Utilization of Recycled Aquaculture Water and Effluents for Forage and Vegetable Crops in the U.S. Virgin Islands

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Abstract

Experiments were conducted from 1992 to 1999 to determine if aquaculture water and effluents can be used to replace expensive irrigation water and fertilizer for vegetable and forage crops. In 1992 and 1993, effluents were applied to bell peppers. (*Capsicum annuum* L.). In 1994 effluents were applied to leafy vegetable Pai tsai (*Brassica rapa* L. Chinensis). From 1997 to 1999 the benefits of utilizing aquaculture effluents was evaluated for guineagrass (*Panicum maximum* Jacq.) hay production. Trials for two seasons demonstrated the positive effects of using aquaculture effluents on vegetables and forage crops. Effluents increased vegetable marketable yield, dry matter and nutrient value of guineagrass. Studies indicated that recycled aquaculture water and effluents are potential sources of irrigation water and fertilizer.

Introduction

In semi-arid and water limited environment of the U.S. Virgin Islands (USVI), shortage of fresh water limits crop production. Vegetables and forage crops are dependent on well-distributed rainfall for year-round production, however, during dry seasons crop failure is common without supplemental irrigation. Vegetable growers incur high cost of irrigation water to maintain production year round. Although the USVI receive 1100 mm annual rainfall, more than 50% of this precipitation occurs only from September to November. High evaporation rates and erratic rainfall patterns contribute to shortage of water throughout the year. Shortage of water for crop production is a major problem facing agriculture in the USVI, therefore, alternative sources of water for irrigation must be explored.

A potential alternative is recycled water from intensive aquaculture system. Intensive aquaculture in tanks may be appropriate for fresh-water limited environment such as the USVI (Cole et al., 1997). A component of intensive fish culture in tanks is the removal of nutrient-rich effluents which are a potential source of irrigation water and nutrients for agronomic and horticultural crops (Chen and Malone, 1991; Palada et al., 1999; Valencia et al., 2001). Fish culture effluent contains essential plant nutrients (i.e., N, P, K, S and Ca) and significant amounts of water. Intensive recirculating systems have been integrated with vegetable hydroponics (Rakocy, 1989; McMurtry et al., 1993) and demonstrated the potential of using wastewater in irrigating greenhouse tomatoes and leafy vegetables. Effluents from pond culture were also used to irrigate cotton (Olsen et al., 1993), soybean (Ghate et al., 1994) and wheat (Al-Jaloud et al., 1993).

In recent years, there has been increasing concern on the adverse ecological consequences of nutrient-rich wastes discharged into bodies of water (rivers, lakes and oceans) which result in siltation and eutrophication (Bond, 1998). Application of effluents to field and vegetable crops can reduce environmental contamination since crops especially grass pastures can be a good sink for aquaculture effluents. An integrated approach using fish culture effluents for

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irrigation of forage and vegetable crops was evaluated in the USVI as a means of conserving water and reducing fertilizer costs. The major objective was to determine if aquaculture water and effluent can be used to replace expensive irrigation water and fertilizer for forage and vegetable crops.

Materials and Methods

Experiments were conducted from 1992 to 1999 at the Agricultural Experiment Station, University of the Virgin Islands (lat. 17°42' N, long. 64°48'W). In 1992 and 1993, effluents from tank culture of Tilapia (*Oreochromis niloticus*) were applied to bell peppers. Experiments in 1994 involved the application of effluents to leafy vegetable Pai tsai and from 1997 to 1999 the benefits of utilizing aquaculture effluents was evaluated for guineagrass hay production.

Bell Pepper. Two experiments were conducted to evaluate effluents generated from Tilapia tank culture for bell pepper (cv. 'Calwonder') production. In 1992, seven treatments were arranged in a randomized complete block design with four replications. Treatments allowed a comparison between tank water, tank sludge and conventional inorganic and organic fertilizers. The treatments were as follows: 1) LD-Low stocking density rearing tank water, 2) HD-High stocking density tank water, 3) SD-Sludge combined from low and high stocking densities, 4) FN-Liquid inorganic N fertilizer applied in drip at 200 kg ha^{-1}, 5) FL-Liquid inorganic N fertilizer applied manually at same rate as 4, 6) FG-Granular inorganic fertilizer applied manually at same rate as 4, and 7) CM-Cow manure applied at rate equivalent to 200 kg N ha^{-1}. Similar trial was conducted in 1993, but the treatments were modified. The hand-applied liquid fertilizer and the cow manure were replaced with tank sludge and tank water. Treatments were as follows: 1) FW1-Effluent from tank with 0% daily water exchange rate applied using Turbo Key (TK) drip emitter, 2) FW2-Effluent from tank with 0% daily water exchange rate applied using Hardie (E-2) drip emitter, 3) FW3-Effluent from tank with 5% daily water exchange rate applied using Turbo Key (TK) emitter, 4) FW4-Similar to 3 but used a Hardie (E-2) drip emitter, 5) TS-Sludge from all tanks combined and applied using Bow Smith Gripper adapter (BSG), 6) FN-Liquid inorganic fertilizer applied in drip irrigation similar to that in the 1992 trial, and 7) FG-Granular inorganic fertilizer applied in bands around individual plants. Data were collected on total number and weight of fruits and weight of marketable fruits. Data on weight of fruits (total and marketable) are reported in this paper.

Leafy Vegetable Pai tsai. Two experiments were conducted in 1994 to evaluate fish culture effluent generated from Tilapia tank culture for production of Pai tsai cv. 'Joi Choi'. Six circular tanks, each with a water volume of 31.2 m^3 were used to culture Tilapia. Tanks were stocked with fingerlings at 24 m^{-3} and cultured for 24 weeks. Solids were removed from the water in the three tanks while the other three had no solids removed. Pakchoi seedlings were transplanted into 6.0 x 1.8 m plots. Treatments included application of fish effluent with and without solids removal, drip fertigation, band fertilizer application, and sludge removed from culture tanks using three methods of irrigation. The first experiment was conducted from 8 July to 19 August followed by the second experiment on 29 August to 5 October. Both experiments used a randomized complete block design with four replications. Data were collected on plant fresh weight at harvest, whole plant tissue concentration of major nutrients and soil N, P and K.
Data on plant tissue analysis are not reported in this paper.

Forage Guineagrass. A three-year study was conducted to determine if fish effluent can be used to replace fertilizer N on guinea grass managed as hay. The experiment compared the effects of irrigated effluent and broadcast N rates of 60 kg ha^{-1} (N_{60}) 0 kg ha^{-1} (N_0) on yield and quality of hay. Experiments were established using a randomized complete block design. Treatments consisted of 1) fish effluent (FE; 120 kg ha^{-1} in 1997, 0 kg ha^{-1} in 1998, and 60 kg ha^{-1} in 1999), 2) N (ammonium nitrate) application of 60 kg ha^{-1} and 3) 0 N ha^{-1} (control). Native guinea grass was broadcast-seeded in late August, 1996 on 6 x 6 m plots. Plants were allowed to establish without interruption during the remainder of the year. Plants were clipped to 15-cm stubble height in February, 1997 and fish effluent was applied weekly thereafter for 18 weeks equivalent to a total application rate of 120 kg N ha^{-1}. Since effluent was not available in 1998, only inorganic N was applied. Result from this year was used to assess the residual effects of fish effluent in 1997. Limited amounts of effluents in 1999, resulted in dilution with water to provide a rate equivalent to 60 kg N ha^{-1} similar to the inorganic fertilizer N application. Forage was harvested at 8-wk interval from a 1 x 2 m section from the center of each plot (three harvests in 1997, 1998, and 1999) using a sickle-bar mower. Yield data were subjected to analysis of variance using SAS (1989).

Results and Discussion

Bell pepper. In 1992, application of effluents (water and sludge) resulted in significantly ($P<0.05$) larger fruit size compared to treatments applied with liquid N fertilizer and cow manure (Table 1A). Fruits produced from plots treated with effluents were on the average larger than fruits produced from plots applied with inorganic fertilizer and cow manure. However, plants under fertigation produced significantly ($P<0.05$) higher fruit yield than all other treatments. Highest fruit yield was obtained from plots fertilized with liquid N followed by plots treated with sludge. Percentage of marketable fruit ranged from 66% for low density tank water to 91% for high density tank water. More than 80% of the total fruit yield in plots applied with inorganic fertilizer and cow manure were marketable. Contrast comparisons of marketable yields between fish effluent, sludge and inorganic fertilizer were not significant, but when effluent (tank water) was compared to fertigation and granular N fertilizer, differences in marketable yield were significant ($P<0.001$ and $P<0.044$, respectively).

In 1993, smallest fruit size was produced from treatment with granular N fertilizer and the largest fruit size was obtained from treatment with 5% exchange rate using a TK emitter (Table 1B). Application of sludge resulted in significantly ($P<0.05$) higher total yield than fertigation. Plants applied with sludge produced the highest marketable yield. The lowest marketable yield was obtained from the fertigation treatment. Overall, the percentage of marketable fruits declined in 1993 compared to 1992. Contrast analysis showed no significant differences in yield among treatments. Combined mean total yields of all aquaculture effluent treatments (water and sludge) were not significantly different than yields from plots fertilized with inorganic fertilizers.

Superior yield under fertigation in 1992 can be attributed to a more rapid and efficient N uptake compared to other treatments. Except for treatments from low density effluent and sludge, the percentage of marketable fruits was above 80%. High yields from fish effluent treated plots during the second year can be explained by the accumulation and release of nutrients from the previous year through mineralization. Although the overall total yields in 1993 were higher than 1992, the percentage of marketable fruits decreased in 1993. Frequent harvesting in 1993 resulted in higher total and marketable yield, but more fruits had either insect damage or were diseased rendering them non-marketable.

Leafy Vegetable Pai tsai. In the first season trial, plant size with weekly sludge application was significantly larger than plants with fertilizer band-application, or with effluent (water), with or without the sludge removed (Table 2).

During the second season, weekly sludge application resulted in larger plants than the fertilizer-band application. Although not significant in both trials, Pakchoi applied with effluent (water) and sludge had higher total yields than fertigation or band-application. Plant size and total yield in the second season trial were higher than the first season trial and this can be attributed to increased soil N (data not shown).

Forage Guineagrass. Forage production in the eastern Caribbean are affected by nutrients and well-distributed rainfall. During the period of this study, guineagrass was irrigated with effluent and well-water (1997 and 1999). Because of the variation in rainfall and our interest in assessing carry-over effects of both the effluents and the inorganic fertilizer (1998), data was analyzed by year. Total rainfall in 1997 (739 mm) was below the 20-yr norm (1060 mm) on St. Croix U.S. Virgin Islands, but rainfall in 1998 (1867 mm) and 1999 (1340 mm) were much higher than the 20-yr norm. There were treatment x date of harvest interaction ($P<0.05$) for DM in1998 and 1999. These were reported in more detail by Valencia et al. (2001).

In 1997, DM yield of guineagrass irrigated with effluent (14.2 Mg ha^{-1}) did not differ ($P=0.10$) from the N_{60} (13.1 Mg ha^{-1}). There was, however, a trend for higher DM yield for guineagrass treated with effluent (Table 3). Both effluent and N_{60} treatments had >4 Mg ha^{-1} higher DM yield than unfertilized guinea grass (Table 3). Studies by Olsen (1972) reported a three-fold increase in DM yield of guineagrass and other tropical grasses when fertilized at high N rates (>400 kg N ha^{-1}). Rainfall in 1997 was below the 20-yr norm, but it is not clear if it had any effect on DM yield. Oakes and Skov (1962) evaluated the response of four tropical pasture grasses to N in the dry tropics and noted that differences in rainfall of this magnitude had no apparent influence on annual DM yield.

Similar results were observed in 1998, despite no treatment application. There was a difference in total annual yield ($P<0.05$) between effluent and N_{60} (Table 3). Dry matter yield was close to 4 Mg ha^{-1} higher for the effluent (13.8 Mg ha^{-1}) compared to N_{60} (9.9 Mg ha^{-1}), similar to what occurred in 1997. Studies by Olson (1992) and Cole et al. (1997) suggests that close to 90% of the N in aquaculture effluent or sludge is in an organic form and is not available in the first year of crop production. Further research with the application of biosolids to bahiagrass (*Paspalum notatum* Flugee) conducted by Muchovej and Rechcigl (1997) estimated a minimum N recovery rate of 70% over a two-year period. Guineagrass DM response to effluent applied the previous year suggests that residual organic N was mineralized in year two and was available for the guineagrass plant to use. Also in 1997, approximately 120 kg ha^{-1} N from effluent were applied and thus it is possible that this residual organic N sustained the higher yields obtained in 1998.

In 1999, there were differences ($P<0.05$) in DM yield for effluent (12.9 Mg ha^{-1}) compared to N_{60} (6.4 Mg ha^{-1}) . There was a two-fold increase in DM yield of guineagrass treated with effluent (Table3). Total yields, however, were much lower than the DM yields of 1997 and 1998. Guineagrass treated with effluent showed higher tiller density and less weed encroachment when compared to N_{60} or unfertilized guineagrass (E. Valencia; personal observations). A linear decrease in DM yield of unfertilized guinea grass was observed over-time (Table3). The low DM yields on unfertilized guinea grass in 1999 indicate that nutrients were lacking to support adequate plant growth. A steady decline in the stand of guineagrass was also observed.

Nutritive value [crude protein (CP) and *In vitro* organic matter disappearance (IVOMD)] were analyzed in 1997 and 1999. There was no treatment X harvest date interaction in 1997 for CP and IVOMD. Guineagrass CP concentration was not affected by treatment either. There was a trend ($P=0.11$), however, for higher CP of guinea grass when irrigated with effluent (9.6%) compared to those fertilized with N_{60} (8.6%). *In vitro* organic matter disappearance did not differ among treatments and averaged 56%. In 1999, averaged across three harvests, the CP of guineagrass treated with effluent (10.3%) was two percentage units higher (*P<0.05*) than the N_{60} CP (8.3%). There was no difference (*P>0.05*) in IVOMD (61.0%) in 1999. Soil pH (7.8), also, did not change in the three years of effluent application. Phosphorus was maintained at 22 mg kg^{-1} during the three years of the study.

Conclusions

Results of the study indicate that effluents can replace the recommended N application rates of 60 kg ha^{-1} per annum for guineagrass. The sustained and increased DM yield of effluent treated guineagrass compared to that of N_{60} in year two suggests that there was a strong mineralization of N. This gives aquaculture effluents the characteristics of a slow release fertilizer. Al-Jaloud et al. (1993) reported a 50% savings in inorganic fertilizer with use of aquaculture effluents containing 40 mg L^{-1} N. Under the arid conditions of the U.S. Virgin Islands, these savings may be higher, particularly with the use of the water source. The two percentage unit increase in CP with addition of effluent can serve to increase the quality of guineagrass hay. Because of the slow release of N from effluents, there would be less leachate of N in the soil profile. This study confirmed that guineagrass hay fields can serve as a sink for this nutrient-rich wastewater, and provide an economically sustainable, and environmentally acceptable effluent discharge method.

Overall, these studies demonstrated the positive benefits of aquaculture effluents in forage and vegetable crops production. Repeated applications of effluents over time accumulated soil nutrients which become available resulting in increased yields of bell pepper, Pai tsai and guinea grass. Studies also suggest that it is feasible to grow crops using recycled aquaculture waste water and sludge without external (commercial fertilizer) inputs. Yields can be sustained at levels comparable to yields obtained using commercial fertilizers. Crop irrigation with nutrient-rich aquaculture effluents is an example of sound resource management through the reuse of water and the recycling of nutrients.

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Table 1. Fruit size and yield of bell peppers fertilized with aquaculture effluents, organic and inorganic fertilizer.

1A. 1992 Trial

Treatment	Fruit size (g)	Total fruit yield ($Mg\ ha^{-1}$)	Marketable yield ($Mg\ ha^{-1}$)
Fish water (LD)	70.8 ab	2.82 b	1.85 b (66)
Fish water (HD)	80.8 a	4.12 b	3.75 b (91)
Fish sludge	74.0 ab	6.62 b	5.00 b (76)
Liquid inorganic N (drip)	69.4 abc	10.60 a	8.98 a (85)
Liquid inorganic N (manual)	58.1 cd	5.28 b	4.54 b (86)
Granular inorganic N	66.9 bc	5.60 b	4.63 b (83)
Cow manure	52.1 d	4.68 b	3.98 b (85)

For each column, means followed by common letters are not significantly different ($P>0.05$) by Duncan's Multiple Range Test (DMRT). LD=Fish cultured at low density (8 fish m^{-3}); HD=Fish cultured at high density (16 fish m^{-3}). Numbers in parenthesis are percentages of marketable fruits based on total fruit yield.

1B. 1993 Trial

Treatment	Water exchange (%)	Drip emitter type[a]	Fruit size[b] (g)	Total fruit yield ($Mg\ ha^{-1}$)	Marketable yield[c] ($Mg\ ha^{-1}$)
Fish effluent 1	0	TK	69.1	12.4 ab	7.05 abc (57)
Fish effluent 2	0	E-2	65.4	13.0 ab	7.29 abc (56)
Fish effluent 3	5	TK	69.7	13.0 ab	9.97 ab (77)
Fish effluent 4	5	E-2	67.5	11.3 ab	6.56 bc (58)
Sludge	combined	BSG	68.4	15.1 a	10.35 a (68)
Fertigation (drip)	0	E-2	63.6	10.5 b	5.76 c (55)
Fertilizer (manual)	0	E-2	57.6	11.4 a	6.93 abc (61)

For each column, means followed by common letters are not significantly different ($P>0.05$) by DMRT

[a]TK=Turbo Key; E-2=Hardie; BSG=Bow Smith Gripper Adapter.
[b]Based on marketable fruits.
[c]Numbers in parenthesis are percentages of marketable fruits based on total fruit yield.

Table 2. Plant size and total fresh yield of Pakchoi fertilized and irrigated with aquaculture effluent and inorganic fertilizers.

Treatment	Emitter	First Season Plant size (g)	First Season Fresh yield ($Mg\ ha^{-1}$)	Second Season Plant size (g)	Second Season Fresh yield ($Mg\ ha^{-1}$)
Effluent with sludge	Hardie E-2	288 b	19.3 b	614 ab	41.0 ab
Effluent without sludge	Hardie E-2	300 b	20.0 b	653 a	43.6 a
Sludge 1	Micro-tubing	333 ab	22.2 ab	612 ab	40.9 ab
Sludge 2	0.5 cm on ½" polyhose	353 ab	23.4 ab	662 a	44.2 a
Effluent+sludge (1x/wk)	0.5 cm on ½' polyhose	393 a	26.1 a	791 a	47.4 a
Fertigation (100 kg N ha^{-1})	Hardie E-2	320 ab	21.2 ab	674 a	45.0 a
Fertilizer band (100 kg N ha^{-1})	Hardie E-2	300 b	19.9ab	527 b	35.2 b

For each column, means followed by common letters are not significantly different (P>0.05) by DMRT.

Table 3. Total dry matter yield of guinea grass (*Panicum maximum* Jacq.) irrigated with aquaculture effluent and fertilized in 1997, 1998 and 1999.

Treatment	1997	1998	1999
		$Mg\ ha^{-1}$	
Effluent	14.2†	13.8	12.9
N_{60} (kg ha^{-1})	13.1	9.9	6.4
N_0 (control)	8.6	5.7	2.6
Effluent vs. N_{60}	0.10‡	0.05	0.05
Effluents vs. N_0	0.05	0.05	0.05
N_{60} vs. N_0	0.05	0.05	0.05

† Three harvests per annum.
‡ P level for planned contrast.