizobium, low viability counts, and improper inoculation techniques have been proposed as possible causes for failure.

When nodulation was achieved in field experiments at the Agricultural Research Extension Centers, yields in the inoculated treatments were often double those of the uninoculated plants and equivalent to the yields obtained at high N application rates (Table 2 and 3). The experiments were conducted on soils representative of those found in soybean producing areas; an estimate of the potential N input from N_2 fixation can be calculated from the data presented in Table 3. Because there were no significant differences in yield or total N accumulation among cultivars in the inoculated treatments, and because no strain x cultivar interaction was observed, the pooled mean for the four inoculation treatments can be used as an estimate of total plant N accumulation by an effectively nodulated soybean plant. By subtracting the N accumulation found in the uninoculated plant without N fertilizer, an estimated 210 kg N/ha was derived from N_2 fixation, or about 60% of total plant N. Theoretically, when an N fertilizer use efficiency of 80% (albeit high) is found in an uninoculated treatment which received 145 kg N/ha, the comparable N fertilizer rate required to obtain an equivalent yield would be 260 kg N/ha.

Table 1. Soybean production in Egypt, 1972-1982.

Year	Area Planted (ha)	Yield (t/ha)	Total Production (t)
1972	1190	1.1	1,356
1973	2630	0.9	2,500
1974	1820	1.1	2,070
1975	3570	1.3	4,820
1976	7120	1.6	11,410
1977	13910	1.9	26,450
1978	34320	2.3	78,850
1979	42180	2.5	106,000
1980	34760	2.6	92,460
1981	45960	2.8	130,500
1982	64260	2.6	169,800

Source: Department of Statistics, Ministry of Agriculture, Cairo

Table 2. Mean yield of cultivars Calland, Forrest, and Ransom as affected by inoculation and N fertilizer rate in the field[z].

N Rate (kg/ha)	Seed Yield (t/ha)[z]	
	uninoculated	inoculated
0	1.9	4.0
70	2.8	4.0
140	3.6	4.0
210	3.9	4.0
LSD 0.05[y]	0.18	

[z] Data obtained from a field experiment with a split-split plot design with cultivars as mainplots, N levels as subplots, and inoculation as sub-subplots. Means shown represent the composite mean for all three cultivars (Bahteem Research Station, 1980)

[y] Used for comparing N subplot treatments within inoculation treatments

Table 3. Mean yield and total plant N accumulation of cultivars Clark, Calland, and Columbus as affected by inoculation and N fertilizer application in the field.

Treatment (subplots)	Seed Yield[z] (t/ha)	Total Plant N[z] (kg)
Uninoculated, No N	1.6	134
Uninoculated, 145 kg N/ha	3.4	252
Inoculated, strain 3407[y]	3.4	328
Inoculated, strain E-B	4.3	383
Inoculated, strain 2110	3.9	324
Inoculated, mixture of 3 strains	4.2	343
LSD 0.05[x]	0.72	70
CV (inoculation/N treatments)	21%	24%

[z] Data represent the composite means for three soybean cultivars tested in a field experiment with a split plot design conducted at the Giza ARC Research Station, Cairo, 1982. There were no significant differences among the three soybean cultivar main plots

[y] Strains supplied by Dr. M. N. Alaa El-Din, Head, Soil Microbiology Section, Agricultural Research Center, Giza

[x] Used for comparing differences among subplot treatments across all varietal main plot treatments

In 1983 summer season trials, well nodulated soybean was obtained in on-farm trials whenever the inoculum contained at least 10^7 viable Rhizobium at planting (personal communication, M. N. Alaa El-Din) (see comments by L. R. Fredrick in Plant Nutrition discussion, eds.).

Stand Establishment

Commercially available soybean cultivars have an average 100-seed weight of about 17 g. At the normal seeding rate (80 to 95 kg/ha), 33 to 39 seeds/m are sown at 70 cm interrow spacings. Where even stands are achieved in farmers' fields, final plant density averages seven to ten hills/m, with one or two plants/hill. Farmers thin the plants when necessary, and sometimes replant when emergence is poor. Skips of 25 to 40 cm are common in heavy clay soils, and weed control can be problematic.

A new approach is being used for soybean varietal testing at the Agricultural Research Extension Centers. In vitro germination tests are conducted on all seed lots before planting. Seeding rates are adjusted so that 28 viable seeds are sown per meter; plant population is measured in each replication 3 weeks after sowing. Data from trials conducted at four sites show significant varietal differences in emergence potential at each site; varietal performance across locations was consistent (Table 4). Seed size was not correlated with emergence. Edwards and Hartwig (1971), working with near isogenic lines, reported that small seed size improved germination in heavy clay soils. Others have also found that percent field emergence, i.e. the proportion of all seeds sown (both viable and dead) that emerge, was correlated with the percentage of in vitro germination (r=0.69**) (Sherf 1953). When only viable seed emergence was considered, there was no significant relationship with percent in vitro germination. This suggests that genotypic differences for emergence exist among the cultivars tested. The two commercial cultivars currently used in Egypt, Clark and Calland, had low emergence vigor in these trials.

If high yielding cultivars with good seed quality are selected, it should be possible to sow directly in dry, heavy clay soils. This would eliminate the need for the pre-sowing irrigation now used on crust-forming soils, reduce land preparation time by seven to ten days, and minimize weed problems.

Varietal Improvement

Intensive cropping systems are used on the prime agricultural soils of the Nile Valley. Land is rarely left fallow during the winter or summer seasons. Most farmers plant cotton once every three years (Table 5). Farmers in some governorates have recently been allowed to plant soybean in lieu of their cotton requirement, a policy which resulted in a rapid expansion of the soybean production area (Table 1). This policy is not being extended to new areas, however, and further increases must come at the expense of other summer crops, primarily maize, or by using an intensive cropping system in which a short duration soybean crop is planted before rice (Oryza sativa).

If planted in place of maize, soybean would be sown in June after wheat (Triticum aestivum) or long-season berseem clover. Only three cultivars - Clark, Calland, and Williams - are currently available to farmers, and these early maturing lines do not perform well when planted in June. They also have little resistance to leaf-feeding insects such as the cotton leaf worm. Insect control is both difficult and costly because the vegetative and flowering stages occur in late June and July when the cotton leaf worm population is at its peak. Later maturing cultivars with resistance to leaf-feeding insects would be useful for this cropping system niche.

Nine soybean lines identified as having resistance to leaf-feeding insects in Mississippi have been obtained from Dr. E. E. Hartwig. These lines are late maturing (US maturity groups V to VII). In trials planted in early July (1982), yields ranged from 3.6 to 4.2 t/ha - double the 1.9 t/ha produced by Clark (Table 6). In 1983, expanded trials with the same lines showed a wide range of resistance to cotton leaf worm. Standard cultivars such as Clark and Essex suffered 70 to 80% defoliation. In contrast, lines D79-10455, D79-10500, and D79-10540 had less than 30% defoliation.

An intensified cropping system in which soybean is planted in late March after berseem clover, and is harvested before the rice crop is transplanted in late June or early July, would require very early maturing cultivars. A large field experiment conducted in 1983 showed that yields in excess of 2 t/ha can be achieved with lines from maturity groups 00 and 0 (Table 7). Both McCall and Evans could be planted in late March and harvested in late June in time for rice

transplanting in the first week of July. It should be noted that the standard interrow spacing of 60 cm was used in this trial and that very early cultivars did not have fully closed canopies. With closer row spacing, yield potentials may be well above 2 t/ha.

Table 4. Differences in field emergence of 12 soybean cultivars from US maturity groups III and IV measured 3 weeks after seeding.

Cultivars	100-Seed Weight (g)	In Vitro Germination (%)	Actual Field[z] Emergence (%)	Viable Seed[z] Emergence (%)
Will	13.2	96	75	78
Kent	16.7	92	66	72
Crawford	13.4	94	65	68
Pella	18.0	97	64	66
Delmar	14.1	95	64	68
Mitchell	13.9	94	59	62
Desoto	18.4	93	56	60
Clark	17.0	79	52	66
Union	17.4	86	51	59
Cutler 71	13.8	95	50	53
Columbus	14.7	89	49	54
Calland	15.7	75	45	59
LSD 0.05			9	10
CV			11%	11%

[z] Means shown represent the composite mean obtained from four sites. A standard seeding rate of 28 viable seeds per meter was used based on percent in vitro germination. The number of seedlings from 10 m of a row was counted from each of the four replicates at each site. Actual field emergence (%) is the (number of seedlings/m)/(total seeds sown/m). Viable seed emergence % is the (number of seedlings/m)/(viable seeds/m) using in vitro germination % to obtain the number of viable seeds sown per meter

Table 5. Traditional three-year crop rotation pattern used on the Nile Valley soils[z].

	First Year	Second Year	Third Year
Winter	berseem (Nov)	wheat (Nov) or faba bean[y] (Nov) or berseem (Nov)	berseem (Nov) or wheat (Nov) or faba bean (Nov)
Summer	cotton (March) or soybean (April)	maize (June) or rice (June-July) or sorghum (June) or truck crops	Maize (June) or rice (June-July) or sorghum (June) or truck crops

[z] Month shown in parentheses indicates recommended planting date
[y] Vicia faba

Table 6. Percent seed damage by pod borer (Etiella zinckenella Tre.), yield, and days to maturity of 14 soybean cultivars/lines from a late planted[z] field trial at the Giza R/E center.

Cultivar	% Damaged Seed	Yield (t/ha)	Days to Maturity
D79-10455	32	4.1	131
D79-10500	29	3.8	120
Forrest	40	3.7	119
D79-10426	40	3.6	131
D79-10494	26	3.5	131
D79-10540	29	3.2	120
Bragg	42	3.1	131
D75-12035	19	3.1	110
D79-10158	24	2.9	119
D79-10520	30	2.9	131
Columbus	37	2.8	104
Tracy-M	37	2.7	120
D79-3749	30	1.9	131
Clark[y]	60	1.9	102
LSD 0.05	9	1.2	-

[z]Planted July 4, 1982
[y]One of three commercial cultivars presently used in Egypt

Table 7. Yield of very early and early soybean cultivars planted before rice in a triple-cropping system at the Sakha Research Center, 1983[z].

Cultivar	Maturity Group	Days to Maturity	Seed Yield (t/ha)
McCall	00	91	2.1
Evans	0	96	2.4
Hardin	I	104	1.8
Clark	IV	122	3.4
LSD 0.05			0.83
CV			18%

[z]Planted 10 April

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Soybean in Rice-Fallows in the Sunderbans

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Introduction

Indian soybean (Glycine max) research began in 1967 under the auspicies of the all India Co-ordinated Research Project on Soybean at Pantnagar Agricultural University. The Project now has five main centers and 12 sub-centers covering different agro-climatic regions.

The production of soybean cultivar Bragg began in 1968 in the states of Uttar Pradesh and Madhya Pradesh. Since then breeding and selection have led to the development of disease resistant, high yielding cultivars adapted to specific agro-climatic conditions. The soybean production area in 1982-83 was 900,000 ha, the largest part of which was located in Madhya Pradesh. The state was awarded a five-year, US $15 million project in 1981 in recognition of its success with soybean.

Soybean processing factories have stimulated production throughout Madhya Pradesh. Annual production capacity may reach 1.5 million t by 1986.

More than 80% of the defatted soymeal produced in India is exported to Southeast Asia, the Middle East, or Europe. The remainder is used by local industry, primarily for food processing. In 1980-81, the export value of defatted Indian soybean meal was more than US $35 million.

In the Tarai region of Uttar Pradesh, at the foothills of the Himalayas, many rice growers are switching to soybean because of the crop's lower input requirements and the absence of yellow mosaic virus, one of India's most serious soybean diseases. Several soybean-based food products are being sold in India. However their market price is beyond the reach of the urban and rural poor.

Slow progress in other states, including West Bengal, has been due to the fact that soybean competes with traditional crops, i.e. rice (Oryza sativa), corn (Zea mays), sorghum (Sorghum vulgare), pearl millet (Pennisetum glaucum), mungbean (Vigna radiata), blackgram (V. mungo), pigeon pea (Cajanus cajan), peanut (Arachis hypogaea), and sesame (Sesamum indicum).

The target for soybean hectarage during the Sixth (national) Plan Period, which ends in 1986, is 2.5 million ha. Of this figure, 1,032,000 ha are targeted for the United Provinces and Madhya Pradesh. Most of this land is left fallow during the southwest monsoon (July to September) so that it can absorb the rainfall needed to grow winter wheat (Triticum aestivum). Farmers are unlikely to grow soybean during this period, however, for fear that their wheat crop will suffer from moisture stress. In addition, farmers may feel that soybean yields are too low to produce adequate profits (Table 1).

As stated, soybean is presently grown during the southwest monsoon under rainfed conditions; it is also grown to a certain extent with supplementary irrigation in the Tarai region of Uttar Pradesh. The potential for growing early maturing, day-neutral cultivars as an unirrigated crop in rice-fallows in Orissa

and West Bengal, including the Sunderbans, has not been carefully considered by planners. In the coastal regions of West Bengal, the rice-fallow area is about 800,000 ha.

Soybean in West Bengal

Soybean has been grown in the Darjeeling hills of West Bengal for decades using black and yellow cultivars from Nepal and Tibet. Soybean cultivation was established in the plains and plateau regions of the state in 1970. The most popular cultivar is Soymax (yellow-seeded) from the Darjeeling hills. The composition of Soymax-processed flour and its energy values are shown in Table 2.

Since the 1970s, summer soybean cultivation in the plateau region of West Bengal has remained stagnant, primarily because the land is used for other crops. Nevertheless, demand from urban centers is growing because of the rising cost of animal protein. The present consumer price for soybean is US $0.65/kg, which is almost at a par with other legume crops. Rural people, however, are not familiar with soybean.

Soybean Trials in the Sunderbans

Rainfall, Temperature, and Humidity: Mean temperatures, relative humidity, and rainfall for Sagar Island (October to June) are presented in Table 3. The southwest monsoon begins in early June and ends in September or October. Rice is the only crop cultivated during the monsoon season.

Subsoil Water and Quality: Adequate data on subsoil water quality are not available. However, experiments conducted in the Sunderbans by the Indian Council of Agricultural Research has produced some data. Their results showed that the subsoil water table, following water drainage before the rice harvest in December, receded to 1.35 m below the ground level in January, and continued to recede in succeeding months. The conductivity values of subsoil water were 335 to 420 micromhos/cm from July to September and 463 to 1,200 micromhos/cm from October to June (Basak 1967). Salinity levels were within permissible limits (Anon. 1954). These values, however, do not apply to all parts of the Sunderbans; subsoil water with high salt concentrations are found in some locations after the monsoon.

Soils: Loams, silt loams, silty clay loams, clay loams, and silty clays are the principal soil types. In the post-monsoon period, cultivated soils (following rice) generally have normal salinity levels within and/or beyond the rooting depth of fall- or winter-sown seasonal crops, except in areas where internal drainage is restricted and where subsoil water salt content is high (Banerjee 1959 and Basak 1967). Soils are slightly acidic or slightly alkaline. Organic carbon and P contents are low, whereas available K levels are usually high.

Soybean Cultivar Trial: AVRDC soybean cultivars AGS 12 and G 2261 were tested in an unreplicated trial. Soil in the trial plot was clay loam. Fertilizer application totaled 19 kg P/ha (single superphosphate) and 18 kg N/ha (urea). Planting was carried out on December 27, 1982. Row spacing and spacing within rows was 30.5 cm and 15 cm, respectively. The crops were harvested 85 days after planting.

G 2261 produced 1.5 t/ha - approximately 30% more than AGS 12 (Table 4). In West Bengal, the average yields of oilseeds and pulses (1975-81) range from 0.3 to 0.5 t/ha.

Soil pH, Conductivity, Organic C, and Available PK: A composite sample made from soil collected at 0 to 30 cm in the trial plots was analyzed. Conductivity was

normal (Anon. 1954), but available K content was very high. As soybean does not tolerate salinity (Hollowel 1957), site selection for future trials is essential.

Farmers' Reaction: Farmers who visited the trial plots appeared to like the AVRDC cultivars because of their high yields, early maturity, low input requirements, and because they can grow them in rice fallows without irrigation. The farmers plan to conduct soybean trials next fall and winter (1984, eds.). Presumably their interest will grow as they learn how to grow soybean and become accustomed to it in their diet. Demonstrations on how to prepare soybean have already been held in schools, social clubs, and village markets.

Table 1. Area, production, and yield/ha of soybean in Madhya Pradesh and Uttar Pradesh.

Year	Area (,000 ha)		Production (000 t)		Yield (t/ha)	
	MP	UP	MP	UP	MP	UP
1978-79	233	69	232	60	0.9	0.9
1979-80	414	76	56	36	1.3	0.5
1980-81	450	132	300	100	0.7	0.8

MP: Madya Pradesh; UP: Uttar Pradesh

Table 2. The composition and energy value of Soymax-processed flour[z].

Moisture	Protein	Fat	Total Ash	Acid Insol. Ash	Carbo-hydrate	Caloric Value/100 g
9.2	47.4	17.0	5.4	0.6	21.0	426.6

[z]Expressed in percent
Source: Central Food and Nutrition Board

Table 3. Air temperature, relative humidity, rainfall, and number of rainy days, October to June, Sagar Island, Sunderbans.

Month	Daily Mean Air Temp. (C°)	Daily Mean Rel. Humidity (%)	Monthly Total Rainfall (mm)	Number Rainy Days
October	27.5	78.5	240.1	8.5
November	24.1	70.0	35.0	1.9
December	20.8	68.5	8.3	0.4
January	20.4	69.5	13.7	0.9
February	22.8	70.0	21.8	1.6
March	26.9	73.0	20.5	1.5
April	28.9	77.5	41.9	3.0
May	29.7	79.0	128.4	5.7
June	29.5	81.0	250.0	11.6

Source: Anon. (1966)

Table 4. Yield and 100-seed weight of AGS 12 and G 2261.

Cultivar	Yield (t/ha)	100-seed wt.
AGS 12	1.1	16.7
G 2261	1.5	14.8

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The FAO Soybean Development Programme

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FAO Soybean Projects

Country Projects

Soybean (Glycine max) is being introduced and tested in hundreds of FAO field projects in Africa, Asia, Europe, and Latin America. Under the auspices of the United Nations Development Programme (UNDP), and recently under FAO's Technical Cooperation Programme (TCP), the organization has assisted member governments in the form of small-, medium-, and large-scale projects.

Consultancies

Under FAO's "Regular Program," short-term consultancies have been commissioned to resolve technical problems, develop programs, and appraise the potential of and/or formulate suitable projects for soybean production and improvement.

Networks and Projects

One of FAO's objectives is to promote regional and sub-regional cooperation on soybean research. The organization's aim is to eventually work under the auspices of an institution or agency established for this purpose.

In 1976 FAO established a European cooperative soybean network in which 14 countries now voluntarily exchange information and data.

Five sub-regional food legume coordination programs were recently established for the Andean countries, the Rio de la Plata Basin countries, Central America, and the Caribbean Spanish- and English- speaking countries.

A regional project entitled "Technical Cooperation Among Developing Countries for Research and Development of Food Legumes in the Tropics and Sub-tropics of Asia" is underway. Soybean is one of its mandate crops.

Seed Exchange

Soybean cultivars obtained from a variety of sources are distributed to research technicians through the FAO Seed Exchange Laboratory. In 1983, 4,424 samples were distributed in 14 countries.

Training

Another FAO objective is to train agronomists and extension workers. FAO is collaborating with several national institutes, as well as INTSOY, in organizing national and regional training courses.

Workshops

FAO workshops promote regional cooperation, help to exploit genetic potential, and explore ways in which international organizations can help accelerate soybean research and production. FAO collaborated with INTSOY in organizing workshops for soybean breeders and agronomists in Latin America (1983) and in Asia (1984).

Meetings

FAO has collaborated with INTSOY and USAID in organizing two international conferences. One was held in Egypt in 1979 on the subject of irrigated soybean production in arid and semi-arid regions; the other was held in Sri Lanka in 1981 and focused on soybean seed quality and stand establishment.

Information

The collection and dissemination of information concerning new developments in crop production and improvement is one part of FAO's central assistance role. This function is carried out through the preparation of technical publications, reports, and other information materials. Some of the most recent publications and reports on soybean include: Soybean Production in the Tropics, 1982; Potential for Soybean Production in the Sudan, 1982; Soybean Production Development in Vietnam, 1982; Soybean Development in Mozambique, 1982; and Soybean Breeding for Selected Tropical Asian Countries (Indonesia, Malaysia, Philippines, Thailand), 1979.

Assistance

FAO anticipates that this symposium will develop practical recommendations and suggestions for the development of soybean in the tropics and sub-tropics. FAO will cooperate with governments to implement the symposium's recommendations to the extent that its resources permit. The services of FAO's Seed Exchange Laboratory are available to interested researchers, and our training program is available to research technicians. FAO can also help to identify and formulate projects suited to international funding.

Discussion Section VIII

Question: What is the millet that you refer to, and what is the effect of growing tall sorghum along with soybean?

Doto: The millet is finger millet, Eleusine coracana. Soybean yield is reduced to 30% when it is grown as an intercrop with tall sorghum.

Question: What is the temperature during the soybean harvest in the Ivory Coast.

Roger: 23° maximum at time of harvest.

Question: What is the particular nitrogen fixation problem in Egypt which you want to tackle?

Nassib: There is no R. japonicum in the soybean area in Egypt.

Carangal: Dr. Dutt and Dr. Chai mentioned that in order to grow an additional crop of soybean, the soybean cultivar should be early maturing. There are some early maturing cultivars available for you to test. You can obtain seeds of these cultivars from Dr. Sumarno in Indonesia and from Dr. Sundar at AVRDC. These cultivars mature in 70 days and looks very promising in terms of yield. Results from our trials in India, Indonesia, and the Philippines suggest that the early maturing cultivars fit well in local cropping systems.

Question: I am from a private company in Tamil Nadu, South India. We have proposals to set up processing plant for soybean, and we are promoting and developing 90,000 ha for soybean cultivation in our state. For that we are establishing a research and development center for soybean production and for processing. What sort of technical assistance can we get from FAO?

Al-Jibouri: Any technical assistance request has to be channeled through the government of India to FAO. If the Government of India would put priority on your work and supports you, then FAO would consider that. But we do not provide support to the private sector. We can consider support for international research centers or an agency which has an agreement with FAO. This is the constitution of FAO, and we have to live with it.

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