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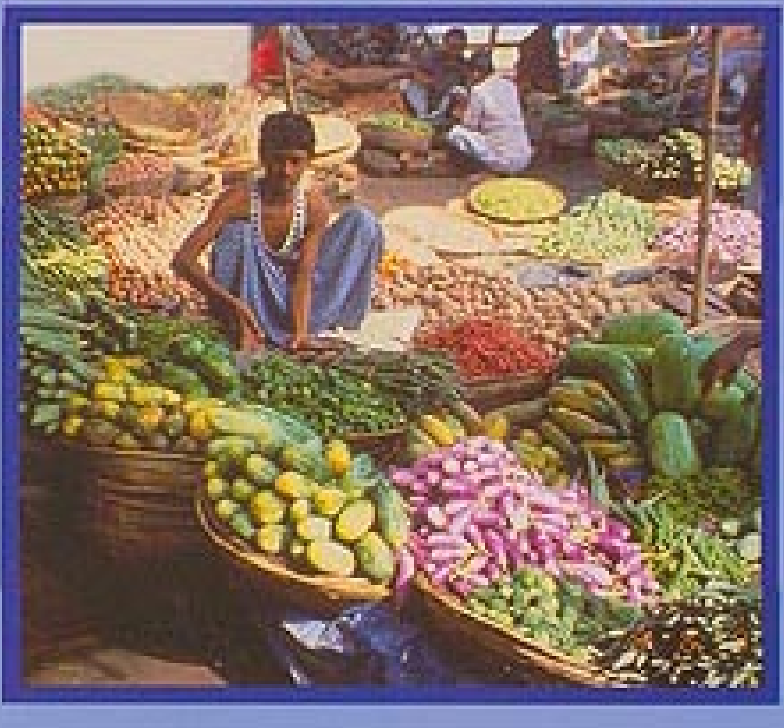
Vegetables in Bangladesh:

Economic and Nutritional Impact of New Varieties and Technologies



Mubarik Ali
Vu Thi Bich Hau

Asian Vegetable Research and Development Center (AVRDC)
United States Agency for International Development (USAID)
Bangladesh Agriculture Research Institute (BARI)

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Mubarik Ali
Agricultural Economist, AVRDC, Shanhua, Tainan, Taiwan

Vu Thi Bich Hau
Research Assistant, Agricultural Genetic Institute, Hanoi, Vietnam

Cosponsors:
Asian Vegetable Research and Development Center (AVRDC)
United States Agency for International Development (USAID)
Bangladesh Agriculture Research Institute (BARI)

P.O. Box 42, Shanhua, Tainan, Taiwan 741

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Fact Sheet

	With adoption	Without adoption	Change (%)
Growth in production (%)	3.12	1.83	70
Growth in area (%)	1.82	1.13	61
Growth in yield (%)	1.30	0.70	86
Share of summer vegetables in total production (%)	28	25	11
Per ha inputs use on vegetables			
Fertilizer (kg of nutrient)	279	211	32
Pesticide (no. of sprays)	3.5	4.5	-22
Irrigation (no.)	3.6	2.8	29
Labor (days)	353	341	4
Yield of vegetables (t/ha)	12.5	9.0	38
Cost of production of vegetables (BTK/ha)	37853	33549	13
Land use efficiency (Net return in BTK/ha)	36775	22223	65
Labor use efficiency (Labor earning in BTK/ha)	160.4	114.6	40
Water use efficiency (BTK/BTK irrigation cost)	29	26	12
Output efficiency (unit production cost, BTK/kg)	3.3	4.1	-20
Rate of return on investment for adoption (%)	241	-	
Off-farm income (BTK/month/family)	670	577	16
Farm cash income (BTK/family)	1743	1611	8
Cash income from vegetables (BTK/family)	704	434	62
Rate of return on investment for technology innovation (%)	42	-	
Total surplus generated from technological innovation (US$ million)	8.8	-	
Consumers' share in surplus (%)	52	-	
Producers' surplus (%)	48	-	
Vegetable consumption (g/capita/day)	201	159	26
Farmers having home garden (%)	62	56	11
Source of vegetable consumed (%)			
Home produced	37	32	16
Purchased	35	46	-22
Home garden	28	22	27
Nutrient availability			
Iron (mg)	14.4	12.4	16
Vitamin A (mg)	3271	2133	53
Vitamin C (mg)	73.5	60.2	22

Note: 50BTK=US$1 (2000).

Executive Summary

Study background

Vegetable production in Bangladesh is characterized by low yields and seasonal availability, which lead to low per capita availability and widespread micronutrient deficiency. On the consumption side, vegetables are not a very strong component of diet. To overcome production constraints, improved production technologies and high-yielding varieties were introduced through an AVRDC/USAID/BARI project during 1991-2000. To achieve this objective, the project employed strategies of distributing germplasm, building national research capacity, and testing, adapting, and promoting new technologies to farmers. High-yielding and nutrient-rich varieties of major vegetable crops, and crop protection technologies such as raised bed, hormones, grafting of tomato with eggplant rootstock, integrated crop management practices, and home garden models were introduced to farmers. To highlight the role of vegetables in health, consumers' awareness and training programs were arranged. This study quantifies the impact of the project on farmers' income and nutrient availability, and estimates the economic viability of the investment made on vegetable research and development.

A combined farm production and household consumption survey was carried out to understand the technological changes in vegetable production and induced changes in consumption patterns, and to measure the impact of the project. The survey was done in the Savar, Jassore, Rangpur, and Noakhali districts of Bangladesh. The farming population in these districts was divided into three groups, depending on the types of crops grown and technology adopted on vegetable crops during 1999. The groups were:

- *Adopters* (those who adopted AVRDC-promoted technologies in some of the vegetable crops);
- *Non-adopters* (those who did not adopt AVRDC technologies in any of the vegetable crops); and
- *Non-vegetable farmers* (those who did not grow vegetables on a commercial scale).

To estimate the consumption patterns for the whole of Bangladesh, samples of randomly selected urban dwellers from the city center of each sample district were also included.

The production survey covered farmer characteristics (the socioeconomic status of the farm household), crops grown during 1999, input, output, and prices of major vegetable and non-vegetable crops, as well as information on the adoption of new vegetable technologies. Adopters were asked about production details of those crops grown before the newly adopted varieties.

The consumption part of the survey covered the quantities, prices, and sources of all food commodities consumed during the previous 24 hours. Information was recorded on home gardens and the contribution of home gardens to overall consumption.

The difference in various production-related parameters between adopter farms "after" and "before" adoption was defined as total effect of technological innovation. Total effect was split into two categories: spillover and unexploited. The difference between parameters at the adopter farms before adoption and non-adopters farms during the survey years (i.e., without adoption) was defined as spillover effect, and the difference between adopters and non-adopters (both during the survey year, i.e., after adoption for adopters and without adoption for non-adopters) as unexploited effect. If data on some parameters were missing on before adoption, differences between non-adopters and non-vegetable farmers were considered as the effect of vegetable cultivation, and differences between adopters and non-adopters as technology effect.

Production and price trends

The trend of vegetable production in Bangladesh was estimated for 1973-90 (pre-innovation period) and 1991-99 (innovation period), using secondary data from the Bureau of Agricultural Statistics. This analysis suggests that there was a remarkable increase in vegetable production during the innovation period. Total vegetable production (including chili, onion and garlic, but excluding potato) increased from 1.3 million tons in 1991 to 1.8 million tons in 1999, a 38% increase. The area under vegetables increased about 17% from 296,000 to 346,000 ha during the same period. Yields increased more than 10%, from 4.6 to 5.1 tons/ha. The annual growth in production almost doubled, from 1.8% during the pre-innovation period to 3.1% during the innovation period. This was the first time a noticeable increase in per capita availability of farm-produced vegetables (18%) was achieved, from 34 g in 1990 to 40 g in 1999. This does not include vegetable supplies from home gardens.

Analysis of nominal farmgate vegetable prices suggests that they became almost stagnant during the last four years, compared to a gradual increase in the pre-innovation period. Moreover, the share of kharif (or summer season) vegetables in total production increased from 25% in 1991 to 28% in 1998, suggesting reduced seasonality.

Socioeconomic characteristics of farm households

Adopter and non-adopter vegetable farmers and their family members have higher levels of education than non-vegetable farmers, although the difference in education between adopters and non-adopters is not significant. Vegetable farmers received more agricultural production training, mainly from non-governmental organizations (NGOs) under the auspices of AVRDC, than non-adopters and non-vegetable farmers. The latter two groups mainly participated in training organized by extension staff of the Bangladesh Ministry of Agriculture.

No significant difference between adopters and non-adopters could be identified for most socioeconomic characteristics (e.g., availability of land and labor resources, soils and land types, education). This could reflect our success in selecting adopters who are typical vegetable farmers. However, both groups have smaller farms, more family labor available for farming, and higher education and vegetable-growing experience than non-vegetable farmers.

Crop schedule and seasonality

Summer vegetables grown on the non-adopter farms generally gave lower yields than the winter season crops. However, the opposite was true on the adopter farms. Comparing the schedule of different vegetable crops across farmer groups suggests that adopters of new technologies have shifted the cultivation of tomato, beans, and leafy vegetables toward the summer season, while heading cole has been shifted more toward winter. More effort is required to shift vegetable cultivation toward the summer season for most crops to overcome seasonality in vegetable supply.

Adoption pattern

The data collected from adopters in the sample area showed that adoption of varieties and/or technologies is widespread in seven crops (gourd, tomato, eggplant, lady's finger, leafy, bean, and heading cole). Four technologies were adopted by the sample adopter farmers: raised bed, polyethylene, tomatotone, and staking. Most farmers adopted variety and raised bed together. In tomato, variety and tomatone were adopted simultaneously, but in other crops variety led the adoption of management technologies.

Farm input

Adopters generally apply more manure and irrigation on vegetables compared to non-adopters. However, pesticide use on adopting farms has decreased, suggesting some success with farmer training on the judicious use of pesticides. Vegetable cultivation creates more productive employment opportunities than cereal crops, and adoption of modern technologies further enhanced these opportunities by about 10%, mainly due to more weeding, manuring, harvesting, and marketing labor for the increased output.

Economic efficiency in production

The adoption of new technologies leads to average yield increases of about 38%, with an overall increase in production costs of about 12.8%. This improved economic efficiency in input use, especially of land (65%), labor (40%), and water (12%) applied to vegetables. Economic efficiency also improved as unit production cost of vegetables was reduced by 20%. Non-adopters have also achieved these gains through the spillover effect, which involves little cost. To achieve the large unexploited effect, substantial input costs are required. This was a major constraint to the adoption of new technologies by non-adopters.

The science-based technologies not only improved efficiencies of inputs used in vegetable cultivation, they also improved the efficiency of inputs used in cereal crops. As adopters gain improved skills to handle these technologies, they use these skills to enhance efficiencies of resources employed in other crops. For example, adoption improved the economic efficiencies of land (165%), labor (41%), and water (90%) used in cereal crops on the adopter farms.

Consumption and nutrition

The household consumption survey showed that the average daily per capita consumption of vegetables in Bangladesh from all sources was 126 g, well below the minimum level of 200 g recommended by AVRDC. Vegetables consumed were mainly fruit types, which are low in vitamin A and iron. Leafy vegetables, which are rich in vitamin A and iron, were consumed in small amounts, with adopter families consuming slightly higher amounts.

Vegetable cultivation and adoption of new technologies enhanced vegetable consumption. Adopting families consumed 67.3% more vegetables than non-vegetable farmers, and 26.2% more than non-adopting farmers. Non-vegetable farmers and non-adopters consume about 50% less than the recommended levels of vitamin A, the adopters are only 25% below the recommended level. There is a marginal difference in nutrient availability between non-adopters and non-vegetable farmers, but the difference is not statistically significant. Vegetable production alone is therefore not enough to enhance nutrient supplies at the family level. Production programs should be accompanied by nutritional awareness campaigns, which were an important part of the Bangladesh project.

Family income

The adoption of science-based technological innovations had an impact on poverty. The mean farm cash income of adopting farmers was about 10% higher than for non-adopters, and 32% higher than that of non-vegetable farmers. Adopting farmers also earned significantly higher off-farm income. The additional income was used to enhance savings, to purchase food and improved farm implements, and on children's education.

Marginal rate of return on farmer investment

The marginal rate of return (MRR) on investment made by adopters to achieve the gain of new technologies is 241%. The marginal rate of return on the spillover effect is higher at 1045%, implying that little cost can give tremendous benefits to non-adopters to achieve the spillover effect of technologies once they are available. Relatively large costs are required to achieve the full gain of new technologies, however.

Internal rate of return on the public sector investment

The technological innovations in vegetable production generated an economic surplus of about US$ 8.8 million for Bangladeshi farmers and consumers during the ten-year project. The project continues to generate benefits. The producers benefited (US$4.6 million so far) through reduced cost of production and higher resource use efficiency, while consumers benefited (US$4.2 million so far) from lower vegetable prices as a result of increased supply. USAID and the Government of Bangladesh invested about US$7.1 million in the project spread over nine years. This gave an internal rate of return (IRR) on vegetable research and development of 42% or more. Investments in vegetable research are highly profitable, and help improve the livelihood of poor farmers and urban dwellers.

Summary and policy implications

The project was able to improve the compatibility of vegetable production with other crops by enhancing yield and reducing production cost. The project also helped improve the resource use efficiency of land, labor, and water, as well as production efficiency. The rate of return on the investment made by farmers to achieve the gains of technologies is reasonable. The promotion of new technologies improved the growth rates in vegetable supplies and per capita availability, halted the increase in vegetable prices, and reduced seasonality. It significantly improved farmer income, which increased investment on farm implements, and on food, especially vegetables. In just nine years the project generated US$8.8 million worth of economic surplus, almost equally distributed among producers and consumers. The internal rate of return on the investment in vegetable R&D is more than 42%. The promotion of new technologies, along with the nutritional awareness program, helped increase micronutrient uptakes. Vegetable consumption is still far below the recommended level, however. Efforts to enhance vegetable supplies, coupled with nutritional awareness programs on the role of vegetables in supplying micronutrients and the importance of micronutrients in health, need to be continued. It is important to launch a new project to broaden our understanding of the constraints to expanded vegetable production and to adoption of new technologies in Bangladesh.

Introduction

Bangladesh is one of the poorest countries in Asia (per capita annual income of US$240 in 1999), with very little land for cultivation (0.08 ha/person in 1999). Pervasive poverty in rural areas of the country is associated with the lack of productive employment opportunities, and malnutrition. Whatever little is earned is spent on food, and that is still insufficient. This results in serious malnutrition that further lowers labor productivity. This cycle of malnutrition and low labor productivity has presented an enormous challenge for scientists and policymakers.

Recent figures indicate that the extent of micronutrient deficiency in Bangladesh is far greater than energy malnutrition. About 60% of the total population suffer from various micronutrient deficiencies (GOB 1997), which is increasingly recognized as the cause of serious health problems. About 70% of women aged 15-45, and children 0-14 years, and 80% of pregnant and lactating women, suffer from anemia caused by low blood hemoglobin levels (GOB 1995). This accounts for about 20% of all deaths among women in Bangladesh (ACC/SCN 1991). The rate of night blindness in Bangladesh, 1.78% among children aged 6-71 months, is double the World Health Organization cutoff level for identifying vitamin A deficiency as a major public health problem (IPHN/UNICEF 1989). About 60% of the people in Bangladesh are deficient in iodine, 47% have goiter (of which 9% are visible) (Yusuf et al. 1993), and the rate seems to be increasing over time (IFPRI 1998). Micronutrient deficiency not only causes health problems but impacts negatively on economic growth. It also robs many countries of 5% of gross domestic product through death and disability (Doryan 2000).

The root cause of micronutrient deficiency is the monocrop rice farming system, which translates into a simple rice-dominated diet, and low employment opportunities. Only 1.42% of the total cropped area in Bangladesh is under vegetables, compared to 15% in Taiwan (Ali 2000). This means that only 40 g of vegetables per person per year are available from farm sources. The average daily consumption per person, including supplies from home gardens, hardly reaches about half of the 200 g level recommended by AVRDC for a healthy life. This was despite the consumption survey having been conducted in the vegetable-growing areas (through the project) during the peak supply season.

The following are possible ways to mitigate micronutrient deficiencies:

- Clinical approaches, such as fortification of commonly used foods that are deficient in nutrients and micronutrient supplements;
- Food-based approaches such as micronutrient-rich cereals, and integration of micronutrient-rich foods such as fruits, vegetables, and livestock products into the diet.

In view of the administrative and logistical constraints associated with supplements and fortification (McKigney 1984), most clinicians and nutritionists believe that food-based approaches are the only sustainable ways of eliminating micronutrient deficiency.

Among the food-based approaches, micronutrient-rich cereals may not provide a solution as it further narrows down the biodiversity in production as well as in diets, the root cause of the problem. AVRDC therefore believes that integration of micronutrient-rich food, particularly vegetables, into the diet, particularly vegetables, is the only viable solution. Among the micronutrient-rich foods, vegetables are relatively inexpensive, and produce micronutrients at a lower unit cost than other micronutrient-rich foods such as livestock products (Ali and Tsou 1997). Vegetable production, however, can be limited by a myriad of production, marketing, and demand constraints. These constraints are more restrictive on vegetable production in Bangladesh than in many other countries, as reflected by low yield and high seasonality in availability. Overcoming constraints on vegetable supply could help to mitigate micronutrient deficiency in the country. Because vegetables can diversify production systems as well as diets, enhancing supply attacks the core problem of rice dominance in production and consumption. Vegetable cultivation generally requires more labor, thereby creating productive employment opportunities and generating higher incomes. Expanding vegetable cultivation can therefore break the cycle of micronutrient deficiency, low labor productivity, and poverty.

A project aimed at overcoming constraints to vegetable production and consumption in Bangladesh was undertaken during 1991-2000. It was supported by the United States Agency for International Development (USAID), the Asian Vegetable Research and Development Center (AVRDC), and the Bangladesh Agriculture Research Institute (BARI). The main objective of the project was to develop and introduce varieties and technologies to enhance annual vegetable production, reduce seasonality, and to overcome micronutrient deficiency in Bangladesh. Details on the organization, structure, and implementation strategies of the project are contained in AVRDC/ARC/BARI (2000). After many years of consistent effort to improve vegetable supply and overcome micronutrient deficiency, we analyzed the impact of the project against the stated goals. The impact, however, is conditional on many factors. First, vegetable output and farmer income will rise only if the technologies are profitable for farmers. Second, even if this leads to more output and higher incomes, farmers and non-farmers will consume more vegetables only if they believe vegetables are important to their health. Finally, even if more vegetables are eaten, the micronutrient situation will be improved only if vegetables supply a major portion of the total micronutrients consumed. These are empirical questions, and need to be addressed after the project has completed a major push to introduce new vegetable technologies to the farmers especially during its second phase (1995-2000).

Empirical research indicates that high incomes from commercial crops such as vegetables do not necessarily result in higher expenditures on food, and higher availability of nutrients (von Braun and Pandya-Lorch 1991). The focus of the earlier studies, however, was on energy, and the issue of micronutrient availability was largely ignored. The purpose of our study was to test the link between vegetable production and micronutrient availability at the household level.

The International Food Policy Research Institute (IFPRI) conducted an economic evaluation of the USAID-sponsored AVRDC and ICLARM projects in Bangladesh during 1996-97. The study found 350% higher monthly net revenue from vegetables than from rice, and AVRDC technologies further increased farmers' income from vegetables. However, the share of agriculture to total income on the sample farms was trivial, area allocated to vegetables was small, and the area allocated to AVRDC vegetables was even less. Therefore, marginal contribution of vegetables and AVRDC technologies was less than 1% of the farmers' income. During 1995-2000, the USAID/AVRDC/BARI project organized 28,171 on-farm demonstration trials in collaboration with non-governmental organizations (NGOs). One hundred and one field days were organized, enabling 8929 additional farmers to visit the field. After five years of demonstrations in the field, we can now assess the impact of the project.

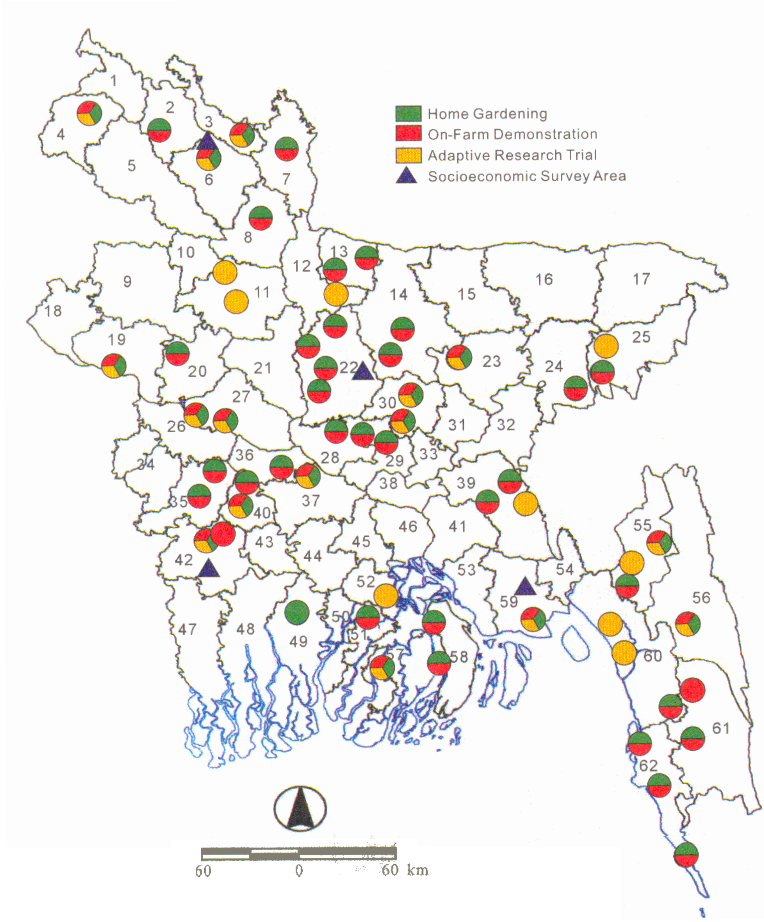
Objectives

The main objective of this study was to evaluate the economic and nutritional impact of new production technologies introduced in vegetable cultivation through the USAID/AVRDC/BARI project in Bangladesh, by exploring links between production, consumption, and nutritional availability. Nutritional uptake of those who adopted modern technologies in vegetable production was compared with those who had not adopted these technologies, and the economic viability of the project was quantified using various economic criteria. The study compares trends in vegetable production and prices during the pre-innovation and innovation periods, and evaluates the effect of technological innovation on:

- Socioeconomic farm and family characteristics;
- Yield, input use, crop duration and schedule, cost; and return of vegetable and non-vegetable crops;
- Consumption and nutritional patterns and sources of food; and
- Home garden size and vegetables grown in the garden.

Survey

To understand the impact of adoption on farm income, and household consumption, a simultaneous farm production and household consumption survey was carried out in Bangladesh during January-May 2000 with the help of BARI (Figure 1).



1. Panchagarh
2. Nilphamari
3. Lalmonirhat
4. Thakurgaon
5. Dinajpur
6. Rangpur
7. Kurigram
8. Gaibandha
9. Naogaon
10. Jaipurhat
11. Bogra
12. Jamalpur
13. Sherpur
14. Mymensingh
15. Netrakona
16. Sunamganj
17. Sylhet
18. Nawabganj
19. Rajshahi
20. Natore
21. Sirajganj
22. Tangail
23. Kishoreganj
24. Hobiganj
25. Moulvibazar
26. Kushtia
27. Pabna
28. Manikganj
29. Dhaka
30. Gazipur
31. Narsingdi
32. Brahmanbaria
33. Narayanganj
34. Chuadanga
35. Jhenaidah
36. Rajbari
37. Faridpur
38. Munshiganj
39. Comilla
40. Magura
41. Chandpur
42. Jessore
43. Narail
44. Gopalganj
45. Madaripur
46. Shariatpur
47. Satkhira
48. Khulna
49. Bagerhat
50. Perojpur
51. Jhalakati
52. Barisal
53. Lakshmipur
54. Feni
55. Khagrachari
56. Rangamati
57. Patuakhali
58. Bhola
59. Noakhali
60. Chittagong
61. Bandarban
62. Cox's Bazar
63. Barguna

Figure 1. Map of Bangladesh showing the AVRDC/USAID/BARI project activities and socioeconomic survey locations

Sampling

The representatives of the NGOs engaged in promoting vegetable production technologies attended a planning meeting at BARI in November 1999. The representatives were interviewed to get a sense of how familiar they were with the extent of the impact of these technologies. All the representatives were quite positive about the impact of the USAID/AVRDC/BARI initiative. The results of the survey and discussions with the management of the project in USAID, AVRDC, and BARI led us to conclude that vegetable production technologies had spread more widely in Jessore (west), Noakhali (south-central), Rangpur (north), and Savar (central), than in other districts of Bangladesh. We therefore decided to concentrate our impact assessment survey in these districts.

The farming population was divided into adopters, non-adopters, and non-vegetable farmers. Those farmers who had adopted any new variety or technology promoted by AVRDC through NGOs in some of the vegetable crops grown during 1999 were considered as adopters. Farmers who did not adopt AVRDC technologies in any of the vegetable crops during 1999 were considered as non-adopters. Some farmers took certain varieties from other sources, but did not approach AVRDC or collaborating NGOs, so they were also considered non-adopters. Farmers who did not grow any vegetable crops on a commercial scale (sold more than 50% of the crop output) during 1999 were categorized as non-vegetable farmers.

The list of collaborator farmers in the four districts was obtained from the NGOs. We randomly chose 50 adopters from the list. These farmers were distributed across many villages in each district. About the same number of non-adopters were chosen at random from nearby villages. As far as possible, non-adopters growing similar crops to adopters were chosen. Similar sample sizes of non-vegetable farmers were chosen at random from the vicinity of adopters and non-adopters (Table 1). To estimate average consumption patterns for the whole country, the sample from rural areas was enlarged by including 25 urban dwellers randomly selected from the city center of each sample district. Only consumption data were obtained from the urban dweller housewives.

Table 1. District-wise sample of the impact evaluation survey

Type of farmer	Jessore	Noakhali	Rangpur [a]	Savar	Total
Vegetable adopter	50	50	47	50	197
Vegetable non-adopter	53	47	40	50	190
Non-vegetable farmer	47	50	31	50	178
Urban dweller	30	30	21	30	111

[a] The sample size in Rangpur was smaller than planned, because of the widespread sample of the adopter farmers, and difficulty in obtaining similar non-adopter farmers.

The data were collected by crop for all major vegetables and non-vegetable crops grown on the farm during 1999. Production data for a total of 1504 crop parcels were recorded including a large number of non-vegetable parcels (Table 2). This allowed us to compare vegetable and non-vegetable crops across the farm types. In addition, adopters provided production details of those crops grown before and replaced by the newly adopted varieties. Because the new technologies have been adopted only since 1995, the farmers had no difficulty recalling and comparing the old and new technologies. This gave us an opportunity to compare new and old technologies under similar management.

Table 2. Number of vegetable and non-vegetable crop parcels surveyed by farmer type

Crop parcels	Adopters (after adoption)	Adopters (before adoption)	Non-adopter	Non-vegetable farmers	Total
Vegetable	410	194	345	—	949
Non-vegetable (non-adopters)	99	82	153	221	555
Total	509	276	498	221	1504

Questionnaire preparation

A survey questionnaire was developed at AVRDC to cover separately production and consumption aspects. The production survey covered farm characteristics (the socioeconomic status of the farm households), crops grown during 1999, input, output, and prices of major vegetable and non-vegetable crops, as well as information on the adoption pattern of new vegetable technologies. The consumption survey covered the quantities, prices, and sources of all food commodities consumed during the 24 hours before the survey was done. It also included information on home gardens and their contribution to overall consumption.

Survey implementation

A local coordinator from Dhaka, an economist, was employed to handle the logistics of the survey and guide the survey team in the local language. Six male and six female enumerators from each district, and the coordinator from Dhaka, were trained by the economist from AVRDC (the first author), and the consultant (the second author). The male enumerators were responsible for gathering production data from the male head, while female enumerators collected consumption data from the female head of the household. The completed questionnaires were processed in Dhaka. The economist at AVRDC prepared the data entry format, and the consultant trained a team of two data-entry specialists. The data were entered in Excel spreadsheet. The consultant did the data validation in collaboration with the data entry team. The analysis was done by the authors at AVRDC in Taiwan.

Theoretical Framework

The resource allocation process of a farm household may be described as maximizing the utility function subject to a number of constraints (Behrman and Deolalikar 1988). Available family resources are allocated across various enterprises and leisure, and food items are consumed from various sources, including the farm. Certain exogenous variables such as output and input prices that have an important affect on household decisions remain unchanged by decisions taken by individual households. Primitive farm technologies are considered major constraints to higher form. This household behavior model stipulates a relationship between production, farm resources, and adoption of technologies on the one hand, and production and consumption on the other. The holistic approach suggested by the model was used in the study: household resources were evaluated, production of different crops (especially vegetables) was related to technology level and resource availability at the farm, and consumption of food was linked with production. The purpose is to see how introduction of high-yielding, low-cost technologies in vegetable production improves the competitiveness of vegetable cultivation, and enhances economic well-being and improves micronutrient availability for people in general and farmers in particular.

The "total effect" of modern technologies in vegetable production was defined as the difference between the "before" and "after" situation of adopters. This, however, may include the effects of other than technological changes, such as improved roads and marketing infrastructure, on production. These changes influence production through their effect on prices, by changing levels of input use, and value of inputs and outputs. To control the second effect to a certain extent, before and after scenarios were evaluated using the same prices that prevailed during the survey year. It is relatively difficult, however, to control the effect on input levels. This effect is expected to be minimal because improvements in infrastructure are unlikely to be significant over the short period of 5-6 years during which the major diffusion occurred. This is especially true when the macroeconomic growth remained typical throughout the adoption period.

When production technologies spread on adopter farms, they also affect non-adopters through the demonstration effect. The difference, therefore, in production-related parameters between non-adopters in the year of the survey and "before" the adoption situation of adopters provides the "spillover" effect. The difference in "after" the adoption situation and non-adopters during the survey year shows the unexploited effect of the technologies. We summarize these effects in the following equations:

$$\text{Spillover (\%)} = ((N_t - B_{tt})/B_{tt}) \bullet 100$$

$$\text{Unexploited (100)} = ((A_t - N_t)/B_{tt}) \bullet 100$$

$$\text{Total (\%)} = ((A_t - B_{tt})/B_{tt}) \bullet 100$$

where A is the parameter value, say yield, cost, input level, etc., for adopters "after" the adoption, B is the parameter value for adopters "before" adoption, N is the value of the parameters for non-adopters, and *t* and *tt* refer to the current year and the year just before the adoption took place, respectively.

Some parameter values for before adoption, such as socioeconomic characteristics of farmers and consumption pattern, were not available. For those values, we estimated the contribution of vegetable cultivation by comparing non-adopters and non-vegetable farmers, and the marginal contribution of adoption (i.e., technology effect) by comparing adopters and non-adopters as follows:

i. Vegetable effect = $((N - C)/C) \cdot 100$

ii. Technology effect = $((A - C)/C) \cdot 100$

iii. Total effect = i + ii

where C denotes the parameter value for the non-vegetable farmers, and N and A are as defined earlier.

Trend Analysis from Secondary Data

Vegetable production

To see the effect of technological innovation on vegetable production from independent sources, individual vegetable area, production, and yield data were collected from the Bureau of Statistics of Bangladesh for the period 1971-99. Data for the last year of the project were not available.

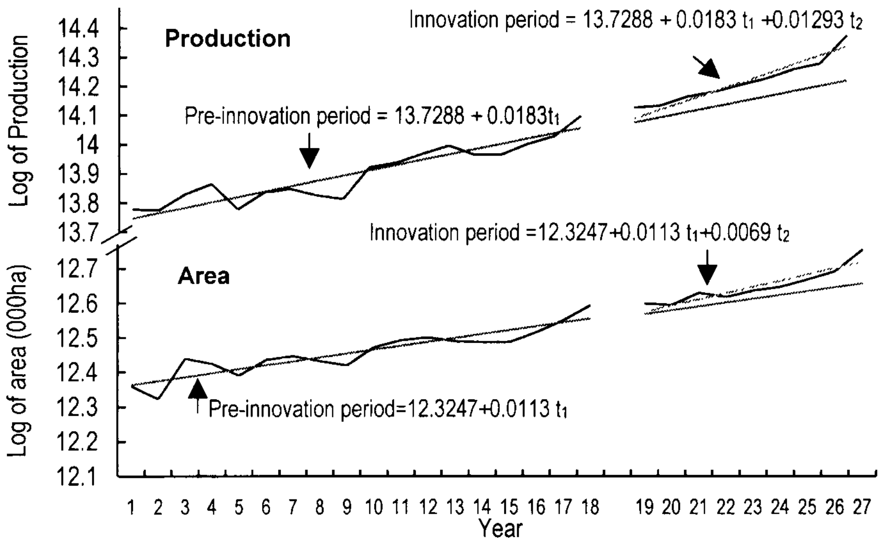
There was a remarkable increase in vegetable production during 1991-99, henceforth called the innovation period. Total vegetable production (including chili, onion, and garlic, but excluding potato) increased from 1.3 million tons in 1991 to 1.8 million tons in 1999, a 38% increase over nine years. The area under vegetables increased about 17%, from 296,000 to 346,000 ha, during the same period, while yield increased more than 10%, from 4.6 to 5.1 t/ha. This was the first time in the history of Bangladesh that per capita vegetable availability increased significantly (18%), from 34 g in 1990 to 40 g in 1999.

To compare the annual growth rates in area, production, and yield of vegetables between the pre-innovation (1973-90) and innovation periods, trends in variables for each period were estimated using the spline-function explained in Appendix 1. There was a significant difference in the growth of vegetable area, production, and yield during the two periods (Fig 2). In the pre-innovation period, annual growth rate in production was dismal at 1.8%, less than the population growth rate. The annual growth rate jumped to 3.1% during the innovation period, higher than the population growth rate (Table 3).

Table 3. Growth (percent per annum) in vegetable area, production, and yield by crop and period in Bangladesh

Crop	Area		Production		Yield	
	1973-90	1991-99	1973-90	1991-99	1973-90	1991-99
Kharif vegetables						
Pumpkin	1.3	4.7	0.3	5.4	-1.0	0.7
Eggplant	-0.1	1.6	-1.8	2.6	-1.7	1.0
Pointed gourd	2.7	4.2	0.8	4.9	-1.9	0.7
Lady's finger	4.5	5.4	2.7	7.1	-1.8	1.7
Ridged gourd	4.1	3.7	2.2	4.2	-1.9	0.5
Bitter gourd	2.9	3.3	0.7	4.0	-2.1	0.7
Aram	5.8	3.4	4.8	5.0	-1.1	1.6
Ash gourd	3.7	1.3	2.4	2.1	-1.3	0.8
Stem amaranth	2.4	3.5	0.5	4.4	-1.8	0.9
Cucumber	2.1	5.1	-0.1	4.7	-2.2	-0.4
String bean	4.8	4.4	5.3	3.4	0.5	-1.0
Spinach	-0.3	9.5	-2.4	9.4	-2.1	-0.1
Snake gourd	5.2	2.0	4.2	2.7	-1.0	0.8
Chili	-0.3	1.3	0.2	4.2	0.5	2.5
Other kharif vegetables	-1.3	-0.1	-2.3	0.1	-1.0	1.1
All kharif vegetables	2.4	3.4	1.4	4.4	-1.1	0.1
Rabi vegetables						
Pumpkin	1.0	4.5	2.2	4.9	1.2	0.4
Eggplant	0.1	4.3	0.0	4.3	-0.1	0.0
Cauliflower	3.0	2.5	4.3	1.8	1.3	-0.7
Cabbage	2.5	3.7	3.4	6.0	0.9	2.3
Bottle gourd	3.2	3.2	3.9	4.2	0.7	0.9
Tomato	2.7	1.9	2.7	1.6	-0.1	-0.3
Radish	4.1	1.1	5.1	2.0	1.0	0.9
Hyacinth beans	3.2	4.3	2.5	4.6	-0.8	0.3
Spinach	4.6	3.8	4.8	4.7	0.2	1.0
Ginger	1.7	0.2	1.2	-1.0	-0.5	-1.2
Garlic	0.1	0.4	-0.4	0.4	-0.5	-0.0
Onion	0.6	-0.2	-0.1	0.2	-0.7	0.4
Chili	-0.8	-1.3	0.4	0.6	1.1	2.0
Other rabi vegetables	1.5	1.3	2.0	0.5	0.5	-0.9
All rabi vegetables	0.8	1.3	1.9	2.7	1.1	1.5
All vegetables	1.1	1.8	1.8	3.1	0.7	1.3

1973-90 = Pre-innovation period; 1991-99 = Innovation period.



Note: All estimated coefficients are statistically significant at the 5% level.

Figure 2. Trend in vegetable area and production (by period) in Bangladesh, 1973-99

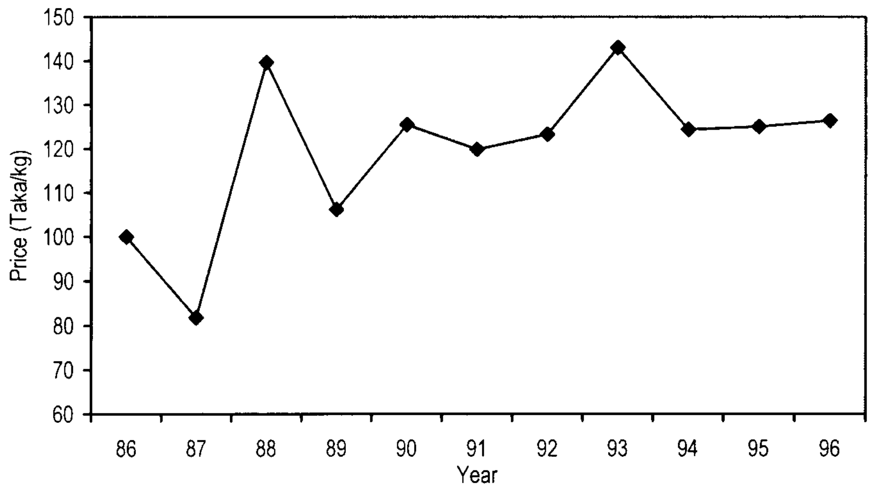
The main source of the small increases in vegetable production has been area expansion. The average area of vegetables increased at only 1.1% annually during the pre-innovation period (t_1 coefficient in Fig. 2), while yield increase was 0.7% (t_1 coefficient for production – t_1 coefficient for area in Fig. 1). These trends, however, significantly improved during the innovation period, with growth in area at 1.8% and 1.3% in yield.

Increases in area and production during the innovation period were higher in kharif, considered as off-season for vegetable production, than in rabi, or the peak vegetable supply season. The declining yield trends in kharif during the pre-innovation period converted into significantly increasing trends in the innovation period (Table 3). The substantially higher increase in area and production of kharif crops compared to rabi crops resulted in a higher proportion of vegetable availability during the off-season. Consequently the share of kharif season vegetable production increased from 25% in 1991 to 28% in 1998.

The project promoted some selected vegetable crops. Production increases of those crops was higher than the average increase during the innovation period (Table 3), especially for pumpkin and spinach (kharif and rabi), lady's finger (kharif), and cabbage and hyacinth beans (rabi). Tomato was the only exception where AVRDC introduced new production technologies, but overall annual growth in production declined during the innovation period. Lower yield of summer compared to winter tomato on non-adopter farms, as discussed later, and the probable shift of some of the tomato area in the summer season by these farmers, may be the cause of this decline.

Vegetable prices

Annual average wholesale nominal prices of 17 vegetables at the peak time of their harvest are reported in various issues of Agricultural Statistics of Bangladesh (GOB 1990-2000). The weighted average price of all vegetables sharply increased during 1986-93, while the upward trend was halted during 1994-96 (Fig. 3). This implies reduction in real or deflated vegetable prices. Although this is too short a period to judge if the trend will remain stable, the non-increasing prices at least hint at abundant vegetable supplies resulting from technological innovations, and brought to market during this period.



Note: The weighted-average prices of overall vegetables were estimated from 17 individual vegetables by assigning the production share of each commodity in the total production of all these commodities as shares.

Figure 3. Trend in nominal wholesale vegetable prices in Bangladesh during 1986–96

Farm and Farmer Characteristics

Socioeconomic

Adopters have slightly larger agricultural landholdings, vegetable areas, and vegetable plots than non-adopters, and both have smaller holdings than non-vegetable farmers, but the differences are not statistically significant (Table 4). Our figures for these parameters are higher than those reported by IFPRI (1998), because the IFPRI study was done near cities where landholdings are naturally small. As a result the contribution of agriculture and vegetables to total income is small, as two-thirds of the respondents were engaged in off-farm activities, and did not claim to be full-time farmers.

Table 4. Characterization of the sample farmers by farmer type

Characteristic	Non-adopter	Adopter	Non-vegetable farmers	Average of all vegetable sites in IFPRI 1998 study
Farm size (m^2)	9325 [a]	9373 [a]	9944 [a]	–
Owned area (m^2)	6521 [a]	7157 [a]	7262 [a]	4352
Vegetable harvested area (m^2)	1437 [a]	1673 [a]	0	789
Vegetable plot area (m^2)	732 [a]	764 [a]	0	324
Age of head (year)	42.4 [a]	42.3 [a]	44.2 [a]	42.8
Family size (number)	5.2 [a]	5.2 [a]	5.3 [a]	4.9
Family labor available on farm (person)	1.7 [a]	1.6 [a]	1.6 [a]	–
Education (year)				
Head	4.1 [a]	4.6 [a]	3.6 [b]	2.3
Male	4.3 [a]	4.7 [a]	3.8 [b]	–
Female	2.8 [a]	3.1 [a]	2.2 [b]	–
Experience of head (year) in:				
Agriculture	20.1 [a]	22.0 [a]	22.5 [a]	–
Growing vegetable	10.2 [a]	10.6 [a]	6.5 [b]	–
Training in Agriculture (number)	1.9 [b]	3.8 [a]	1.2 [c]	–

The same superscript in a row implies that the figures are not statistically different across groups, and different superscripts imply a statistical difference, both tested at the 10% level.

No significant differences were observed across farm types in age of the household head, family size, family labor available for agriculture, and experience in agriculture. Although education of the head of the household and experience in vegetable cultivation were higher for vegetable farmers (both adopters and non-adopters) than non-vegetable farmers, there was no significant difference in these parameters between adopter and non-adopter farmers. This suggests we successfully selected adopters as typical vegetable-growing farmers. The only significant difference in adopters and non-adopters was the higher level of training of adopters, because of the extensive vegetable production training and demonstration programs sponsored by AVRDC through collaborating NGOs. Average education levels are higher for all members of adopter families than those for non-adopters, mainly because of the higher level of education of the children. The latter is a result of the higher income produced by the adoption, although such differences are not yet statistically significant.

Farm machinery and household belongings

The adopter farmers have accumulated more farm machinery, especially tractors and weeders, than non-adopters and non-vegetable farmers (Table 5). Contrary to normal perception, however, there is no significant difference in tubewell ownership between vegetable (both adopters and non-adopters) and non-vegetable farmers. Access to water may therefore not be a major factor in deciding vegetable cultivation or adoption of modern technologies in Bangladesh. There was no significant difference between vegetable (both adopter and non-adopter) and non-vegetable farmers in the ownership of home appliances, except for hand pumps and furniture, and standard animal units, area covered by the house, or source of light.

Table 5. Ownership of farm machinery, home appliances, and animals by farmer type

	Adopter	Non-adopter	Non-vegetable farmer
Farm machinery (number)			
Tractor	0.028[a]	0.005[b]	0.006[b]
Weeder	2.022[a]	1.745[b]	1.717[b]
Tubewell	0.335[a]	0.277[a]	0.265[a]
Thresher	0.346[a]	0.335[a]	0.355[a]
Home appliance (number)			
Hand pump	0.575[a]	0.500[a]	0.404[b]
Radio	0.453[a]	0.468[a]	0.488[a]
TV	0.184[a]	0.170[a]	0.223[a]
Bicycle	0.559[a]	0.505[a]	0.464[a]
Furniture	4.631[a]	3.843[a]	2.032[b]
Animal (standard animal unit)[1]	2.012[a]	1.812[a]	2.032[a]
Covered house area (m^2)	411[a]	385[a]	370[a]
Source of light (% of farmers)			
Electricity	40.2[a]	38.3[a]	38.0[a]
Kerosene	57.0[a]	61.2[a]	60.2[a]

The same superscript in a row implies that the figures are not statistically different across the groups, and different superscripts imply a statistical difference, both tested at the 10% level.

[1]Standard animal units (SAU) were estimated as:

SAU = Buffalo • 1.375 + Cow • 1.15 + Young stock • 0.5 + (sheep and goat) • 0.19

Soil and land type

Adopters, non-adopters, and vegetable farmers had similar soils (Table 6). Most soils in Bangladesh are heavy and medium. The decision by farmers to allocate a parcel to vegetables or cereals does not seem to depend upon soil type, because the percentage of different soils allocated to them is similar to the average distribution of soil types of the whole sample. However, some individual vegetables did get higher proportion of one or the other type of soil than the sample average (Appendix 2).

Table 6. Soil type (% of the total parcel in each farmer group) under vegetables and cereals by farmer type

Crop	Non-Adopter			Adopter			Non-vegetable		
	H	M	L	H	M	L	H	M	L
Vegetable	45	45	10	43	47	10	0	0	0
Rice	52	46	2	59	27	14	54	40	6
Wheat	56	44	0	21	72	7	22	56	22
All parcels	48	44	8	44	45	11	53	40	7

H= heavy soil includes clay, clay loam, loam; M = medium soil includes sandy loam; L = light soil includes sandy and silt.

Land type based upon drainage, however, differs across vegetable and non-vegetable farmers, although there was no difference between adopters and non-adopters (Table 7). Vegetable farmers have a relatively higher percentage of upland and medium land parcels, while non-vegetable farmers have a higher percentage of lowland parcels. It should be noted that these results are based on the number of parcels, not parcel size, therefore, a higher percentage of upland parcels of vegetable farmers does not necessarily mean that they have a higher proportion of upland area. Generally, vegetables are grown on upland and medium-high lands, while medium lands and lowlands are allocated to rice. A similar picture emerges when we look at the type of land allocated to individual vegetables and cereal crops (Appendix 3).

Table 7. Land type (% of the total parcel in each farmer type) under vegetables and cereals by farmer type

Crop	Non-Adopter			Adopter			Non-vegetable		
	UL	ML	LL	UL	ML	LL	UL	ML	LL
Vegetable	47	38	15	55	34	12	0	0	0
Rice	16	37	47	27	34	39	22	22	56
Wheat	19	62	19	36	50	14	23	33	44
All parcels	41	39	20	52	33	15	23	23	54

UL= upland implies that water drains out when heavy rain occurs; ML = medium land implies that water stays for less than 10 hours after heavy rain stops; LL = lowland implies that water stays more than 24 hours after heavy rain stops.

Adoption Pattern

High-yielding varieties of a number of vegetable crops and new production technologies were widely demonstrated to farmers throughout Bangladesh. It was neither our objective nor was it possible to cover all these crops and technologies in the survey. The data collected from adopters in the sample area showed that adoption of varieties and/or technologies are widespread in seven crops: gourd, tomato, eggplant, lady's finger, leafy, bean, and heading cole. Sample adopter farmers adopted four technologies: raised bed, polyethylene, tomatotone, and staking.

The different adoption pattern of a particular technological component depends upon profitability, riskiness, divisibility or initial capital requirement, complexity, and availability (Byerlee and Polanco 1986). Without quantifying these attributes of different technology components, we looked at the differential pattern of technology adoption. Only variety was adopted on one-third of the new technology parcels. Interaction between variety and raised bed is quite strong, such that together they were adopted on 174 or 43% of the parcels (Table 8). This pattern confirms the hypothesis that farmers adopt technologies in a step-wise fashion starting with simple technologies, such as variety, and then moving toward more complicated combinations (Byerlee and Polanco 1986). The adoption in tomato is more complex, where variety was combined with raised bed, mulching, tomatotone, and staking. This may be because the introduction of new technologies in tomato was demonstrated and promoted in package form, and tomatotone, polyethylene, and other inputs were provided at subsidized prices. Variety and management technologies (mainly tomatotone) were adopted simultaneously in tomato. In other crops, the adoption of varieties was faster than technologies (Table 9).

Table 8. Number of adopters who adopted varieties and technologies in selected crops

Variety/technology	Gourd	Tomato	Eggplant	Okra	Leafy	Bean	Heading cole	Total
Variety only	20	0	12	60	18	13	6	129
Technology only								
Raised bed	0	0	5	0	2	0	0	7
Polyethylene	1	0	0	0	0	0	0	1
Both variety and technology								
Variety+raised bed	26	0	7	56	56	18	11	174
Variety+polyethylene	1	0	0	0	0	1	0	2
Variety+tomatotone	0	2	0	0	0	0	0	2
Variety+staking	6	0	0	0	0	5	0	11
Variety+raised bed+polyethylene	0	0	0	1	1	1	2	5
Variety+ raised bed+polyethylene+tomatotone	0	26	0	0	0	0	0	26
Variety + raised bed + poly-ethylene + tomatotone + staking	0	21	0	0	0	0	0	21
Variety + raised bed + tomatotone + staking	0	4	0	0	0	0	0	4
Variety + raised bed + staking	7	0	1	0	1	3	0	12
Variety +raised bed + tomatotone	0	8	0	0	0	0	0	8
Total	61	61	25	117	78	41	19	402

Table 9. Adoption patterns in selected vegetables

Year	Number of adopters adopting varieties (technologies)						
	Gourd	Tomato	Eggplant	Okra	Leafy	Beans	Heading cole
Before 1995	2 (0)	0 (0)	1 (0)	0 (0)	4 (1)	1 (0)	2 (0)
1995	4 (4)	1 (1)	1 (0)	0 (0)	1(1)	1 (2)	2 (2)
1996	3 (1)	5 (5)	2 (2)	12 (5)	7 (5)	6 (1)	4 (2)
1997	14 (7)	3 (3)	5 (2)	8 (2)	13 (13)	10 (10)	4 (2)
1998	13 (8)	7 (5)	8 (6)	18 (8)	16 (11)	11 (6)	6 (3)
1999	24 (21)	45 (47)	5 (3)	79 (42)	35 (29)	12 (9)	1 (4)
Total	60 (41)	61 (61)	22 (13)	117 (57)	76 (60)	41 (28)	19 (13)

Seasonality in Production

One of the objectives of the project was to reduce seasonality in vegetable availability, because most of the total vegetable supplies are concentrated during the winter season. For this purpose, varieties tolerant to heat and humidity, and new production technologies, were developed and released to the farmers. Special technologies included structures, raised bed, tomatotone, and varieties.

The farm survey data suggest that vegetable yields during winter are generally higher than during summer on the non-adopter farms (Table 10), which explains why farmers concentrate vegetable production during the dry season. Introduction of science-based technologies improved yield for adopters in both seasons. Adoption of summer production technologies has also significantly shifted the tomato and leafy vegetable yield balance between summer and winter (in favor of summer) on the adopter farms. Because of the yield advantage during the summer, adopters have shifted the summer crop schedule more toward summer compared to the crop schedule followed by non-adopters in these crops. The summer crop schedule for beans shifted more toward summer, despite the fact that technology failed to narrow the yield gap across seasons. In heading cole, however, adopters shifted the summer crop schedule toward winter compared to non-adopters, despite any yield advantage across seasons.

Table 10. Crop schedule and duration for selected vegetables by season and farmer type

Crop/season	Adopter				Non-adopter			
	Parcels (number)	Duration (week and month)	Yield (kg/ha)	Duration (days)	Parcels (number)	Duration (week and month)	Yield (kg/ha)	Duration (days)
Summer								
Gourd	33	3rd Apr - 4th Aug	11678	127	77	3rd Apr - 1st Sep	9351*	133
Tomato	34	3rd Jun - 3rd Oct	19178*	114	3	2nd Aug - 3rd Dec	11938*	120
Eggplant	16	1st May - 3rd Nov	13358	187	71	2nd May - 2nd Dec	10696*	203
Lady's finger[1]	113	4th Apr - 1st Sep	10474*	124	20	4th Apr - 4th Aug	7508	117
Leafy	49	3rd May - 4th Aug	11199*	94	43	4th Apr - 4th Jul	9116*	90
Bean	19	1st Jun - 1st Oct	11113*	121	34	4th Jun - 1st Dec	9789*	158
Heading cole	2	3rd Aug - 1st Dec	16673	103	8	3rd Jul - 3rd Oct	13588	90
Winter								
Gourd	26	3rd Sep - 4 Feb	11539	157	30	4th Sep - 3rd Feb	12393*	141
Tomato	27	4th Oct - 4th Feb	15674*	117	12	1st Oct - 4th Dec	14535*	114
Eggplant	9	2nd Sep - 4thFeb	14874	149	13	4th Sep - 2nd Mar	12189*	163
Lady's finger	4	2nd Aug - 2nd Nov	9005*	86	1	1st Sep - 3rd Jan	6175	132
Leafy	29	2nd Oct - 2nd Feb	8155*	117	15	1st Nov - 2nd Feb	4921*	96
Bean	22	1st Sep - 2nd Feb	13833*	155	15	1st Sep - 1st Feb	10880*	147
Heading cole	17	2nd Oct - 1st Jan	15561	84	14	1st Oct - 2nd Jan	13666	96

*Implies that the yield of the same crop of the same group across seasons is statistically significant at least at the 10% level.

[1]Significantly higher yield across seasons may be due to only a few observations in the winter season.

Input Use

Fertilizer

Vegetables received 2-3 times more fertilizer per unit of land than cereal crops, depending upon the type of farmer and vegetable crop. This highlights the critical role of vegetables in generating demand for agricultural inputs, and agricultural business activities. There is no significant difference, however, in fertilizer application to vegetables between adopters and non-adopters, although adopters applied significantly less fertilizer before adoption (Table 11). Except for gourd and heading cole, fertilizer application is slightly higher on adopter farms (Appendix 4).

Vegetables in general also received more manure than cereal crops, and adoption of modern technologies in vegetable cultivation created a higher demand for manure (Table 11). The same was generally true for individual vegetables (Appendix 4). Adopter farmers apply significantly less manure to cereals than their counterpart non-vegetable farmers.

Table 11. Fertilizer and manure use on vegetables and cereals

	Fertilizer (nutrient kg/ha)		Manure (kg/ha of material)	
	Vegetables	Cereals	Vegetables	Cereals
Non-adopters	276 [a]	113 [a]	3995 [a]	1673 [a]
Adopters	279 [a]	91 [a]	6258 [b]	1394 [a]
Before adoption	211 [b]	111 [a]	7041 [b]	1332 [a]
Non-vegetable farmers	—	115 [a]	—	1397 [a]

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Pesticides

Farmers apply 12-18 times more pesticide on vegetable fields than on cereals. Adoption of modern technologies on vegetables, however, generally reduced the number of sprays and the quantity of pesticide applied on vegetables and cereals. The number of pesticide sprays by non-adopter farmers was double that of adopter farmers. The difference in pesticide quantities across the two groups was about 30% (Table 12). The reduction in pesticide use was mainly attributed to the vegetable production training of collaborative farmers on the judicious use of pesticide. The same pattern can be observed by looking at the pesticide application for individual crops (Appendix 5).

Table 12. Pesticide use (liters/ha) on vegetables and cereals by farmer type

Farmer type	Vegetables	Cereals
Non-adopters	5.02 [a] (6.5 [a])	0.42 [a] (1.3 [b])
Adopters	3.51 [b] (3.2 [b])	0.33 [a] (0.7 [ab])
Before adoption	4.53 [ab] (4.8 [a])	0.26 [a] (0.5 [ac])
Non-vegetable farmers	—	1.03 [b] (1.3 [b])

Figures in parentheses are number of sprays
The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Irrigation

Vegetables are usually grown under irrigated conditions. They require more irrigation than do cereal crops (Table 13). The same was true when individual vegetable and cereal crops were compared (Appendix 6). However, vegetables generally require less water per irrigation. Moreover, vegetable yields are generally higher than cereal crops. Therefore, water use per unit of land or per unit of output may be more efficient in vegetable cultivation than in cereal production. This hypothesis will be tested in a later section.

Adoption of modern technologies in vegetable cultivation significantly increased the amount of irrigation, because adopters are now using more irrigation than non-adopters and before the adoption situation. Adopters reduced irrigation to cereal crops after adoption.

Table 13. Number of irrigations applied to vegetables and cereals by farmer type

Farmer type	Vegetables	Cereal
Non-adopter	3.2 [ab]	2.9 [a]
Adopter	3.6 [a]	2.8 [a]
Before adoption	2.8 [bc]	3.2 [a]
Non-vegetable farmers	0.0	2.8 [a]
All sample farmers	3.3	2.9

The same superscript in each column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Labor

Vegetables are more labor intensive than cereal crops. About 205 additional labor days are required to cultivate one hectare of vegetables in one season (Table 14). This is equivalent to about one additional year-round job. The same pattern can be observed in individual crops (Appendix 7). The conversion of one hectare of cereal land to vegetables will generate in two seasons about two labor jobs on a yearly basis.

Adoption of new technologies in vegetable cultivation generally increased labor demand as adopters used about 10% more labor than non-adopters (Table 14). Labor requirements for crop management, harvesting, and marketing were generally higher (Appendix 7). Because of a general improvement in wage rates in the country (about 10% over the last 4 years), the increase in labor due to adoption was not as great as expected. The difference between non-adopters and before adoption, and adopters and before adoption, was not significant.

Table 14. Labor use per hectare (labor days) in vegetables and cereals by farmer type

Farmer type	Vegetables	Cereal	Difference
Non-adopter	321 [a]	137 [a]	184 (134)
Adopter	353 [b]	123 [b]	230 (187)
Before adoption	341 [ab]	134 [ba]	207 (154)
Non-vegetable farmers	—	139 [ca]	—
All sample farmers	338	133	205 (154)

Figures in parentheses are percentage difference between cereal and vegetables.
The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Vegetables need intensive management during all stages of cultivation. More fertilizer and pesticides are used in vegetables than in cereal production, and the applications are more numerous. Land is prepared more thoroughly, and more operations such as furrowing and raised-bed formation are required. Physical structures are necessary to protect the crop. Vegetables require more frequent weeding than cereals (Table 15). These operations increased labor requirements for vegetable growing. The same is true when individual vegetables are compared with cereal crops (Appendix 8).

Table 15. Number of different operations to vegetables and cereals by farmer type

Type of farmer/crop	Land preparation	Weeding	Manuring	Spraying	Structures	Harvesting
Non-adopter						
Vegetable	8.9[a]	2.2[a]	1.9[a]	6.5[a]	0.6[a]	14.4[a]
Cereal	6.6[a]	1.1[a]	1.9[a]	1.3[b]	0.0	1.9[a]
Adopter						
Vegetable	8.9[a]	2.4[a]	2.7[b]	3.3[b]	0.6[a]	12.8[b]
Cereal	6.2[a]	0.9[a]	1.4[b]	0.7[ab]	0.0	1.9[a]
Before adoption						
Vegetable	8.5[a]	2.1[a]	2.8[b]	4.8[a]	0.4[b]	12.9[a]
Cereal	7.5[b]	1.2[a]	2.2[ac]	0.5[ac]	0.0	1.9[a]
Non-vegetable farmers						
Vegetable	0.0	0.0	0.0	0.0	0.0	0.0
Cereal	7.7[b]	1.7[b]	2.3[c]	1.3[b]	0.0	2.0[b]

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

The share of marketing labor is much higher in vegetables than cereals (Table 16). Because vegetables require many harvestings compared to a single harvesting for cereals, labor increases to get each harvest to market before it perishes. Added to this is the higher packaging and grading labor requirements in vegetables than in cereals. Intensive management, as discussed above, increased the share of labor that went into crop management in vegetables compared to cereals. The relative shares of labor that went into land preparation and harvesting, however, were far less in vegetables than in cereals, although this did not necessarily mean that absolute labor for these operations in vegetables was less.

Table 16. Average distribution of labor (%) by activity in vegetables and cereals

Activity	Vegetables	Cereal
Planting and land preparation	23.2[a]	37.2[b]
Crop management [1]	26.3[a]	16.6[b]
Harvesting	29.6[a]	35.7[a]
Marketing [2]	20.9[a]	10.4[b]
Total labor (days)	338.2[a]	133.2[b]

The same superscript in a row implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

[1] The crop management input application or preparation of protective structure, and weeding.

[2] Marketing includes carrying or transporting from farm to house and market, grading, and packaging.

Total Production Cost

The cost of inputs and services used to cultivate and market a crop was estimated by multiplying the quantities with the respective farm-specific input prices or wage rates. If input was owned or produced at the farm, it was evaluated at its shadow price, assumed to be the average market price in the district, or in the whole sample. Total production cost of a crop was estimated by taking the sum across individual input costs. The cost before adoption was estimated by multiplying the input quantities with current prices. All costs were reported in Bangladesh Taka (BTK) (50 BTK=US$1).

The production cost was about three times higher in vegetables than in cereals (Table 17). Despite excluding costs of family-owned resources, such as labor and manure, the proportion did not change. The high costs may be one of the major constraints in vegetable production. One similarity in vegetable and rice cultivation was that labor and fertilizer were the major cost items in each case. Labor shares in total cost, however, were lower and the shares of marketing, protective structure, and pesticide were substantially higher in vegetables than in cereals. Similar differences can be observed when individual vegetable crops are compared with cereals (Appendix 9).

There is no statistical difference in the cost of vegetable production between non-adopters and before adoption, suggesting that adopters were typical vegetable-growing farmers before the adoption. The adoption of modern technologies in vegetable growing significantly increased total production cost. The total effect on cost of production was about 12.8%. The unexploited effect was about 11.3%, and the spillover effect only 1.5% (percentages not reported in the table; but can be estimated from the figures in the last column of Table 17). The small spillover effect suggests that non-adopters did not use additional inputs, and additional cost required to harness the unexploited benefit of technology may be the major constraint to adoption. This suggests that modern technologies are input intensive, and resource-poor farmers need public support in terms of credit to adopt these technologies.

As discussed earlier, the adopters used higher amounts of fertilizer (mainly manure) on vegetables, thereby increasing its absolute cost and share in the total cost. The science-based technological innovation, on the other hand, reduced pesticide use, its absolute cost and cost share. Marketing cost increased with adoption, but in terms of share of marketing cost, the difference compared to non-adopters was not great (Table 17).

Table 17. Total cost and factor share in vegetables and cereals

Farmer type	Percentage of the total cost							Total cost (BTK/ha)
	Seed	Protective structure	Fertilizer	Pesticide	Irrigation	Labor	Marketing	
Vegetables								
Non-adopter	3.3	5.7	22.5	7.6	5.4	48.6	6.9	34069 [a]
Adopter	3.8	4.6	25.5	4.6	6.6	47.6	7.3	37853 [b]
Before adoption	3.9	3.2	25.0	7.0	6.2	49.9	4.8	33549 [a]
Overall sample	3.7	4.6	24.2	6.1	6.1	48.4	6.9	35556
Cereals								
Non-adopter	8.7	0	26.1	2.0	8.2	54.6	0.4	11473 [a]
Adopter	9.3	0	22.6	1.1	7.1	58.5	1.4	9815 [b]
Before adoption	10.6	0	21.4	1.4	10.3	55.9	0.4	11035 [ab]
Non-vegetable farmer	9.6	0	23.9	2.0	4.9	58.5	0.4	12175 [ca]
Overall sample	9.5	0	23.9	1.8	6.8	57.2	0.8	11457

The same superscript in a column implies that the figures are not statistically different across farmer types for the given crop, and different superscripts imply a statistical difference, both tested at the 10% level.
50 Bangladesh Taka (BTK) = US$1.

These adjustments in vegetable cost had implications for the resource allocation in cereal crops. In an apparent attempt to finance the additional costs of innovations in vegetable production, adopters had to reduce the production cost of cereal. The absolute cost and shares of pesticide and irrigation in the cereal costs were lower, and higher for labor and marketing on the adopter farms, when compared with non-adopter farms and before adoption. The training on judicious use of pesticides in vegetables also helped to reduce pesticide use on cereals. Technological innovation in vegetables also forced farmers to use irrigation water more judiciously, and reduce the share of irrigation in the total cost of cereals. In summary, savings from fertilizer and irrigation costs in cereals and pesticide cost in all crops helped adopters to finance more manuring and higher labor costs in vegetables.

The share of irrigation cost in cereals was higher on vegetable farms than non-vegetable farms, although each has equal access to water. This indicates the enhanced ability of vegetable farmers to buy water both for vegetables and cereals from the cash they earned from vegetable cultivation.

Output

Yield

The adoption of science-based innovations in vegetable production significantly improved yields, by about 38% (Table 18). The highest total effect was in tomato, followed by lady's finger, eggplant, gourd, heading cole, and beans (Appendix 10). The spillover effect was about 13% or one-third of the total increase in vegetable yields, suggesting that although the new technology package was not adopted, vegetable yields on the non-adopter farms improved significantly through demonstrations. About two-thirds of the higher vegetable yields on the adopter farms remained to be exploited by non-adopters.

Improvement in vegetable yield is not only associated with the adoption of specific crop production and management techniques, but is also a reflection of the improved management capacity of farmers. The decision to grow vegetables is, in fact, depends on how well farmers can understand the complex input response of vegetables, and matching a production schedule with marketing demand. Once managerial skills of vegetable farmers are improved, the management of other crops will also benefit. We tested this hypothesis by comparing the yields of cereal crops across farmer groups. Although there were numerical differences (adopters had higher cereal yields than non-adopters and before adoption), we failed to prove the hypothesis of difference in cereal yields at the 10% level (Table 18).

Table 18. Yield level and yield difference in vegetables and cereals across farmer type

	Vegetables	Cereals
Yield (kg/ha)		
Non-adopter	10221 [a]	2033 [ab]
Adopter	12455 [b]	2109 [a]
Before adoption	9004 [c]	1931 [b]
Non-vegetable farmers	—	2106 [a]
Effect of technologies (%)		
Spillover effect	13.5	5.3
Unexploited effect	24.8	3.9
Total effect of technology	38.3	9.2

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Output disposal pattern

Vegetables are considered as commercial crops. Because of their short shelf life, only a small proportion of vegetable output is used for home consumption. Between 81 and 90% of the vegetables produced on-farm in Bangladesh were sold in the market, whereas only 7-29% of the cereal output was marketed (Table 19). The same difference was observed when individual vegetables and cereals were compared (Appendix 11), suggesting that vegetables generate higher immediate demand for agricultural business activities. The higher percentage of vegetables sold to the market also suggests that vegetable crops create a higher multiplier effect than cereal crops, through secondary and tertiary effects (i.e., buying shoes, clothes, food, etc., by those whose income increases indirectly, in this case the people in the agriculture business sector).

The adoption of modern technologies has improved the commercial nature of vegetables and cereal crops, as adopters brought a higher proportion of vegetable and cereal output into the market (Table 19). This does not mean, however, that adopters consume lower quantities of vegetables than other groups. Because production of adopters is higher, they keep larger quantities of vegetables for home consumption, as well as selling more to the market. Absolute quantities of cereals kept for home consumption are, however, lower on the adopter farms, because vegetables bring more cash income to the farmers, and adopters can buy cereals from the market.

Table 19. Output disposal pattern (% of the total output sold) in vegetables and cereals

Farmer type	Vegetables	Cereals
Non-adopter	89	19
Adopter	90	11
Before adoption	81	7
Non-vegetable	—	29
Overall sample	89	22

The remaining output was damaged during transportation, kept as seed, and/or consumed at home.

Economic Efficiency in Production

Low agricultural productivity in developing countries is a result of low economic efficiency in production, with primitive production technologies being responsible for the low efficiency. Improvement in economic efficiency in production is considered to be an important criterion to judge the economic viability of new technology, as well as its role in improving agricultural productivity. Economic efficiency can be defined in terms of higher return on individual inputs (i.e., more production from a given input, called input-use efficiency or partial productivity), or reduction in unit output cost (called output efficiency). The purpose of estimating partial productivity is to see how technological innovations affect the productivity of a particular input. The basic formula is:

Partial productivity of an input = (gross revenue – variable cost)/quantity of the input

Gross revenue includes total value of all outputs (main and by-products) produced from a piece of land in a given period. In estimating the partial productivity of variable inputs, say labor or water, the cost of all other inputs is assumed as fixed, and only the cost of that input is considered as variable. In estimating the partial productivity of a fixed input, such as land, only land cost is assumed as fixed. Net revenue that is equal to gross revenue less cost of all variable inputs, therefore, is an indication of economic efficiency of land use.

Parallel to the shadow prices of inputs, outputs consumed at home were evaluated at opportunity cost, which was assumed to be the average market price of the output in the district or in the whole sample. In the following sections, we estimated the economic efficiency across farm types of land, labor, and water, used in vegetable and cereal production.

Land

Vegetable cultivation improved net revenue over cereals. Net revenues from vegetables are 10-15 times higher than cereal production depending upon crop and types of farmers (Appendix 12). On average, revenue from vegetable cultivation was enhanced by about 66% through the adoption of modern technologies (Table 20). Again, non-adopters gained a little less than one-third of the total effect on net revenue, benefiting from the spillover effect.

Improved managerial capacity resulting from technology adoption in vegetable cultivation may benefit cereal crops as well. Although cereal yields were not increased, production cost reduced significantly resulting in higher net revenue for adopters compared to non-adopters and before adoption (Table 20). The total effect of improved managerial capacity on net return from cereals was about 165%. The positive effect of technological innovation on net return from cereals indicates an improvement in land use efficiency. The effect of modern technologies on land productivity is enhanced when net return was estimated on a per crop-month basis, because adopters grow relatively short-duration crops.

Table 20. Land use efficiency measured in net revenue from vegetables and cereals by farmer type

Farm type/type of effect	Per crop season basis		Per crop-month basis	
	Vegetable	Cereal	Vegetable	Cereal
Net revenue (BTK/ha)				
Non-adopter	27659 [a]	1508 [a]	5752	371
Adopter	36775 [b]	4306 [b]	8749	1090
Before adoption	22223 [c]	1625 [a]	4961	411
Non-vegetable farmers	—	1939 [a]	—	529
All samples	29937	2170	6667	570
Effect of technology (%)				
Spillover	24.5	-7.2	15.9	-10.0
Unexploited	41.0	172.2	60.4	174.9
Total	65.5	165	76.3	164.9

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Labor

As discussed earlier, the adoption of modern technologies in vegetable production increased both yield and labor, but impact on labor productivity was uncertain. Our estimates suggested that the adoption improved vegetable yields more than labor costs, thus boosting labor productivity (Table 21). The total positive effect on labor productivity was about 40%, with more than one-half of this achieved by non-adopters through spillover effect. The high spillover effect in labor productivity is a result of non-adopters increasing labor costs very little to obtain higher yields. However, about one-half of the improvement in labor productivity remained to be exploited. Labor productivity in cereals on the non-adopter farms was almost equal to the daily market wage rate of BTK50 (about US$1), but it is about 100-300% higher in vegetables depending upon the type of farmer. Adoption of science-based technologies in vegetables increased labor productivity in cereals as well. Thus converting cereal area to vegetable cultivation can improve overall labor productivity in agriculture. Heading cole gave the highest labor productivity among vegetables (Appendix 12).

Table 21. Labor productivity (BTK/labor day) in vegetables and cereals by farmer type

Type of farmer	Vegetables	Cereals
Non-adopter	140.6 [a]	49.0 [a]
Adopter	160.4 [b]	68.3 [b]
Before adoption	114.6 [c]	48.4 [a]
Non-vegetable	—	50.3 [a]
All sample farmers	138.5	65.8
Effect of technology (%)		
Spillover	22.7	1.2
Unexploited	17.3	39.9
Total	40.0	41.1

The same superscript in each column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Water

Water is getting scarcer, and is seriously limiting agricultural production (Rosegrant and Pingali 1994). Efficient use of water is becoming an important criterion in the selection of crop and technology by farmers. On average, vegetables have about 80% higher water use economic efficiency than cereals (Table 22). When there is a water shortage, vegetables can be good substitutes for cereal crops to diversify the overriding cereal cropping system in Bangladesh. Gourd, bean, and heading cole generally gave higher water-use efficiency than other vegetable crops (Appendix 12).

The introduction of research-based innovations in vegetable production further improved water productivity by about 12%, with only spillover effect being positive. The water use efficiency of adopters in vegetables was lower than for non-adopters, producing a negative unexploited effect. This implies that the increase in the amount of water used on vegetables by the adopter farmers was more than required. The increase in water use efficiency in vegetables would have been much higher had adopters applied irrigation to vegetables to the level of non-adopters. However, as adoption in vegetables reduced water applications to cereal crops (to provide more water for vegetables), the adoption dramatically improved the water use efficiency in cereals, where both spillover and unexploited effects were positive (Table 22).

Table 22. Economic efficiency of water use (BTK/ BTK of irrigation cost) in vegetables and cereals by farmer type

Type of farmer	Vegetables	Cereals
Non-adopter	32 [a]	13 [a]
Adopter	29 [b]	19 [b]
Before adoption	26 [b]	10 [a]
Non-vegetable	—	23 [c]
All sample farmers	29	16
Effect of technology (%)		
Spillover	23.1	30.0
Unexploited	-11.5	60.0
Total	11.6	90.0

The same superscript in each column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Output efficiency

Another way of looking at the improvement in production environment is to analyze output efficiency measured in terms of unit output cost. Reduction in unit cost of output is an important tool to encourage consumption. If modern technologies give higher yield at exorbitant cost, such that it does not reduce unit output cost and prices, marketing of additional outputs soon becomes difficult. Change in per unit cost of output is therefore an important indication of economic performance of technologies. Unit output cost was estimated as total cost of all inputs except land including marketing cost divided by the output produced from the cost. The unit of land was in hectares, and duration of crop was one crop season both for the cost and output.

Adoption of modern technologies in vegetables improved output efficiency (Table 23). The total effect of the adoption on unit cost is about 19%. The spillover effect in reducing unit cost is small, at only 2.4%, suggesting that the effect produced higher yields with a proportional increase in input cost. The spillover effect will be difficult to sustain in the long run unless non-adopters harness the unexploited effect, as additional output produced by the non-adopters will be difficult to market at about the same price. On the other hand, it would be difficult to harness the unexploited effect, as non-adopters may not finance the necessary cost required for it. Therefore, there is a need to push continuously the vegetable production frontier upward. This can create some margin for the non-adopters to further reduce their cost through the spillover effect.

Table 23. Output efficiency (BTK/kg) in vegetables and cereals

Farm type/type of effect	Vegetable	Cereal
Non-adopter	4.0 [a]	6.3 [a]
Adopter	3.3 [b]	5.1 [b]
Before adoption	4.1 [a]	6.1 [a]
Non-vegetable farmers	—	6.1 [a]
Percentage reduction in unit cost		
Spillover effect	2.4	-3.3
Unexploited effect	17.1	19.7
Total effect	19.5	16.4

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Consumption Patterns

Quantity consumed

Vegetables are an important source of micronutrients, which are essential to human health. The per capita daily consumption of vegetables in the first quarter of 2000 was only 126 g (Table 24), well below the 200-g minimum recommended by AVRDC (Ali and Tsou 1997), despite the importance of micronutrients and the fact that the survey was conducted during the peak vegetable supply period. The vegetable supply in Bangladesh during off-season may be only 30% of the peak season supply (Ali 2000). Moreover, as the survey was conducted in the intensive vegetable-growing areas with higher representation for the vegetable farmers than in the population, the average consumption figure for Bangladesh may be biased toward the high side. Major vegetables consumed in Bangladesh are fruit-types (Fig. 4), which have relatively low micronutrient content and nutritive value.

As vegetable cultivation in general, and modern production technology in particular, improves farmers' income, adopters are consuming 8% more food and non-adopters 3% more food than non-vegetable farmers. The adoption of modern technologies in vegetable cultivation especially improved the quality of food, as adopter families are consuming 67% more vegetables than non-vegetable farmers, and 26% more than non-adopters. The consumption effect of technological innovation in vegetable production is underestimated here, because improved vegetable supply has decreased prices, and encouraged vegetable consumption by all sectors of the society. Thus vegetable consumption by non-adopters and non-vegetable farmers would have been even lower without technological innovations.

Table 24. Average per capita food consumption (g/day) by farmer type

Respondent	Cereal	Vegetable	Fruit	Meat	Fish	Egg and milk	Pulses	Root and tuber	Others	Total food
Adopter	403[a]	201[a]	27[a]	19[a]	46[a]	20[a]	26[a]	100[ab]	39[a]	881[a]
Non-adopter	410[a]	159[b]	22[a]	18[a]	49[a]	17[a]	22[ab]	110[a]	34[ab]	841[b]
Non-vegetable farmer	446[b]	120[c]	24[a]	15[a]	44[a]	19[a]	20[b]	94[b]	32[b]	814[b]
Bangladesh	431	126	29	19	48	22	22	97	35	831

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Note: The consumption for overall Bangladesh was estimated assuming 84% rural and 16% urban dweller (GOB 1997). Among the rural population, 10% were assumed to be vegetable farmers, and 74% non-vegetable farmers. Eight percent of the vegetable farmers were assumed to be non-adopters and 2% adopters. The consumption data for the urban population were used here to estimate the average values for Bangladesh. The average values for urban dwellers are not given here, however, to avoid detracting from the main purpose of the study, which was to look at the comparative effect of the project on controlled farmer groups.

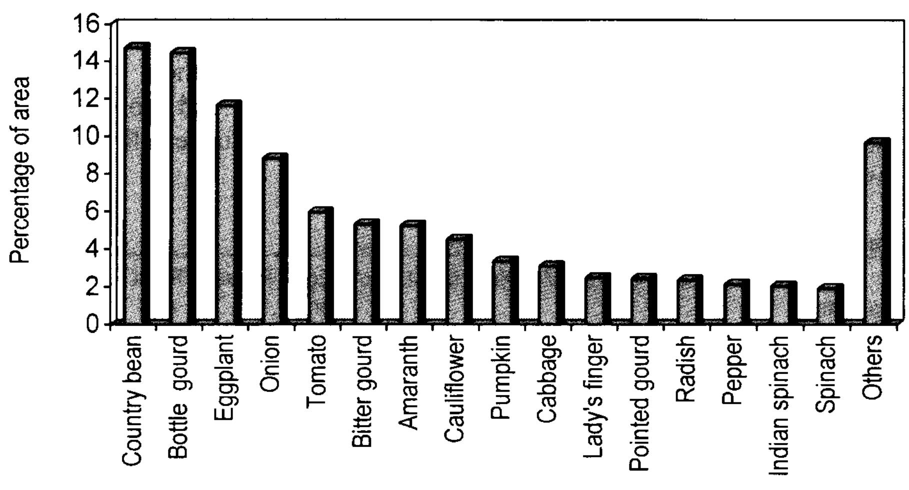


Figure 4. Major vegetables consumed in the sample areas

Non-adopters consumed about 32% more vegetables than non-vegetable farmers, indicating that expansion of vegetables to non-vegetable farmers could also improve vegetable consumption.

The consumption of leafy vegetables and heading cole was highest among adopters (about 23.1% versus 19.2% overall). The consumption of allium was highest among non-vegetable farmers (10.6% versus 9.3% overall), and non-vegetable farmers consume more cucurbits than non-adopters (28.9% versus 22.9%).

Higher vegetable consumption by adopters and non-adopters (i.e., vegetable growers) compared to non-vegetable growers did not significantly affect the consumption of other food items. Although the consumption of cereals is slightly lower, the consumption of pulses, roots and tubers, and 'other food' items is higher by vegetable farmers compared to non-vegetable farmers.

Food expenditure and budget share

On average, total daily expenditure on food (including home-produced food valued at shadow prices) in Bangladesh is 16 BTK per person (Table 25). As adopters receive more income from vegetable cultivation, they spend 1.7 BTK per person per day (about 11.6%) more on food compared to non-vegetable farmers. Non-adopter vegetable farmers spend 0.7 BTK per person per day (4.8%) more on food than the non-vegetable farmers.

Vegetable cultivation and adoption of technological innovation have the effect of improving the amount of the food budget allocated to vegetables, as adopters and non-adopters spend significantly higher proportions of their food budget on vegetables. They allocate proportionately less on cereals and more on vegetables, meats, pulses, and 'other foods,' compared to the food budget allocations by non-vegetable farmers.

Table 25. Budget share (%) of food groups

Respondent	Cereal	Vegetable	Fruit	Meat	Fish	Egg and milk	Pulses	Root and tuber	Others	Total food expenditure (BTK/person)
Adopter	34.1	10.4	3.1	8.9	18.3	3.4	5.6	5.6	10.7	16.3 [a]
Non-adopter	37.1	9.0	2.3	8.2	19.1	3.3	4.7	6.4	10.1	15.3 [b]
Non-vegetable farmer	41.4	7.4	2.5	7.5	19.1	3.5	4.5	5.5	8.8	14.6 [b]
Bangladesh	37.7	7.3	3.4	8.9	19.5	4.2	4.7	5.2	9.1	15.9

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Home Garden

More adopter and non-adopter vegetable farmers have home gardens than the non-vegetable farmers and urban dwellers. Vegetable farmers also have, on average, larger and more diversified home gardens. During the day the survey was conducted, vegetable farmers harvested more vegetables from their home garden than the other two groups, and adopters and urban dwellers consumed a higher proportion of harvested vegetables from the home garden than non-adopters and non-vegetable farmers (Table 26).

Table 26. Characteristics of home gardens by type of farmer

Home garden characteristics	Adopter	Non-adopter	Non-vegetable
Percentage of farmers having home garden	62.4	55.8	49.4
Average home garden size (m^2)	52. 8 [a]	56.4 [a]	26.0 [b]
Number of vegetables grown	2.8[a]	2.2 [b]	1.9 [c]
Average production of vegetables (kg/day)	1.9 [a]	2.0 [a]	1.2 [b]
Vegetable consumed (% of production)	25.4	14.7	14.2

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

About one-half of the vegetables grown in the home garden in Bangladesh are gourds and cucurbits, and more than one-fourth are other fruit vegetables. Adopters produce more heading cole and leafy vegetables in the home garden than other groups, perhaps due to the emphasis on leafy vegetables in the nutritional awareness campaign among the housewives of adopters (Table 27).

Table 27. Vegetables grown in the home garden (% of daily production) by vegetable group and farmer type

Respondent	Adopter	Non-adopter	Non-vegetable	Overall
Leafy vegetable	7.4	2.2	2.0	3.0
Gourds and cucurbits	43.4	42.3	52.9	51.9
Other fruit vegetable	32.4	38.7	25.6	27.0
Heading cole	7.2	1.6	0.9	1.3
Stem and root vegetable	4.7	7.2	2.3	3.2
Fruits	4.9	8.0	16.3	13.7

Source of Food

In Bangladesh, 54% of food is purchased, 42% is farm produced, and 3% comes from home gardens. About 17% of the vegetables and 6% of the fruit consumed come from home gardens. A small quantity of fruits and vegetables is also shared among neighbors as gift (Table 28).

Vegetable production and adoption of new technologies in their cultivation altered food sources. Adopters and non-adopters obtained more vegetables and fruits from farm and home gardens, and a higher proportion of fish is produced on the farm than non-vegetable farmers. Vegetable farmers, however, had higher purchases of cereal, egg and milk, and meat, and overall food from the market (Table 28).

Table 28. Source of food (%) consumed in Bangladesh by farmer type

Respondent/ food source	Cereal	Vegetable	Fruit	Meat	Fish	Egg and milk	Pulses	Others	Root and tuber	Total
Bangladesh										
Farm produce	68	5	36	16	6	53	6	11	13	42
Purchase	32	75	53	82	94	46	94	87	87	54
Home garden	0	17	6	0	0	0	0	0	0	3
Adopter										
Farm produce	52	37	47	17	20	69	16	19	32	42
Purchase	48	35	32	83	80	31	83	81	68	51
Home garden	0	27	17	0	0	0	1	0	0	7
Non-adopter										
Farm produce	61	32	40	20	16	58	15	11	31	44
Purchase	39	45	40	80	84	39	85	87	68	50
Home garden	0	22	18	0	0	1	0	1	1	5
Non-vegetable										
Farm produce	82	1	54	22	5	72	6	15	14	51
Purchase	18	77	38	75	95	27	93	83	86	45
Home garden	0	18	5	0	0	0	0	0	0	3

The figures from all sources for an individual group may not add up to 100, because the remaining part is shared as gifts.

Nutrient Uptake

Nutrient availability was estimated by multiplying per capita food quantity with its respective nutrient content, using nutrient content tables from Bangladesh and India.

Our data confirm conclusions from other studies that there is a severe deficiency in micronutrient supply in Bangladesh (Jahan 1996). Important micronutrients, such as calcium, iron, and vitamins A, B_1, B_2, and C, and niacin are all either lower than or at the lower range of the recommended levels (Table 29). Deficiency in micronutrient supply appears to be more serious than energy shortage.

Adoption of modern technologies coupled with the nutrient awareness program improved micronutrient supply to adopters (Table 29). Availability of important micronutrients to adopters, especially iron and vitamin A, mainly derived from vegetables are significantly higher than to non-adopters and non-vegetable farmers. It seems that there was not much spillover effect in nutrient uptake. Despite non-adopter families using more vegetables than non-vegetable families, the nutritional availability between non-adopters and non-vegetable farmers was not statistically different, except for vitamin C and B_1, because of the compositional differences in individual vegetable consumption. On the other hand, enhancing vegetable production on adopter farms only partially mitigated micronutrient deficiency. They are still consuming less than the recommended level. Vegetable production alone, therefore, is not enough to increase nutrient availability at the family level in Bangladesh. Nutrient awareness and vegetable production enhancement programs should go hand in hand to achieve the objective of higher micronutrient uptake. This goal was pursued in the project through lectures and discussions among the females in households of adopters on the role of vegetables in supplying micronutrients.

Table 29. Nutrient uptake by farmer type

Nutrient	Unit	Recommended level	Adopter	Non-adopter	Non-vegetable farmer	Bangladesh
Calories	Kcal	1800-2400	2002.4 ^{a}	1986.5 ^{a}	2029.0 ^{a}	2005.7
Protein	G	45-65	70.2 ^{a}	64.9 ^{ab}	61.2 ^{b}	66.8
Fat	G	—	17.4 ^{a}	16.3 ^{a}	15.7 ^{a}	18.2
Carbohydrate	G	—	351.7 ^{a}	355.0 ^{a}	379.8 ^{b}	357.2
Calcium	Mg	800-1200	347.8 ^{a}	315.2 ^{ab}	294.8 ^{b}	329.8
Iron	Mg	37178	14.4 ^{a}	12.4 ^{b}	11.7 ^{b}	13.2
Vitamin A	(mg)	4200-5000	3271.3 ^{a}	2133.5 ^{b}	2027.0 ^{b}	2619.8
Vitamin B_1	Mg	1.12	0.56 ^{a}	0.54 ^{a}	0.51 ^{b}	0.54
Vitamin B_2	Mg	1.22	0.7 ^{a}	0.6 ^{b}	0.6 ^{b}	0.7
Niacin	Mg	14.66	11.8 ^{a}	11.6 ^{a}	11.7 ^{a}	11.8
Vitamin C	Mg	50-70	73.5 ^{a}	60.2 ^{b}	50.0 ^{c}	61.5

The same superscript in a column implies that the figures are not statistically different, and different superscripts imply a statistical difference, both tested at the 10% level.

Importance of Vegetables in Nutrient Uptake

Despite low supplies, vegetables are important sources of all critical micronutrients such as vitamin A and C, whereas cereals are the main source of calories, carbohydrates, vitamins B_1 and B_2, and niacin (Table 30). Cereals, vegetables, and tubers contribute almost equally to iron supply. Improving vegetable supply can obviously help to reduce micronutrient deficiency in Bangladesh.

Table 30. Nutrient uptake and source of nutrient uptake

Nutrient (unit)	Percentage of total uptake supplied by								
	Cereals	Vegetables	Fruit	Meat	Fish	Egg and milk	Pulses	Root and tuber	Others
Calories (Kcal)	70.3	5.5	1.1	2.5	2.7	0.9	4.1	9.5	3.4
Protein (g)	42.7	9.8	0.4	15.0	10.9	1.7	9.1	8.7	1.7
Fat (g)	11.9	1.8	0.3	6.1	2.6	6.9	0.3	69.7	0.4
Carbohydrate (g)	89.2	1.7	1.3	0.0	0.1	0.2	0.7	2.3	4.5
Calcium (mg)	13.3	29.6	2.0	2.7	28.9	7.0	5.2	8.9	2.4
Iron (mg)	25.2	23.7	2.1	14.5	4.2	0.9	8.3	18.3	2.7
Vitamin A (mg)	0.4	78.1	11.6	1.2	0.1	5.2	1.8	0.6	1.0
Vitamin B_1 (mg)	51.5	21.5	1.7	2.1	0.3	2.4	3.7	3.5	13.3
Vitamin B_2 (mg)	38.5	22.4	3.1	8.3	1.4	7.2	15.7	2.1	1.3
Niacin (mg)	68.1	9.4	0.8	9.3	1.9	0.2	0.9	2.3	7.1
Vitamin C (mg)	0.0	63.5	8.8	0.0	7.7	0.6	0.0	0.1	19.3

Nutritive Value of Vegetables

Vegetables may provide some important micronutrients, but may be lacking in others. What is the overall nutritive value of vegetables compared with other food items? To estimate these values, the relative nutrient cost of each nutrient was estimated as total expenditures on all the commodities containing a particular nutrient, divided by the nutrient quantities obtained from all these commodities. We then multiplied the relative nutrient cost with the respective nutrient content of a commodity, and summed these values to get the relative nutritive value of all the nutrients present in the commodity (Ali and Tsou 2000). The relative nutritive value of a commodity was compared with its price to estimate the nutritive efficiency.

The nutritive values of meat and pulses are highest (Table 31). When nutritive values were compared with respective market prices, however, vegetables had the highest nutritive efficiency in Bangladesh. A vegetable production enhancement program would therefore help to improve the overall nutritional status of the people of Bangladesh.

Table 31. Nutritive value and efficiency at the food group level

Food item	Price (BTK/100 g)	Quantity (100 g)	Nutritive value (BTK/100 g)	Efficiency
Cereals	1.4	4.1	1.5	1.1
Vegetable	0.7	1.4	1.8	2.5
Fruit	1.9	0.3	1.1	0.5
Meat	7.5	0.2	5.3	0.7
Fish	6.4	0.5	2.9	0.5
Egg & milk	3.1	0.2	1.7	0.6
Other pulses	3.4	0.2	4.5	1.3
Root crops	0.9	1.0	0.6	0.7
Spices	3.7	0.3	3.6	1.0
Overall	1.9	8.5	2.0	1.0

Leafy vegetables such as amaranth and Indian spinach have the highest nutritive efficiency (Table 32), so these vegetables should be emphasized in production as well as in nutritional awareness programs to enhance the nutritive value of Bangladeshi food.

Economic Viability of the Innovations

After discussing the effect of technological innovations on various aspects of production and consumption, we can now evaluate their overall economic viability. The following criteria were used for the evaluation: family income, return on investment, and economic surplus and rate of return on the public sector investment.

Family income

Vegetable cultivation and adoption of science-based innovations improved input use and output efficiencies. How much does this impact the overall income of the farmer? The impact depends upon the following:

- The relative share of agriculture in total income (i.e. farm versus off-farm income);
- The proportion of income from vegetables to total income and the area on which new technologies are adopted; and
- The extent of improved management skills (learned through vegetable cultivation and adoption of new technologies applied to other crops).

Table 32. Nutritive value of selected food commodities

Vegetable	Price (BTK/100 g)	Quantity (100 g)	Nutritive value (BTK/100 g)	Efficiency (ratio)
Garlic	3.57	0.02	1.29	0.36
Ginger	3.67	0.00	0.93	0.25
Onion	1.22	0.14	0.65	0.53
Tomato	0.80	0.09	1.50	1.87
Pepper	3.24	0.05	6.72	2.08
Eggplant	0.73	0.18	0.75	1.03
Country bean	0.77	0.23	3.10	4.02
Bottle gourd	0.56	0.23	0.35	0.63
Bitter gourd	1.18	0.08	1.58	1.34
Pumpkin	0.70	0.05	0.76	1.08
Other gourd	0.90	0.06	0.64	0.71
Amaranth	0.65	0.11	5.58	8.65
Indian spinach	0.40	0.03	3.24	8.11
White jute	0.50	0.02	1.18	2.36
Heading cole	0.58	0.12	1.27	2.20
Okra	1.01	0.04	2.20	2.18
Radish	0.24	0.04	0.56	2.36
Banana	1.36	0.07	0.55	0.41
Papaya	0.74	0.05	2.03	2.74
Coconut	1.47	0.04	0.33	0.22
Lentil	2.91	0.03	4.78	1.65
Other pulse	3.53	0.20	4.44	1.26
Egg	5.43	0.05	2.77	0.51
Milk	2.44	0.17	1.42	0.58
Beef	6.82	0.09	8.73	1.28
Mutton	11.30	0.01	3.13	0.28
Chicken	7.67	0.10	2.57	0.34

Adopters received agriculture training through AVRDC production training and demonstration programs. This training, and the fact that adopters are producing and selling more output, helped them to secure more off-farm income opportunities. The off-farm activities in which vegetable farmers engaged were agriculture related (for example, marketing of vegetables, supplying of inputs). Apart from the direct effect of increasing farmers' income, vegetable cultivation and adoption of modern technologies helped overall development of the rural economy by encouraging agricultural business activities. The effect of vegetable cultivation was 5% (Table 33) and the technology effect in earning off-farm income was about 17%.

Table 33. Source of family income by farm type

Type of income	BTK/month/family			Percentage effect of		
	Non-adopter	Adopter	Non-vegetable farmers	Vegetable cultivation	Technology in vegetables	Total
Off-farm income	577	670	549	5.1	16.9	22.0
Income from vegetables as a % of total farm cash income	27	40	—	—	49.9	49.9
Farm cash income including vegetables	1611	1743	1325	21.6	10.0	31.6
Value of farm-produced food	1119	1171	1243	-10.0	4.2	-5.8
Total cash and non-cash income	3307	3583	3116	6.1	8.9	15.0
Expenditure on purchased food	1723	1857	1546	11.4	8.7	20.1
Money available for non-food expenditures	465	555	328	41.9	27.4	69.3

Vegetable cultivation contributed 27% of the farm cash income of non-adopters, and 40% of adopters. However, some of this contribution came at the cost of other crops. At the margin, vegetable cultivation increased farm cash income by 21.6%, while adoption of modern technologies further enhanced it by 10.0%.

However, adopters and non-adopters consumed slightly less food from farm-produced output. Vegetable cultivation increased cash and non-cash income (including the value of home-produced food) by about 6%, and technologies further enhanced it by about 9%. This is a significant contribution to poor farmers' income and welfare in Bangladesh. The additional income helped to boost savings, increased expenditure on purchased food, and as noted earlier, contributed to improved farm implements and children's education. These conclusions contrast with the IFPRI study that found the marginal increase in farmers' income with AVRDC technology was less than 1%. The contribution of AVRDC technologies in enhancing farmers' income was downplayed in the IFPRI study because of the following:

- Unusual study location near a city, where off-farm income of farmers was higher than farm income. In our case, off-farm income of vegetable farmers constitutes about 17% of the total farm income; and
- Small agricultural land ownership of 4352 m^2, and vegetable harvested area of 789 m^2, and even less for AVRDC crops. In our case, adopters owned an average of 7157 m^2, and vegetable harvested area was 1693 m^2. Average field size in the IFPRI study was 202 m^2, whereas in our study the average plot size was 764 m^2.

Return on farmers' investment

The marginal rate of return (MRR), defined as additional net return from the innovations divided by the additional cost expressed in percentage terms (CIMMYT 1988), was estimated to determine the overall economic viability of the resources invested on the adoption. The MRR was estimated at each of the two stages of adoption, as well as for the whole adoption. For example, MRR for the spillover effect was estimated as the difference in net revenue (Table 17) divided by the difference in cost (Table 19) between non-adopters and adopters before adoption. Similarly, MRR for the unexploited effect and total adoption can be calculated by taking differences in net revenue and cost of the respective group of farmers.

The MRR of the spillover effect was highest (1045%), because few resources were required to achieve tremendous initial benefits. To achieve the full benefit after the spillover effect, the additional cost increased and additional benefit decreased, lowering the MRR. However, the rate of return on the investment required to achieve the unexploited benefits of the technology after the spillover effect was still high at 338%. This is higher than the opportunity cost of the capital (expected to be not more than 100% in Bangladesh).

The MRR to achieve the full gain of the technology is 241%. Adoption of modern vegetable technologies therefore gives a high rate of private return on investment to farmers.

Rate of return on public sector investment

Until now we quantified the effect of modern technologies separately on different groups of consumers and producers at the farm and household levels. We are now in a position to estimate the economic benefits of technological innovation in vegetable production to the whole society at the macro-level. The society is still divided into vegetable consumers and producers. As indicated earlier, vegetable producers in Bangladesh benefited from the adoption because of higher returns on the resources invested in vegetable production, such as land, labor, and cash. Consumers benefited because of abundant supplies available at low prices. The main question is: what is the relative share to producers and consumers of the additional welfare generated from the adoption of science-based innovations? The productivity gains of modern technologies estimated in the previous section provide the basis for calculating welfare gains, while demand and supply elasticities are critical in segregating the total gains among producers and consumers. The theoretical model, estimation procedure, and assumptions used in the estimation of welfare gains are defined in Appendix 13. The data used in the estimation are given and explained in Appendix 14.

The estimates suggest that science-based technological innovations generated a total value of US$8.8 million during 1991-99. This gain was divided between consumers (US$4.6 million) and producers (US$4.2 million). The total expenditure on the project by USAID was US$4.25 million, and the Government of Bangladesh invested about US$2.9 million. These returns and costs were spread over the period 1991-99 in a way that costs and returns were low in the earlier years. The internal rate of return on the investment made by USAID and the Government of Bangladesh on vegetable R&D in the country was 42%. The economic surplus estimated here is limited to increased vegetable productivity. The effect of technological innovations in vegetables was not confined to vegetables only, however. It spread to other crops due to enhanced managerial capacity of the farmers. The impact of research will continue to generate a surplus for many years. This will greatly increase the value of the economic surplus and internal rate of return on investment in vegetable research and development.

Summary and Policy Implications

Micronutrient deficiency in Bangladesh is causing serious health problems and economic losses to society. The main cause of this deficiency is the cereal-based monocropping system that traps farmers and farm families in a vicious cycle of low resource productivity-malnutrition-poverty. The introduction of science-based technological innovation in vegetable cultivation through the AVRDC/USAID/BARI project was seen as a possible solution to this problem in the early 1990s.

Based on secondary data from the Bureau of Agricultural Statistics, there were remarkable increases in vegetable production during the innovation period (1991-99). The annual growth in production doubled from 1.8% during the pre-innovation period (1973-90) to 3.1% during the innovation period, and vegetable prices remained stable. For the first time in the history of Bangladesh, per capita vegetable availability increased — by about 18%. There was also some improvement in seasonal supplies of vegetables.

The farm survey on production and consumption conducted in four major vegetable-growing provinces in Bangladesh during early 2000 gave additional insights. The survey results indicated that Bangladeshi farmers welcomed the vegetable production technologies and varieties promoted through the project, as these generated clear economic benefits to adopters. On average, vegetable yield increased by 38% on the adopter farms, while increase in cost was about 13%. This improved resource use economic efficiency of land, labor, and water by about 65, 40, and 12%, respectively, and output efficiency through reduction in unit output cost by about 20%. Vegetable cultivation itself creates additional productive employment opportunities over cereal crops, and adoption of modern technologies further enhanced these opportunities by about 10%, mainly due to higher labor requirements in weeding, manuring, harvesting, and marketing the increased output. This gave a boost to agricultural business activities. Adopter farmers seized these opportunities as shown by their significantly higher off-farm incomes, compared to non-adopters and non-vegetable farmers. There was some spillover effect of technology adoption by adopters to non-adopters. Substantial additional costs, however, are required to achieve the unexploited gain of new technologies, which may be one of the major constraints to wider adoption.

There has also been a significant improvement in the managerial skills of the adopter farmers, through AVRDC-sponsored training and demonstration programs. This training helped farmers to understand the requirements of new technologies and to adjust their management activities accordingly. As adopters gained new skills to manage their crops, they used these skills to improve efficiencies of resources employed in other crops. This is demonstrated by improvements in the economic efficiency of inputs used in other than vegetable crops. For example, the resource use efficiencies on the adopter farms of land, labor, and water used in cereal crops improved by 165, 41, and 90%, respectively.

Adoption of new technologies increased vegetable consumption of adopting families by about 67% compared to non-vegetable families, and 26% compared to non-adopter families. While non-vegetable farmers and non-adopters consume about 50% less than the recommended levels of vitamin A, the adopters are only 25% below the recommended level. Although non-adopter farm families consume significantly higher amounts of vegetables than non-vegetable families, the difference in types of vegetable consumed reduces the difference in nutrient availability between the two groups. Vegetable production alone is therefore not enough to enhance nutrient supplies at the family level. The production enhancement programs must be accompanied by nutritional awareness campaigns. These were an important component of the AVRDC/USAID/BARI Bangladesh vegetable project.

The adoption of science-based technologies was able to make a decisive impact on poverty. The mean farm cash income of adopting farmers was about 10% higher than the farm cash income of non-adopters, and 32% higher than that of non-vegetable farmers. Adopting farmer's also earned significantly higher off-farm income. The additional income helped to boost savings, to increase expenditures on purchased food, and to improve farm implements and children's education.

The estimated marginal rate of return (MRR) on investment made by adopters to achieve the full gain of new technologies is 241%. It is estimated that the technological innovations in vegetable production generated about US$8.8 million economic surplus to Bangladeshi farmers and consumers during the nine-year project. Producers benefited (US$4.6 million) through reduced cost of production and improved resource use economic efficiency, and consumers benefited (US$4.2 million) from lower vegetable prices through increased supply. The internal rate of return (IRR) on the public sector investment in vegetable R&D was 42% or higher.

Investing in vegetable R&D is highly profitable, and is the best way to improve the livelihoods of poor farmers and urban dwellers. Despite the initial achievements through the USAID/AVRDC/BARI Bangladesh vegetable project, vegetable consumption in the country is still far below the recommended level. Efforts to enhance vegetable supplies, coupled with nutritional awareness of the role of vegetables in supplying micronutrients that are vital to good health, need to be pursued vigorously. Research efforts should focus on reducing the cost of production, which seems to be the major constraint to adoption. As well, a research project should be undertaken to provide an in-depth understanding of constraints to the expansion of vegetable production, and to the adoption of new technologies, in Bangladesh.

References

ACC/SCN (Administrative Committee on Coordination/Sub-committee on Nutrition). 1991. Controlling iron deficiency. State of the Art Series No. 9. A Report Based on an ACC/SCN Workshop, Geneva.

Ali, M. 2000. Dynamics of vegetable production, distribution, and consumption in Asia. Shanhua, Tainan, Taiwan: Asian Vegetable Research and Development Center.

Ali, M., and Tsou, C.S. 1997. Combating micronutrient deficiencies through vegetables - a neglected food frontier in Asia. Food Policy, 22(1), 17-38.

Ali, M., and Tsou, C.S. 2000. AVRDC's Integrated Research Approach to Enhance Micronutrient Availability. Food and Nutrition Journal, 21(4), 472-482.

Alston, J.M., Norton, G.W., and Pardey, P.G. 1995. Science under scarcity: Principles and practice for agricultural research evaluation and priority setting. Ithaca and London: International Service for National Agricultural Research, Cornell University Press. 585 p.

AVRDC/ARC/BARI. 2000. AVRDC-USAID Bangladesh project: introduction and development of adaptive technologies for sustainable year-round vegetable production and consumption in Bangladesh. AVRDC-USAID Bangladesh project completion report. Asian Vegetable Research and Development Center (Tainan, Taiwan)/Asian Regional Center (Bangkok, Thailand)/Bangladesh Agriculture Research Institute.

Behrman, J.R., and Deolalikar, A.B.1988. Health and nutrition. In: Hollis, B. C., and Srinivasan, T.N. (ed.) Handbook on Development Economics, Vol. 1, p. 631-711. Amsterdam: North-Holland Publishing Co.

Byerlee, D., and Polanco, H.E. 1986. Farmers' stepwise adoption of technological packages: Evidence from the Mexican Altiplano. American Journal of Agricultural Economics, 68(3), 519-527.

CIMMYT (International Maize and Wheat Improvement Center). 1988. From agronomic data to farmer recommendation: An economic training manual. (Revised Edition) Mexico, D.F.: CIMMYT.

Doryan, E. 2000. Welcome Address in the United Nations System's Forum on Nutrition. SCN News, United Nations Administrative Committee on Coordination, Sub-Committee on Nutrition (ACC/SCN), No. 21, December 2000, p. 38.

GOB (Government of the People's Republic of Bangladesh). 1995. Country Paper on Nutrition. Dhaka: Ministry of Health and Family Welfare, and Bangladesh National Nutritional Council.

GOB (Government of the People's Republic of Bangladesh). 1997. National Plan of Action for Nutrition. Dhaka: Ministry of Health and Family Welfare, and Bangladesh National Nutritional Council.

GOB (Government of the People's Republic of Bangladesh). (various issues) 1990-2000. Yearbook of Agricultural Statistics. Dhaka: Bangladesh Bureau of Statistics, Statistics Division, Ministry of Planning.

IFPRI (International Food Policy Research Institute). 1998. Commercial vegetable and polyculture fish production in Bangladesh: Their impact on income, household resource allocation, and nutrition, Volume 1. Washington, D.C.: IFPRI.

IPHN (Institute of Public Health Nutrition)/UNICEF. 1989. Night Blindness Prevention Program Evaluation Report. Dhaka, Bangladesh.

Jahan, K. 1996. Nutrition Survey of Bangladesh 1995-96. Dhaka: Institute of Nutrition and Food Science, Dhaka University. 73 p.

McKigney, J.I. 1984. Some observations on the potential for the dietary approach to combat vitamin A deficiency. In: Tanphaichir, V., Dahlan, W., Suphakaran, V., and Valyasaevi, A. (ed.) Human Nutrition: Better Nutrition Better Life. Bangkok, Thailand: Aksornsmai Press, p. 17-78.

Rosegrant, M.W., and Pingali, P.L. 1994. Policy and technology for rice productivity growth in Asia. Journal of International Development 6: 665-688.

Von Braun, J., and Pandya-Lorch, R. 1991. Income sources of malnourished people in rural areas: Microlevel information and policy information. Working Paper on Commercialization of Agriculture and Nutrition No. 5. Washington, D.C.: International Food Policy Research Institute.

Yusuf, H.K.M., Salamantullah, M., Islam, N., Haque, T., and Pandav, C.S. 1993. Report of the national iodine deficiency disorder survey in Bangladesh. UNICEF.

Appendixes

Appendix 1: Spline function to estimate the growth rate for different periods

The following spline function was used to estimate the percentage annual growth in area, production, and yield during the pre-innovation period (1973-90) and innovation period (1991-99):

$$\ln Y = a + bT + cT_1$$

where Y is area, production, or yield during 1973-99, T is 1, 2, ,26 for 1973, 1974, , 1999, respectively, T_1 is 1, 2, 3, 9 for 1991, 1992, , 1999, respectively, and zero otherwise. The growth rate for 1973-99 is equal to the coefficient of b in the equation, and the growth rate for 1991-99 is estimated as $b+c$. The spline function estimates the growth rates for different periods in one go by using all observations for the whole period. This is different than the traditional approach, where growth rates are estimated separately for each period using the respective period observations. The use of all observations in the spline function makes the period-specific growth rates insensitive to the starting value of each period, which is a major problem in estimating growth rates in the traditional approach.

Appendix 2: Soil types (% of total parcel in each farmer group) by crop and farmer type

Crop	Non-adopter			Adopter			Non-vegetable		
	H	M	L	H	M	L	H	M	L
Gourd	43	42	15	51	34	15	0	0	0
Tomato	40	60	0	36	54	10	0	0	0
Eggplant	40	50	10	20	72	8	0	0	0
Lady's finger	45	50	5	39	52	9	0	0	0
Leafy	70	21	9	57	37	6	0	0	0
Bean	41	49	10	56	34	10	0	0	0
Heading cole	18	73	9	21	63	16	0	0	0
Overall vegetable	45	45	10	43	47	10	0	0	0
Rice	52	46	2	59	27	14	54	40	6
Wheat	56	44	0	22	71	7	22	56	22
Cereal	53	45	2	52	36	12	51	41	7
All parcels	48	44	8	44	45	11	53	40	7

H= heavy soil including clay, clay loam, loam; M = medium soil including sandy loam; L = light soil including sandy and silt.

Appendix 3: Land type (% of the total parcel in each farmer group) by crop and farmer type

Crop	Non-adopter			Adopter			Non-vegetable		
	H	M	L	H	M	L	H	M	L
Gourd	36	57	7	44	42	14	0	0	0
Tomato	86	7	7	66	26	8	0	0	0
Eggplant	62	24	14	64	20	16	0	0	0
Lady's finger	32	50	18	57	33	10	0	0	0
Leafy	33	42	25	44	46	10	0	0	0
Bean	43	35	22	59	29	12	0	0	0
Heading cole	63	14	23	63	11	26	0	0	0
Overall vegetable	47	38	15	55	33	12	0	0	0
Rice	16	37	47	27	34	39	22	22	56
Wheat	19	62	19	36	50	14	23	33	44
Cereal	16	41	43	29	37	34	22	23	55
All parcels	41	39	20	52	33	15	23	23	54

H= High land implies that water drains out when heavy rain occurs; M = medium land implies that water stays for less than 10 hours after heavy rain stops; L = low land implies that water stays more than 24 hours after heavy rain stops.

Appendix 4: Fertilizer and manure use (per hectare) on selected vegetables and cereals by farmer type

	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Overall vegetables	Average of cereals
Fertilizer (kg of nutrient)									
Non-adopters	259	304	427	199	181	183	291	276	113
Adopters	206	349	561	286	234	263	236	286	91
Before adoption	166	159	261	304	77	238	269	212	111
Non-vegetable farmers	—	—	—	—	—	—	—	—	115
Manure (kg of material)									
Non-adopters	4677	4602	3643	3881	4571	2936	2589	3995	1673
Adopters	6043	8074	3476	6619	5645	7538	2298	6258	1394
Before adoption	5736	6750	8708	8215	5637	7627	2260	7041	1332
Non-vegetable farmers	—	—	—	—	—	—	—	—	1397

Appendix 5: Pesticide use (per hectare) on selected vegetables and cereals by farmer type

Farmer type	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Overall vegetables	Average of cereals
Pesticide (liter/kg of material)									
Non-adopters	4.95	6.14	7.46	5.01	1.35	5.89	2.94	5.02	0.42
Adopters	3.79	3.50	8.01	4.48	0.90	3.31	1.95	3.51	0.33
Before adoption	3.92	3.65	8.60	4.41	1.29	4.30	5.76	4.53	0.26
Non-vegetable farmers	—	—	—	—	—	—	—	—	1.03
Pesticide (number of sprays)									
Non-adopters	2.4	3.3	18.8	2.6	0.6	5.5	2.8	6.5	1.8
Adopters	1.8	3.4	16.1	3.4	0.4	2.1	2.1	3.2	1.0
Before adoption	3.0	4.0	14.5	2.7	0.8	3.8	2.8	4.8	0.8
Non-vegetable farmers	—	—	—	—	—	—	—	—	1.5

Appendix 6: Number of irrigations given to selected vegetables and cereals by farmer type

Farmer type	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Overall vegetables	Average of cereals
Non-adopters	3.3	3.4	4.0	1.3	2.2	2.8	4.8	3.2	2.9
Adopters	2.9	4.2	8.1	4.0	1.8	3.0	4.3	3.6	2.8
Before adoption	1.9	3.4	3.5	3.7	1.5	2.5	2.7	2.8	3.2
Non-vegetable farmers	—	—	—	—	—	—	—	—	2.8
All sample farmers	2.7	3.7	5.2	3.0	1.8	2.8	3.9	3.3	2.9

Appendix 7: Labor use (days/hectare) by activity and farmer type in selected vegetables and cereals

Farmer type/labor activity	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Overall vegetables	Cereal
Non-adopter									
Planting and land preparation	75	77	93	70	55	89	86	78	51
Crop management[1]	102	93	110	48	36	92	65	86	26
Harvesting	79	169	121	97	68	112	26	93	47
Marketing [2]	67	73	61	56	52	91	29	64	14
Total labor (days)	323	412	385	271	211	384	206	321	138
Adopter									
Planting and land preparation	72	96	85	77	66	74	92	78	44
Crop management[1]	107	144	129	94	60	87	67	97	20
Harvesting	79	167	111	118	66	130	26	106	45
Marketing [2]	62	86	52	81	62	85	22	71	13
Total labor (days)	320	493	377	370	254	376	207	352	122
Before adoption									
Planting and land preparation	79	82	100	71	61	83	91	79	49
Crop management[1]	84	89	116	81	47	98	64	84	21
Harvesting	98	179	70	99	93	123	17	101	49
Marketing [2]	66	90	90	84	64	76	32	77	15
Total labor (days)	327	440	376	335	265	380	204	341	134
Non-vegetable farmers									
Planting and land preparation	—	—	—	—	—	—	—	—	39
Crop management[1]	—	—	—	—	—	—	—	—	15
Harvesting	—	—	—	—	—	—	—	—	36
Marketing [2]	—	—	—	—	—	—	—	—	10
Total labor (days)	—	—	—	—	—	—	—	—	140
All sample farmers									
Planting and land preparation (%)	23.4	19.0	24.5	22.5	24.9	21.5	43.5	23.2	37.2
Crop management (%)[1]	30.2	24.0	31.2	22.4	19.4	24.3	31.7	26.3	16.6
Harvesting (%)	26.3	38.5	26.5	32.5	31.1	32.1	11.2	29.6	35.7
Marketing (%)[2]	20.1	18.5	17.8	22.6	24.5	22.1	13.5	20.9	10.4
Total labor (days)	322.9	448.6	379.4	325.7	244.0	380.0	206.4	338.2	133.2

[1] The crop management labor includes input application, preparation of protective structure, and weeding.

[2] Marketing includes carrying or transporting from farm to house and market, grading, and packaging.

Appendix 8: Number of operations in selected vegetables and cereals by farmer type

	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Vegetable	Cereal
Non-adopter									
Land preparation	8.2	9.4	9.9	8.4	7.8	9.5	9.8	8.9	7.0
Weeding	2.2	3.1	3.2	1.7	1.4	1.7	2.1	2.2	1.1
Manuring	2.1	2.1	2.3	1.5	1.7	1.7	1.7	1.9	1.9
Spraying	2.4	3.3	18.8	2.6	0.6	5.5	2.8	6.5	1.8
Irrigation	3.1	2.1	3.7	0.8	1.3	2.4	4.2	2.7	3.7
Structures	1.3	0.3	0.0	0.0	0.1	1.1	0.1	0.6	0.0
Harvesting	12.7	12.5	25.9	14.3	7.2	13.4	1.0	14.4	1.7
Adopter									
Land preparation	7.5	10.7	9.4	9.7	7.6	7.7	9.5	8.9	6.8
Weeding	1.9	2.2	5.2	2.7	1.5	1.6	3.2	2.4	1.0
Manuring	2.4	3.0	3.2	2.9	2.4	2.0	2.1	2.7	1.6
Spraying	1.8	3.4	16.1	3.4	0.4	2.1	2.1	3.2	1.0
Irrigation	2.5	2.0	7.1	3.0	1.3	2.1	4.3	2.7	3.2
Structures	1.4	1.7	0.0	0.0	0.1	0.8	0.0	0.6	0.0
Harvesting	12.4	11.0	21.2	19.6	5.5	10.7	1.0	12.8	1.7
Before adoption									
Land preparation	8.1	9.0	10.1	8.4	7.4	7.9	8.5	8.5	7.6
Weeding	1.5	2.2	2.8	2.8	1.2	1.6	1.8	2.1	1.2
Manuring	2.0	3.0	3.9	2.8	2.1	2.8	3.7	2.8	2.1
Spraying	3.0	4.0	14.5	2.7	0.8	3.8	2.8	4.8	0.8
Irrigation	1.3	1.6	2.8	2.4	1.1	2.1	2.2	1.9	4.6
Structures	1.3	0.3	0.2	0.0	0.1	0.7	0.0	0.4	0.0
Harvesting	13.5	10.1	15.5	16.5	8.1	12	1.0	12.9	1.8
Non-vegetable farmers									
Land preparation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9
Weeding	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
Manuring	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3
Spraying	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5
Irrigation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
Structures	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Harvesting	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9

Appendix 9: Total cost, and factor share in selected vegetable and cereal production by farmer type

Farmer type/ cost item	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Vegetables	Cereal
Non-adopter									
Seed (%)	2.7	3.1	2.0	6.8	4.9	4.3	5.0	3.3	8.7
Structure (%)	13.3	3.4	0.0	0.0	0.7	8.6	0.0	5.7	0.0
Fertilizer (%)	21.2	21.4	26.7	21.1	25.5	13.8	30.6	22.5	26.1
Pesticide (%)	6.4	10.1	9.8	8.5	3.0	8.4	7.0	7.6	2.0
Irrigation (%)	4.2	8.5	6.0	3.7	7.9	3.9	7.5	5.4	8.2
Labor (%)	47.3	44.8	49.0	49.8	46.7	55.3	40.1	48.6	54.6
Marketing (%)	4.9	8.7	6.5	10.1	11.3	5.7	9.8	6.9	0.4
Total cost (BTK/ha)	34818	45379	39667	28817	23754	37772	25067	34069	11473
Adopter									
Seed (%)	2.9	2.9	1.6	4.8	4.2	4.5	6.2	3.8	9.3
Structure (%)	11.6	8.4	0.0	0.4	2.0	8.1	0.0	4.6	0.0
Fertilizer (%)	22.3	21.7	34.4	25.9	27.1	25.7	31.8	25.5	22.6
Pesticide (%)	5.7	3.3	9.7	4.8	2.0	4.6	4.9	4.6	1.1
Irrigation (%)	4.7	7.4	8.4	7.2	5.6	5.5	6.5	6.6	7.1
Labor (%)	49.3	49.6	41.0	47.8	48.5	46.4	43.2	47.6	58.5
Marketing (%)	3.5	6.7	4.9	9.1	10.6	5.2	7.4	7.3	1.4
Total cost (BTK/ha)	33526	53770	46612	39657	27265	38523	19574	37853	9815
Before adoption									
Seed (%)	2.7	3.0	2.1	5.3	6.4	4.8	3.7	3.9	10.6
Structure (%)	11.3	3.0	0.0	0.1	0.0	8.2	0.0	3.2	0.0
Fertilizer (%)	19.4	20.3	28.1	29.3	18.9	28.5	32.8	25.0	21.4
Pesticide (%)	8.5	9.2	6.2	6.9	3.4	5.4	12.8	7.0	1.4
Irrigation (%)	4.4	7.0	6.9	7.7	5.9	3.6	5.1	6.2	10.3
Labor (%)	48.4	53.7	51.4	46.0	58.1	48.2	39.9	49.9	55.9
Marketing (%)	5.3	3.8	5.3	4.7	7.3	1.3	5.7	4.8	0.4
Total cost (BTK/ha)	31405	41820	36888	35818	22696	38210	23096	33549	11035
Non-vegetable farmers									
Seed (%)	—	—	—	—	—	—	—	—	9.6
Staking/fencing/ shading (%)	—	—	—	—	—	—	—	—	0.0
Fertilizer (%)	—	—	—	—	—	—	—	—	23.9
Pesticide (%)	—	—	—	—	—	—	—	—	2.0
Irrigation (%)	—	—	—	—	—	—	—	—	4.9
Labor (%)	—	—	—	—	—	—	—	—	58.5
Marketing (%)	—	—	—	—	—	—	—	—	1.1
Total cost (BTK/ha)	—	—	—	—	—	—	—	—	12175

Appendix 10: Yield level and yield difference in vegetables and cereals across farmer type

	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Vegetables	Cereals
Yield (kg/ha)									
Non-adoption	10193	14016	10949	7443	8042	10123	13637	10221	2033
New technology	11912	17998	13830	10426	10080	12786	16068	12455	2109
Before adoption	8878	11031	10290	7256	7868	10241	12021	9004	1931
Non-vegetable	—	—	—	—	—	—	—	—	2106
Effect of technology (%)									
Unexploited	14.8	27.1	6.4	2.6	2.2	-1.2	13.4	13.5	5.3
Spillover	19.4	36.1	28.0	41.1	25.9	26.0	20.2	24.8	3.9
Total	34.2	63.2	34.4	43.7	28.1	24.8	33.6	38.3	9.2

Appendix 11: Output disposal pattern (% output sold) in vegetables and cereals by farmer type

	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Vegetables	Cereals
Non-adopter	93.3	83.9	89.1	84.5	71.8	91.0	89.8	86	11
Adopter	95.3	92.0	86.5	85.3	82.2	91.6	95.8	90	16
Before adoption	88.7	80.2	77.9	72.6	71.4	83.7	86.3	80	6
Non-vegetable farmer	—	—	—	—	—	—	—	—	23

The remaining percentage output was damaged during transportation, kept as seed, and/or consumed at home.

Appendix 12: Economic measures of new technologies in vegetables and cereals by farmer type

	Gourd	Tomato	Eggplant	Lady's finger	Leafy	Bean	Heading cole	Veg-etable	Cereal
Net revenue (BTK/ha)									
Non-adopter	28968	32728	23522	18565	21256	28959	35231	27659	1508
Adopter	38469	50694	28162	32571	30810	41897	48009	36775	4306
Before adoption	24100	28003	22017	12433	20855	29533	32479	22223	1625
Non-vegetable farmer	—	—	—	—	—	—	—	—	1939
Return on investment (percentage)									
Non-adopter	83	72	59	64	89	77	141	81	13
Adopter	115	94	60	82	113	109	245	97	44
Before adoption	77	67	60	35	92	77	141	66	15
Non-vegetable farmer	—	—	—	—	—	—	—	—	16
Return on labor (BTK/labor day)									
Non-adopter	147	140	114	122	161	119	242	141	49
Adopter	173	158	147	144	176	166	286	160	68
Before adoption	123	107	106	95	115	130	226	115	48
Non-vegetable farmers	0	0	0	0	0	0	0	0	50
Cost per unit of output (BTK/kg)									
Non-adopter	4.6	3.3	4.0	4.0	3.3	4.2	2.0	4.0	6.3
Adopter	3.3	3.2	3.7	4.0	2.9	3.3	1.3	3.3	5.1
Before adoption	4.2	3.9	4.1	5.0	3.6	3.9	2.0	4.1	6.1
Non-vegetable farmers	—	—	—	—	—	—	—	—	6.1
Economic efficiency of water use (BTK/BTK of water cost)									
Non-adopter	43	19	26	43	23	44	31	32	13
Adopter	45	25	18	24	37	37	52	29	19
Before adoption	39	23	22	17	31	48	46	26	10
Non-vegetable farmers	0	0	0	0	0	0	0	0	23

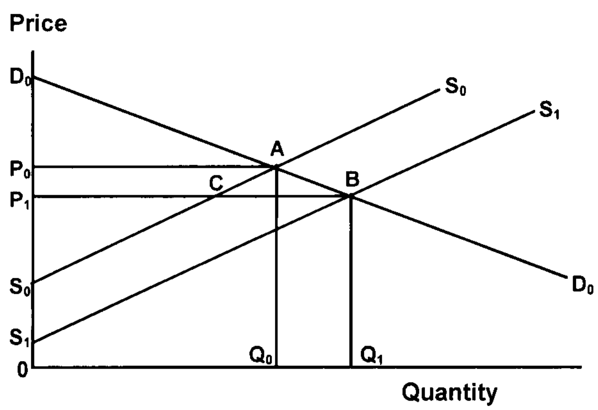
Appendix 13: Theoretical model to estimate consumer and producer surplus

The Marshallian concepts of consumer and producer surplus are applied to quantify the welfare generated through research. As a result of the adoption of advanced technologies, the aggregate supply curve in the following shifts from S_0 to S_1. Assuming linear supply and demand functions, a parallel shift in the supply curve will produce a change in the "consumers' surplus" by the area AP_0P_1B. The same supply shift will produce a change in "producers' surplus" by the area BP_1S_1 minus AS_0P_0. The total change in "economic surplus" (producers' plus consumers') will be the area BS_0S_1A. These effects can be expressed algebraically as follows (Alston et al. 1995):

Consumers' surplus due to yield improvement = $\triangle CS = P_0 Y_0 Z (1+0.5Z\varepsilon)$ (A4.1)

Producers' surplus due to yield improvement = $\triangle PS = P_0 Y_0 (k-Z) (1+0.5Z\varepsilon)$ (A4.2)

Total surplus due to yield improvement = $\triangle TS = \triangle CS + \triangle PS = P_0 Y_0 k(1+0.5Z\varepsilon)$ (A4.3)



Consumers surplus = $BD_0P_1 - AP_0D_0 = AP_0P_1B$
Producers surplus = $BP_1S_1 - AP_0S_0 = BCS_0S_1 - AP_0P_1C$
Total surplus = BAS_0S_1

Figure A1. Effect of high yielding mungbean technologies on consumers' and producers' surplus

where k is the vertical downward shift in the supply function expressed as a percentage reduction in the unit cost of production, ε is the absolute value of the own-price elasticity of demand, α is the own-price elasticity of supply, and $Z= k\alpha/(\alpha+\varepsilon)$ is the reduction in price, relative to its initial (i.e., pre-research) value due to shift in supply. Y_0 and P_0 are respectively initial production and price before innovation started.

Appendix 14: Data used in estimating the welfare gains of technological innovations

Variable	Value
Average retail price of vegetables during 1991-99 (US$/t)[1]	175
Total production without innovation during 1991-99 (million t)[2]	12.58
Total production with innovation during 1991-2000 (million t)[3]	13.50
Shift in cost or supply curve (%)[4]	0.19
Demand elasticity (estimated)[5]	0.21
Supply elasticity (assumed)[5]	0.21
Change in price due to shift in supply[6]	0.09
Cost of the project to Bangladesh government (millions US$)[7]	2.90
Cost of the project to USAID (million US$)[8]	4.25

[1] The 1999 price was estimated as the weighted-average price of all vegetables used in consumption, where weights were the relative share of each vegetable in the total vegetable consumption. The prices for the earlier years were estimated by indexing the 1999 price with the index of the wholesale vegetable prices in Bangladesh.

[2] This represents the sum of the annual production during 1991-99 had there been no technological innovation. This was estimated as the sum of the predicted trend production during 1996-98 using the trend coefficients for 1971-90.

[3] This is the sum of actual annual production during 1991-99.

[4] See Table 23.

[5] We could not find a reliable estimate from the literature, therefore assumed. However, the estimated total surplus is not very sensitive to the value of this coefficient.

[6] See formula to calculate the value of Z in Appendix 13.

[7] Obtained from the official files of AVRDC Finance Unit.

[8] Estimated cost of the Horticultural Research Center, Joydapur, Bangladesh, and its regional programs provided by the Director General of BARI.