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ABSTRACT

When fish are recovered from ponds, the effluent is often drained presenting both an environmental challenge and an agricultural opportunity. The effects of irrigation with pond effluent and its interaction with applied fertilizer were assessed in a field experiment using French bean (*Phaseoulus vulgaris*) over two growing seasons near Sagana, Kenya. Fresh yield of beans was recorded at harvest, and leaf samples were collected for determination of tissue nutrient concentration. In the first season plots receiving canal water and fertilizer at recommended rates had the highest yield (9.1 Mg

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fresh pod ha^{-1}), while those receiving no fertilizer or irrigation had the least yield (1.3 Mg fresh pod ha^{-1}). In the second season, the highest (4.4 Mg ha^{-1}) fresh pod yield was observed in pond effluent irrigated and fertilized plots, while the lowest (1.3 Mg ha^{-1}) was observed in nonirrigated/unfertilized plots. Low nutrient status in the pond water was responsible for low yield where it was substituted for canal water. Pond water from the Sagana Fish Farm supplied low amounts of nitrogen (N) and phosphorus (P) for crops, indicating that recommended rates of mineral fertilizers should be used when pond water is used for irrigation.

INTRODUCTION

In Kenya there are approximately 46,000 fish ponds producing about 1.1 Gg of fish annually.[1] Fertilizers are applied to ponds to increase inorganic nutrient concentrations that favor phytoplankton growth, enhancing production of fish and crustaceans.[2] During harvesting, ponds are drained to levels where fish can be recovered via nets. A result of pond draining is effluent discharge.[3] Such effluents are often allowed to run into natural waterways. Effluents from fertilized ponds can have relatively high nutrient concentrations, and in turn can be potential sources of pollution and eutrophication for receiving waters.

Pond effluents have been applied to crops as irrigation water.[4–6] Hussein and Al-Jaloud[6] report wheat grain yields ranging from 0.8 to 5.0 Mg ha^{-1} with well water and 2.1–5.8 Mg ha^{-1} with aquaculture effluent. Improved water use efficiency (WUE) was also reported with aquaculture effluent irrigated crops having a WUE of 11–30 kg ha^{-1} mm^{-1}, whereas well water treatments had a WUE of 7–22 kg ha^{-1} mm^{-1}. Grain yield and WUE obtained with well water combined with 75–100% of the N requirement as fertilizer, were comparable with treatments irrigated with aquacultural effluents combined with 25–50% of the N requirement. These results imply that application of 150–225 kg N ha^{-1} for well water irrigation and 75–160 kg N ha^{-1} for aquaculture effluent irrigation containing 40 mg N L^{-1} is sufficient for optimum grain yield and WUE. Similar results were obtained by Al-Jaloud et al.[5]

When pond effluents are applied in arid and semiarid environments, greater crop returns may be obtained through more efficient application methods. In Kenya, where farm ponds can also serve as water reservoirs for irrigation, drip irrigation could be profitable. Drip irrigation is a technique whereby water and fertilizers can be placed directly over the root zone through use of emitters that are calibrated for low flow rates. Drip irrigation appears most promising when water and fertilizer application is split into several events over a cropping season.

Little work has been conducted in East Africa on the use of fish pond effluent as a source of irrigation water for high value crops. A study was undertaken to determine the effects of irrigation with polyculture [tilapia (*Oreochromis nilotica*) and African catfish (*Clarius gariepinus*)] pond water as a source of irrigation water and nutrients for French bean.

MATERIALS AND METHODS

The study was conducted during October 1998 through September 1999 at the Kenya Department of Fisheries Fish Farm at Sagana in central Kenya. The farm lies at an elevation of 1231 m above sea level. Rainfall at the farm ranges from 1332 mm $year^{-1}$ to 1612 mm $year^{-1}$, and daily average air temperatures range from 16.3 to 26.9°C. Water supply to the farm is the Ragati River. The soil at the study site is a ‘‘black cotton soil’’ (Vertisol) of volcanic origin. Table 1 shows selected chemical and physical properties of the study site soil in October 1998.

The experiment was conducted during two growing seasons. The first season started in October 1998 and ended in February 1999. The second season started in June and ended in September 1999. For both growing seasons, one of the fish ponds on the Sagana Fish Farm was selected to supply effluent. The pond was fertilized with 8 kg P ha^{-1} as diammonium-phosphate (DAP) during a 17 week prior to stocking. The pond was then stocked with tilapia and African catfish. Subsequently, the pond received 20 kg N ha^{-1} $week^{-1}$ and 8 kg P ha^{-1} for the 17 week grow out periods for both runs of the experiment.

Table 1. Selected soil characteristics at the Sagana Fish Farm in October 1998.

Depth (cm)	K_{sat}[a] ($cm\,day^{-1}$)	Bulk density ($kg\,m^{-3}$)	pH (water) 1:1.5	Total N ($g\,kg^{-1}$)	Total C ($g\,kg^{-1}$)	Extractable P ($mg\,kg^{-1}$)
0–15	0.98	1160	6.8	0.5	27.0	8.1
15–30	0.99	1260	7.3	0.4	20.8	6.2
30–45	—	1322	8.2	0.3	15.7	8.3

[a] K_{sat} is the saturated hydraulic conductivity of the soil in $cm\,day^{-1}$.

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First Growing Season

Eighteen field plots measuring 10 by 6 m were prepared on land previously under star grass (*Digituara scalarum*). Plots were hand tilled and hand harrowed sufficiently for planting French bean. In October 1998, plots were planted with French bean (var. Samantha) at a spacing of 0.6 by 0.1 m. Bean plants were sprayed with Antracol® and Ripcord® at a rate of $80\,L\,ha^{-1}$ at 14 days interval for pest and disease control.

The experiment design was an incomplete factorial arranged as a randomized complete block with six treatments replicated three times. Treatments consisted of: nonirrigated, unfertilized ($-I-F$); nonirrigated, fertilized ($-I+F$); drip irrigated with canal water, unfertilized ($+I-F$); drip irrigated with canal water, fertilized ($+I+F$); drip irrigated with fish pond effluent unfertilized ($+P-F$); and, drip irrigated with equal parts canal and pond water, unfertilized ($+IP-F$). At planting, DAP ($200\,kg\,ha^{-1}$) was applied to treatments receiving fertilizer. These treatments received an additional $200\,kg\,ha^{-1}$ of calcium-nitrate as top dressing after bean emergence. Plots receiving irrigation water were fitted with garden drip irrigation systems. A 10-L distribution bucket suspended on a post held water (canal or pond) to irrigate individual plots receiving irrigation treatments. Plots receiving water via drip irrigation were fitted with a F1 1.9-cm filter (Lego, Inc., Israel) to remove particulate matter. Drip irrigated treatments received $0.33\,mm\ water\,day^{-1}$ over a growing season of 74 days.

French bean harvest began 46 days after planting, and continued for 28 days. Fresh and dry weight of bean pods was recorded. Twenty-one days after planting, leaf samples were picked for nutrient analysis.

Second Growing Season

Eighteen plots measuring 5 m by 6 m were prepared on the previous season's experiment site. The land was hand tilled and hand harrowed to the recommended tilth for French bean.

The experiment consisted of six treatments arranged as a two (fertilization; 0 and $40\,kg\,P\,ha^{-1}$ plus $36\,kg\,N\,ha^{-1}$ after emergence) $\times$ 3 (drip irrigation; 0, canal water ($2.3\,mm\,day^{-1}$), and pond effluent ($2.3\,mm\,day^{-1}$) factorial in a randomized complete block design having three replicates. Treatments were: nonirrigated, unfertilized ($-I, -F$); nonirrigated, fertilized ($-I, +F$); canal water, unfertilized ($+I, -F$); canal water, fertilized ($+I+F$); pond effluent unfertilized ($+P, -F$); pond effluent, fertilized ($+P+F$). French bean seeds were sown on 12 June

1999 at a row spacing of 0.6 m and line spacing of 0.1 m. Other cultural practices were the same as in the first season.

Plots receiving irrigation water were fitted with garden drip irrigation systems. Water for drip irrigation was lifted to a 70-L distribution barrel in each irrigated plot, using a peddle pump and applied daily at 11:00 a.m. Plots receiving drip irrigation water were fitted with an Alkal 3.75 cm filter.

Second season French bean harvest began 52 days after planting and continued for 28 days. Yield of fresh French bean pods was determined gravimetrically. Samples for leaf nutrient analyses were collected from the third uppermost leaf during flowering.

Soil Analyses

Soil pH, nutrient status, and other chemical characteristics were determined by methods used at the Auburn University Soil Testing Laboratory,[7] whereas soil bulk density and hydraulic conductivity were estimated according to methods outlined by the Soil Science Society of America.[8] Water analyses was done using standard methods.[9]

Plant Tissue Analyses

For both growing seasons, plant tissue samples for nutrient analyses were oven dried at 65°C for 24 h, hand crushed using a mortar and pestle, and kept in plastic cans for analysis in laboratories of the Department of Agronomy and Soils at Auburn University. Total N in plant tissue was determined by dry combustion with a LECO CHN-600 analyzer (LECO Corp., St. Joseph, MI).[7] Phosphorus and K in plant tissue was determined by dry ashing, followed by dissolution in *M* hydrochloric acid, followed by determination with a Jarrell-Ash inductively coupled argon plasma (ICAP) spectroscopy (ICAP 9000, Thermo Jarrell Ash, Franklin, MA).[7]

Statistical Analyses

For both growing seasons, analyses of variance were performed to determine variation in French bean fresh pod weight and leaf nutrient concentrations owing to treatments.[10] Differences in yield and nutrient concentrations were considered different if $P \leq 0.05$.

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RESULTS AND DISCUSSION

The two sources of irrigation water (fishpond effluent and canal water) used in this study differed in the concentration of N, P, and the total suspended solids (Table 2) with fishpond effluent having higher levels than canal water. Nutrient concentration increase in fish pond effluent over canal water was due to the addition of fertilizers and fish excreta with the latter also contributing suspended solids in the water.[2]

In the first season, all treatments had significantly higher ($P \leq 0.05$) fresh pod yield than the control, which yielded 1.3 Mg of fresh pods ha^{-1} (Mg fw ha^{-1}) (Fig. 1). When irrigation with canal water was combined with fertilization, the highest yield of 9.1 Mg fw ha^{-1} was recorded. Irrigation with canal water alone resulted in 7 Mg fw ha^{-1} yield with a decline as fishpond effluent was substituted for canal water. Irrigation with fish pond and canal water at a ratio of 1:1 without fertilization and irrigation with fishpond effluent without fertilization provided 6.1 and 4.3 Mg fw ha^{-1}, respectively.

A 53% yield decline when pond water was substituted for fertilizer application was observed (Fig. 1). This observation is in contrast to previous work using pond effluent for flood irrigation of tomatoes[4] and wheat.[5,6] Pond effluent at the Sagana Fish Farm supplied inadequate N and P to bean owing to the low concentration of these nutrients (Table 2). Irrigation with pond water at 0.3 mm day^{-1} supplied only 1.6 kg N ha^{-1} and 1.0 kg P ha^{-1} to the root zone over the growing period. This input was equivalent to 4.2 and 2.4% of the recommended rates of N and P. The total N concentration in pond water (Table 2) was within the acceptable range for irrigation water,[11] but could not support yields similar to those obtained with fertilizers.

Table 2. Average nutrient and total suspended solids (TSS) concentrations of canal and fish pond effluents at the Sagana Fish Farm.

Source	Total N (mg L^{-1})	Total P (mg L^{-1})	TSS (mg L^{-1})
Season 1			
Canal	0.49	0.04	80
Pond	6.03	3.89	331
Season 2			
Canal	0.72	0.16	54
Pond	3.16	1.33	193

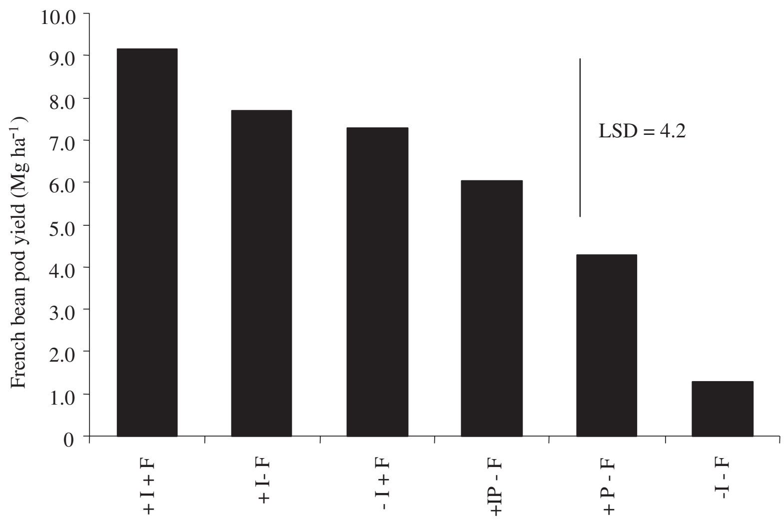

Figure 1. Fresh pod yield from French bean in the first season.

In the second season, significant differences ($P \leq 0.05$) in fresh pod yield among treatments were observed. Fresh weight yield of bean pods in the $+P-F$ treatment was significantly greater than that of the $-I-F$ treatment (Fig. 2). Irrigation with fish pond effluent combined with fertilization at the 36 kg N and 40 kg P ha^{-1} resulted in the highest yield of 4.4 Mg fw ha^{-1}.

Contrary to observations made in the first season, no significant change in fresh pod weight was observed when pond water was substituted for canal water. This finding was due to effects of improved distribution of pond water or the greater irrigation amount or their interaction. An increase of irrigation amount from 0.33 mm day^{-1} in the first season to 2.3 mm day^{-1} assured sufficient water supply to the root zone. Total suspended solids concentration in pond water was 42% higher in the first season than in the second season (Table 2). In the second season, larger filters (Alkal filter 3.75 cm, Lego, Inc., Israel) were fitted on the drip irrigation system leading to improved filtration. Low concentrations of TSS in pond water coupled with improvement on the filtration system resulted in a better distribution of pond water along the drip line reducing emitter clogging problems like over-irrigation, soil saturation, and insufficient water supply. Consumptive use of water was thus satisfied and relatively better yields were obtained.

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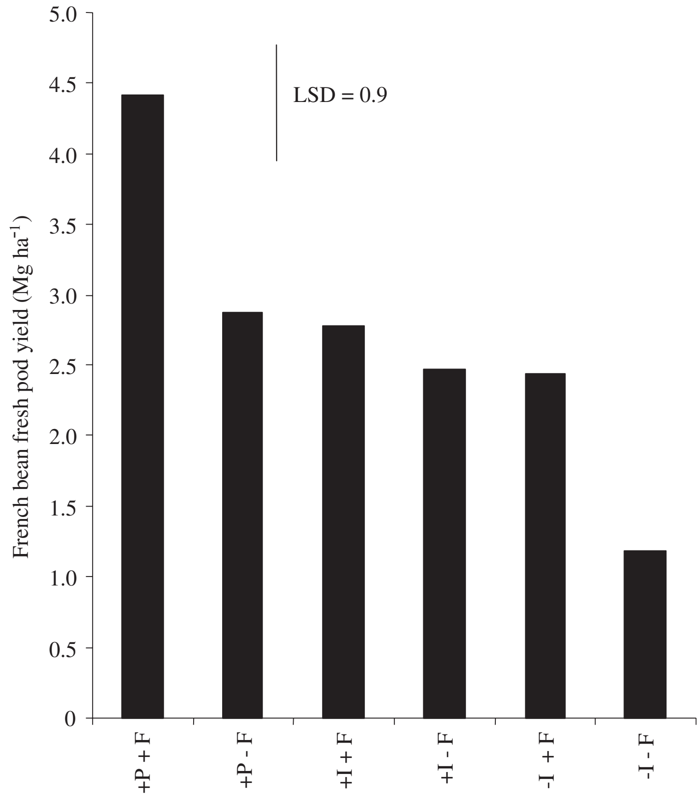

Figure 2. Fresh pod yield from French bean in the second season.

Overall yields were greater in the first than the second growing season. No other crops were grown in the adjacent area of the trial plots, and a higher pest incidence on the trial plots was witnessed in the second season, which resulted in the relatively lower bean yield in the second season.

In the first growing season, significant differences ($P \leq 0.05$) in leaf N and P concentrations were observed among treatments (Table 3). Leaf N and P levels were higher in fertilized treatments, suggesting that availability of N and P to bean was higher in those treatments. In the second growing season, only N concentrations varied significantly with treatment (Table 4). Treatment $-I+F$ had the highest foliar N concentration ($55.3\,\mathrm{g\,kg^{-1}}$). Low foliar N concentration ($45.2\,\mathrm{g\,kg^{-1}}$) was observed in bean plants irrigated with fish pond effluent without

Table 3. Nutrient concentration of French bean leaves in the first season.

Treatment	Total N ($g\,kg^{-1}$)	P ($g\,kg^{-1}$)	K ($g\,kg^{-1}$)
$-I-F$	42.7	2.8	1.70
$-I+F$	50.0	3.2	1.67
$+I-F$	44.4	3.0	1.89
$+I+F$	52.5	4.0	1.84
$+IP-F$	43.3	2.6	1.65
$+P-F$	42.1	2.6	1.82
$LSD_{0.05}$	3.6	0.1	0.31
C.V.	9.5	16.8	10.4

Table 4. Nutrient concentration of French bean leaves in the second season.

Treatment	Total N ($g\,kg^{-1}$)	P ($g\,kg^{-1}$)	K ($g\,kg^{-1}$)
$-I-F$	45.9	2.4	1.5
$-I+F$	55.3	3.6	2.5
$+I-F$	47.3	2.7	1.8
$+I+F$	48.4	3.0	1.7
$+P-F$	45.2	2.5	1.4
$+P+F$	50.2	2.9	2.0
$LSD_{0.05}$	4.7	0.9	0.4
C.V.	9.7	21.4	17.2

fertilizer addition ($+P-F$), and with canal water without fertilizer addition ($+I-F$), suggesting a reduced availability of N in irrigated plots or leaching out of the root zone.

CONCLUSIONS

Application of chemical fertilizers in ponds and activities of fish increases nutrient concentration of pond water. Application of pond water to crops during fish grow-out is feasible, but filters capable of removing particulates will be required if it is to be delivered through a

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drip irrigation system. Nutrient enrichment of pond water during aquaculture production is insufficient to meet crop nutrient demand, and fertilizer recommendations for crops should not be altered when pond water is used as an irrigation source.

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