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USE OF POND EFFLUENT FOR IRRIGATION IN AN INTEGRATED CROP/AQUACULTURE SYSTEM

Ninth Work Plan, Effluents and Pollution Research (9ER1)
Final Report

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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 (*Phaseolus vulgaris*) and kale (*Brassica oleracea*) over two growing seasons near Sagana, Kenya. Fresh and dry matter yields of the crops were recorded at harvest, and samples were collected for determination of tissue nutrient concentration. In the first season, French bean fresh pod yield differed significantly ($P = 0.05$) among treatments. Plots receiving canal water and fertilizer at recommended rates had the highest yield (9.1 t fresh pod ha^{-1}), while those receiving no fertilizer or irrigation had the lowest yield (1.3 t fresh pod ha^{-1}). In the second season, significant differences ($P = 0.05$) were observed among treatments in fresh bean pod and fresh kale leaf yields. The highest (4.4 t ha^{-1}) fresh pod yield was observed in pond-effluent-irrigated and fertilized plots, while the lowest (1.3 t ha^{-1}) was observed in non-irrigated, unfertilized plots. The highest fresh kale leaf yield (11.5 t ha^{-1}) was obtained using irrigation with canal water combined with fertilizer application, while the lowest (4.2 t ha^{-1}) was observed in non-irrigated, unfertilized plots. Low nutrient status in the pond water, together with inadequate water supplied to some crops due to emitter clogging, was responsible for low yields in treatments where pond water 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. In the second experiment, the effectiveness of two types of soil occurring at Sagana, Kenya—a vertisol (black clay soil) and a cambisol (red clay soil)—in retaining nutrients from pond effluent was investigated. A laboratory experiment was conducted with soil columns containing red or black clay soil. Pond effluent application rates of 31, 81, and 161 mm d^{-1} were tested on both soils. Both soils retained over 60% of total phosphorus from pond effluents, with red clay soil retaining 27% more phosphorus than black clay soil. At the high effluent loading rate, low % N removal was observed in both soils. Total nitrogen removal efficiency declined with time after 21 days at the high rate, and after that time no nitrogen removal was observed where red clay soil was used. Black clay soil was more enriched by nitrogen than red clay soil, while phosphorus enrichment was higher in red clay soil than in black clay soil. It appears that land application can remove substantial amounts of phosphorus and nitrogen from pond effluent.

INTRODUCTION

In Kenya there are approximately 46,000 fish ponds, producing about 1,100 Mg of fish annually (Government of Kenya, 1997). Fertilizers are applied to ponds to increase inorganic nutrient concentrations that favor phytoplankton growth, enhancing production of fish and crustaceans (Boyd, 1990). During harvesting, ponds are drained to levels where fish can be recovered via nets. A result of pond draining is effluent discharge (Sumari, 1982). Such effluents are often allowed to run into natural waterways. Effluents from fertilized ponds have relatively high nutrient concentrations and can be potential sources of pollution and eutrophication for receiving waters.

Pond effluents have been applied to crops as irrigation water (Prinsloo and Scoonbee, 1987; Al-Jaloud et al., 1993; Hussein and Al-Jaloud, 1995). Hussein and Al-Jaloud (1995) report wheat grain yields ranging from 770 to 5,010 kg ha^{-1} with well water and 2,140 to 5,790 kg ha^{-1} with aquaculture effluent. Improved water use efficiency (WUE) was also reported with aquaculture-effluent–irrigated crops having a WUE of 11 to 30 kg ha^{-1} mm^{-1}, whereas well water treatments had a WUE of 7 to 22 kg ha^{-1} mm^{-1}. Grain yield and WUE obtained with well water combined with 75 to 100% of the nitrogen requirement as fertilizer were comparable with treatments irrigated with aquacultural effluents combined with 25 to 50% of the nitrogen requirement. These results imply that the application of 150 to 225 kg N ha^{-1} for well water irrigation and 75 to 160 kg N ha^{-1} for aquaculture effluent irrigation containing 40 mg l^{-1} is sufficient for optimum grain yield and WUE. Similar results were obtained by Al-Jaloud et al. (1993).

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 (*Tilapia aureus*) and African catfish (*Clarias gariepinus*) pond water on yield of French bean (*Phaseolus vulgaris*) and kale (*Brassica oleracea*). Specific objectives of the study were to:

1) Evaluate pond effluents as a source of irrigation water for French bean and kale;
2) Assess the ability of pond effluents to supply nitrogen and phosphorus to French bean and kale; and
3) Determine the effectiveness of two soil types from the Sagana, Kenya, area to retain nutrients from fish pond effluent.

METHODS AND MATERIALS

The project was conducted between October 1998 and September 1999 at the Department of Fisheries Fish Farm at Sagana in central Kenya. The farm lies at an elevation of 1,231 m above sea level. Rainfall at the farm ranges from 1,332 to 1,612 mm yr^{-1}, and daily average air temperatures range from 16.3 to 26.9°C. Water supply to the farm was from the Ragati River.

Separate studies were conducted in this project. The first study was conducted to investigate the potential benefits of applying pond effluents to crops and the effects of the effluents on the yield of French bean and kale. The second investigation examined the potential use of land to purify fish pond effluents.

Soils at the farm are “black cotton soils” (vertisols) of volcanic origin. Table 1 shows the pH, nutrient, and other chemical concentrations (Hue and Evans, 1986), bulk density, and hydraulic conductivity (Klute et al., 1986) of the vertisol (black clay soil) and cambisol (red clay soil) used in both the experiments at the start of the trials. Water analyses for both experiments were done using standard methods.

French Bean and Kale Field Experiment

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 runs of the experiment, 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 during a 17-wk period prior to stocking. The pond was then stocked with tilapia and African catfish. Subsequently, the pond received 20 kg N ha^{-1} wk^{-1} and 8 kg P ha^{-1} for the 17-wk grow-out periods for both runs of the experiment.

First Growing Season

Eighteen field plots measuring 10 × 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 × 0.1 m. Bean plants were sprayed with Antracol® and Ripcord® at a rate of 80 l ha^{-1} at 14-d intervals for pest and disease control.

The experimental design was an incomplete factorial arranged as a randomized complete block with six treatments replicated three times. Treatments consisted of:

- Non-irrigated, unfertilized (–I –F);
- Non-irrigated, 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, diammonium phosphate (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 0.75-in filter (Lego Inc., Israel) that was intended to remove particulate matter. Drip-irrigated treatments received 0.33 mm water d^{-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 and total biomass dry weight (dry pods, leaves, and stems) were recorded. Twenty-one days after transplanting, leaf samples were picked for nutrient analysis. After 76 days, the bean crop was uprooted and the above-ground biomass dried out on polythene sheets for biomass yield records.

Second Growing Season

Twenty-four plots measuring 5 × 6 m were prepared on the previous season’s experimental site, with an additional twelve plots prepared on an adjacent uncultivated portion under star grass. The land was hand-tilled and hand-harrowed to the recommended tilth for French bean and kale.

The experiment consisted of twelve treatments arranged as a 2 (crops; French bean and kale) × 2 (fertilization; 0 and recommended rates) × 3 (drip irrigation; 0, canal water, and pond water) factorial laid in randomized complete block design with three replicates. Treatments were:

- No irrigation and no P or N for kale (K: –I, –F);
- No irrigation and no P or N for bean (B: –I, –F);
- No irrigation plus 78 kg N ha^{-1} in splits of 48 kg N ha^{-1} at

planting time and 30 kg N ha^{-1} four weeks after planting and 54 kg P ha^{-1} for kale (K: –I, +F);

- No irrigation plus 36 kg N and 40 kg P ha^{-1} for bean (B: –I, +F);
- Drip irrigation at 2.3 mm d^{-1} with canal water and no P or N for kale (K: +IC, –F);
- Drip irrigation at 2.3 mm d^{-1} with canal water and no P or N for bean (B: +IC, –F);
- Drip irrigation at 2.3 mm d^{-1} with water from the canal and application of 78 kg N ha^{-1} in splits of 48 kg N ha^{-1} at planting time and 30 kg N ha^{-1} four weeks after planting and 54 kg P ha^{-1} for kale (K: +IC, +F);
- Drip irrigation at 2.3 mm d^{-1} with water from the canal and application of 36 kg N and 40 kg P ha^{-1} for bean (B: +IC, +F);
- Drip irrigation at 2.3 mm d^{-1} with pond effluent providing 6.3 kg N ha^{-1} and 2.6 kg P ha^{-1} for kale (K: +IP, –F);
- Drip irrigation at 2.3 mm d^{-1} with pond effluent providing 6.3 kg N ha^{-1} and 2.6 kg P ha^{-1} for bean (B: +IP, –F);
- Drip irrigation at 2.3 mm d^{-1} with pond effluent providing 6.3 kg N ha^{-1} and 2.6 kg P ha^{-1} with application of 78 kg N ha^{-1} in splits of 48 kg N ha^{-1} at planting time and 30 kg N ha^{-1} four weeks after planting and 54 kg P ha^{-1} for kale (K: +IP, +F); and
- Drip irrigation at 2.3 mm d^{-1} with pond effluent providing 6.3 kg N ha^{-1} and 2.6 kg P ha^{-1} with application of 36 kg N and 40 kg P ha^{-1} for bean (B: +IP, +F).

Kale seedlings were transplanted to the field on 9 June 1999 at a spacing of 0.9 × 0.3 m and watered for seven days using a watering can to facilitate establishment. The crop was sprayed with Dimethoate® and Antracol® every two weeks to protect it against insect and fungal attacks, respectively. French bean seeds were direct seeded on 12 June 1999 at a row spacing of 0.6 m and line spacing of 0.1 m. Other practices were done 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 pedal pump and applied daily at 1100 h. Plots under French bean receiving drip irrigation water were fitted with an Alkal 1.5-in filter (which was bigger and more efficient than F1 0.75-in used in the first season), while those under kale were fitted with F1 0.75-in filters used in the first season.

Kale harvesting began 22 days after transplanting and continued for 42 days by removal of the lowest three leaves per plant every four days. The weight of fresh kale leaves harvested was measured at the desired harvesting period from each of the plots receiving different treatments and summed over the harvest period. Samples for leaf nutrient analyses were collected from the second uppermost leaf of kale just before the final harvesting period. Harvest ceased 80 days after transplanting, and dry matter yield for kale was determined for all treatments as the sum of leaf dry matter over the course of the experiment.

Second-season French bean harvest began 52 days after planting and continued for 28 days. The weight of fresh French bean pods were measured at the desired harvesting period from each of the plots receiving different treatments. Samples for leaf nutrient analyses were collected for French bean from the third uppermost leaf during flowering. After 81 days the bean crop was uprooted and the above-ground biomass dried out on polythene sheets for biomass yield records. Total above-ground dry matter yield for French bean was determined from all the treatments at the end of the experiment.

Plant Tissue Analysis

For both growing seasons, plant tissue samples for nutrient analyses were oven-dried at 65°C for 24 hours, hand-crushed using a mortar and pestle, and kept in plastic cans for analysis in laboratories at the Department of Agronomy and Soils at Auburn University. Total nitrogen in plant tissue was determined by dry combustion with a LECO CHN-600 analyzer (LECO Corp., St. Joseph, Michigan) (Hue and Evans, 1986). Phosphorus, potassium, iron, manganese, and aluminum in plant tissue were measured by dry ashing, followed by dissolution in 1 M hydrochloric acid, followed by determination with a Jarrell-Ash inductively coupled argon plasma (ICAP) spectroscope (ICAP 9000, Thermo Jarrell Ash, Franklin, Massachusetts) (Hue and Evans, 1986).

Statistical Analysis

For both growing seasons, analyses of variance were performed to determine variation in French bean and kale (second season only) fresh and dry biomass and leaf nutrient concentrations owing to treatments.

Pond Effluent Nutrient Removal by Soil Experiment

The experiment, conducted in the laboratory at Sagana Farm, was designed with soil columns set up to filter and retain pollutants from fish pond effluents. Soil columns are commonly used in solute transport and nutrient leaching experiments. Columns simulating a soil profile allow easy access to through-flow water and hence their adoption in this study.

Two soil samples were obtained, one from an uncultivated field under star grass for the vertisol (black clay soil) and the other batch from a field previously cultivated with soybean (*Glycine max*) for the cambisol (red clay soil) by excavation to a depth of 45 cm using a soil auger. For the two types of soils, samples were taken from 0–15 cm, 15–30 cm, and 30–45 cm depths and maintained as individual samples. The soil samples were air-dried in the laboratory, crushed, and sieved through a 2-mm mesh screen. Dry bulk density, hydraulic conductivity, and initial concentration of total nitrogen and extractable phosphorus were determined from subsamples taken from each of the soil types as previously described.

In the same fields, undisturbed samples were obtained using the core ring method (Klute et al., 1986). Four sites were selected randomly on the experimental site. Mini pits were dug to a depth of 0.50 m and steps demarcated at 0–0.15 m, 0.15–0.3 m, and 0.3–0.5 m. Three cores were placed at random on each step and driven into the soil using a core driver. The cores were then dug using a sharp knife, wrapped in aluminum foil, and taken to the laboratory for analysis.

Three portions of pipe (10-cm diameter) were used to simulate a soil profile of three layers with depths of 0–15 cm, 15–30 cm, and 30–45 cm. Each portion of 15-cm length was filled with soil taken from a particular soil layer. Based on the determined bulk densities (Table 1), 1.56 kg of the red clay soil and 1.93 kg of the black cotton soil from the 30–45 cm soil layer were

Table 1. Initial soil chemical and physical characteristics at the onset of the experiment.

Soil Type	Depth	K_{sat}	Bulk Density	pH (water)	Total N	Total C	P	Fe	Al	Mn	K
	cm	*cm d^{-1}*	*kg m^{-3}*	*1:1.5*	*(g kg^{-1})*		*(mg kg^{-1})*				
Black Clay	0–15	0.98	1,160	6.8	0.5	27.0	8.1	13.4	27.5	28.9	31.0
	15–30	0.99	1,260	7.3	0.4	20.8	6.2	11.4	25.2	11.3	9.6
	30–45	–	1,322	8.24	0.3	15.7	8.3	13.6	33.2	20.9	7.9
Red Clay	0–15	466	1,330	5.32	0.5	16.3	20.6	12.2	31.0	212.2	79.1
	15–30	339	1,373	5.01	0.4	12.1	7.3	10.7	26.7	110.4	57.9
	30–45	–	1,447	4.97	0.2	11.7	3.7	10.4	25.2	102.6	44.7

Table 2. Treatments in the soil column filters.

Treatment	Irrigation Intensity (mm d^{-1})	Application Period (d)	Water per Land (m^3 m^{-2})	Pond:Land
1	0	0	0	0:0
2	31	32	1	1:1
3	81	62	5	5:1
4	161	62	10	10:1

Table 3. Average nutrient and total suspended solids (TSS) contents of canal and fish pond water.

Source	Season 1			Season 2		
	Total N	*Total P*	*TSS*	*Total N*	*Total P*	*TSS*
	(mg l^{-1})			(mg l^{-1})		
Canal	0.49	0.04	79.7	0.72	0.16	54
Pond	6.03	3.89	330.6	3.16	1.33	193

pushed down into the lowest portion. The second 15-cm portion of the pipe was fitted on the top side of the first portion already filled with soil from the 30–45 cm soil layer and fixed by duct tape; then 1.48 kg of the red clay soil and 1.84 kg of the black cotton soil from the 15–30 cm soil layer were packed into this second portion of the pipe. A third portion of the pipe, which was longer (22-cm depth) to hold pond effluent, was fitted on the top side of the system and fixed using the same procedure. Red clay soil (1.51 kg) and black cotton soil (1.63 kg) from 0–15 cm soil layer were packed into the portion to a depth of 15 cm and compacted by shaking so as to attain the bulk density of the field soils in the same horizon. The three portions fixed together formed an individual soil column filter, which was mounted on a collection pan. Pond water to be purified was then collected from the pond receiving 20 kg N ha^{-1} wk^{-1}, containing on average 5.18 mg l^{-1} N and 0.68 mg l^{-1} P, and passed through the soil column filters at varying depths of irrigation, which served as the treatments.

Four treatments were administered at the depths of water corresponding to varying loading rates of pond effluent to land as shown in Table 2. Three replicates of the soil column filters were arranged on the laboratory floor in a completely randomized design.

At the end of experiment, soil was retrieved from column filters at the three 15-cm depths, prepared, and analyzed for total nitrogen and extractable phosphorus. The through-flow water from soil columns was collected on Tuesdays and Fridays and stored at 4°C for chemical analysis. Using standard methods, pond effluents and through-flow water were analyzed for total nitrogen and phosphorus. The difference between the concentration of total nitrogen and phosphorus in pond effluents and the through-flow water obtained from the soil column gave the estimated nutrients retained from the pond effluents by the soil columns. Percent nutrient removal (% NR) from effluents was calculated as:

$$\%NR = (\text{conc. } X - \text{conc. } F) \times 100/\text{conc. } X$$

where

$\%NR$ = % nutrient removal,
conc. X = nutrient concentration in the pond effluent, and
conc. F = nutrient concentration in the filtrate.

Change in soil nutrient content after application of effluents was determined using the following equation:

$$dX = X_1 - X_2$$

where

dX = change in nutrient X content in the soil,
X_1 = concentration of nutrient X in the soil at 0 level of effluent application, and
X_2 = concentration of nutrient X in the soil at a given irrigation depth used to apply pond effluent.

Data on soil nutrient content from the columns were entered into a spreadsheet with the various treatments in rows and the nutrient levels in columns. Analysis of variance was performed using the general linear model of Statgraphics to compare the mean effects of water application rates on nutrient retention by the soil. The means were separated using the least significant difference procedure.

RESULTS AND DISCUSSION

French Bean and Kale Field Experiment

The two sources of irrigation water used in this study differed in nitrogen, phosphorus, and total suspended solids (TSS) concentrations (Table 3). Total nitrogen and phosphorus concentrations were higher in pond water than canal water. After filling the pond with canal water and subsequent fertilization, nitrogen and phosphorus concentrations in pond

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

Treatment	Total N	P	K	Mn	Fe	Al
	(g kg^{-1})			(mg kg^{-1})		
B: –I, –F	42.7	2.8	1.70	342	184	79
B: –I, +F	50.0	3.2	1.67	298	146	115
B: +IC, –F	44.4	3.0	1.89	302	166	144
B: +IC, +F	52.5	4.0	1.84	274	134	97
B: +IP and C (1:1), –F	43.3	2.6	1.65	296	152	125
B: +IP, –F	42.1	2.6	1.82	931	167	139
LSD$_{0.05}$	3.6	0.1	0.31	96	54	37
C.V.	9.5	16.78	10.40	15	23	26

water increased. Fish activities and their excreta increased the TSS in pond water.

Figures 1 and 2 show fresh, dry pod, and above-ground biomass yields for French bean in the first season. Significant differences were observed in fresh pod yield of bean among treatments ($P = 0.05$), with all treatments having higher fresh pod yield than the control. The control yielded 1.3 t fresh weight ha^{-1} (t fw ha^{-1}). When irrigation was combined with fertilization the highest yield of 9.1 t fw ha^{-1} was recorded. Irrigation with canal water alone supported 7.7 t fw ha^{-1} yield, with a gradual decline as fish pond water was substituted for canal water. Irrigation with fish pond and canal water at a ratio of 1:1 without fertilization and irrigation with fish pond water without fertilization provided 6.1 and 4.3 t fw ha^{-1}, respectively.

A 53% yield decline when pond water was substituted for fertilizer application was observed. This observation is in contrast to those of Prinsloo and Schoonbee (1987) using flood irrigation on tomatoes, Al-Jaloud et al. (1993) using flood irrigation on wheat, and Hussein and Al-Jaloud (1995) using flood and furrow irrigation on wheat, all of whom observed an increase in crop yield when pond water was used for irrigation instead of well water. Pond water supplied inadequate nitrogen and phosphorus to bean, owing to the low concentration of these nutrients (Table 3). Irrigation with pond water at 0.3 mm d^{-1} supplied only 1.6 kg N ha^{-1} and 1.03 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 nitrogen and phosphorus. The total nitrogen concentration in pond water (Table 3) was within the acceptable range for irrigation water but could not support yields similar to those obtained with fertilizers.

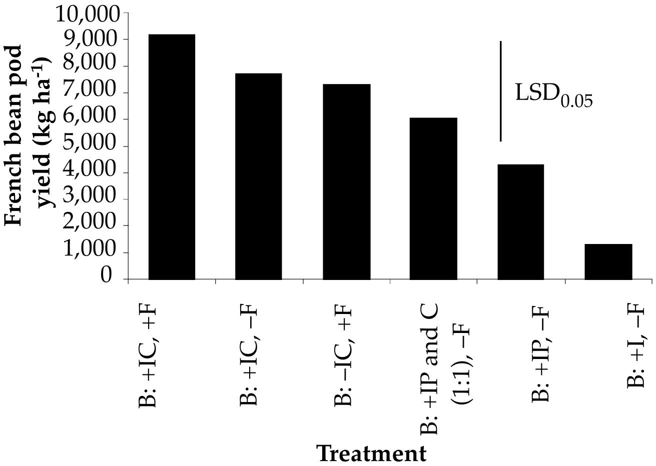

Figure 1. Fresh pod yield of French bean in the first season.

French bean foliar nutrient concentration in the first season is summarized in Table 4. Significant differences ($P = 0.05$) in leaf nitrogen and phosphorus concentrations among treatments were observed. Leaf nitrogen and phosphorus levels were higher in fertilized treatments, suggesting that availability of nitrogen and phosphorus to bean was higher in those treatments. These data help explain yield differences between treatments receiving fertilizers and those without fertilizer. Pond water containing 6 mg N l^{-1} and 4 mg P l^{-1} when applied at rates used in this study did not supply sufficient amounts of nitrogen and phosphorus to French bean to support optimum yields. It is apparent from this study that pond water cannot be a substitute for fertilizer application.

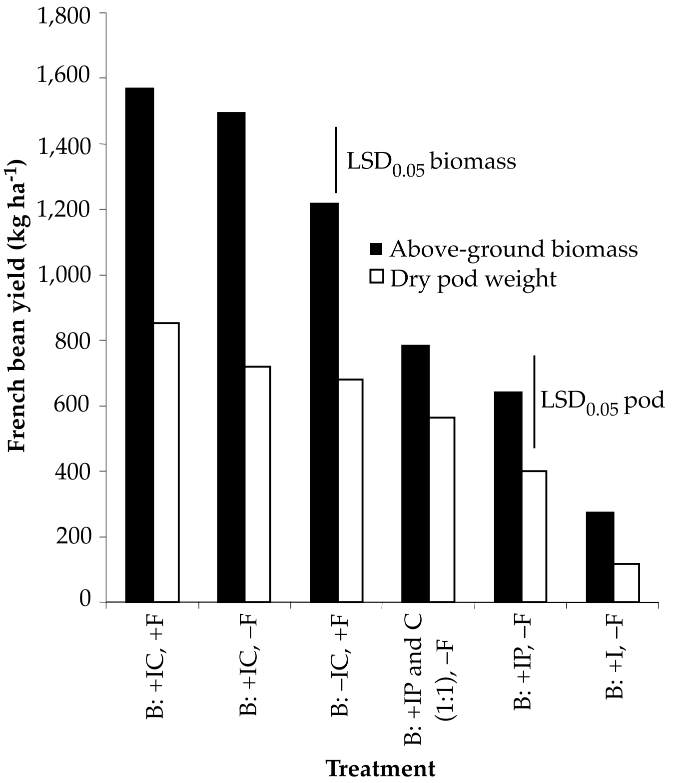

Figure 2. Dry pod weight and above-ground whole plant biomass (dry weight basis) of French bean in the first season.

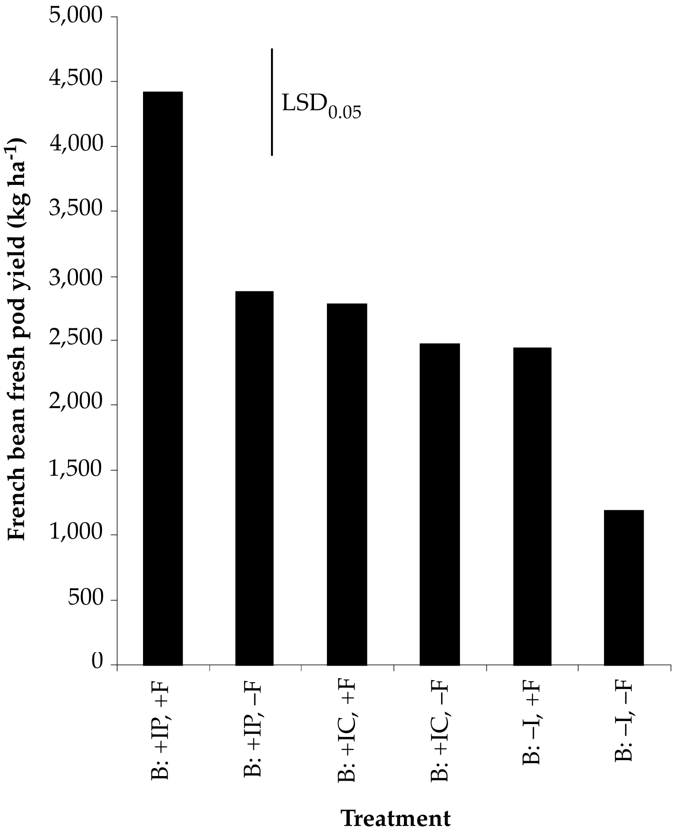

Figure 3. Fresh pod yield of French bean in the second season.

Beneficial effects of water application to crop yields are widely recognized (Hillel, 1980). A comparison made between the two water sources used in this experiment showed a 44% bean pod yield decline when pond water was substituted for canal water. The observed yield decline was due to insufficient water supplied to bean receiving irrigation from the pond. Pond water was poorly distributed along drip irrigation lines due to irregular clogging of emitters, resulting in patchy, inadequate water supply to bean plants. Clogging of emitters frequently occurred due to suspended particles and algae in pond water. Some of these particles may have escaped the filtration system and ended up in drip tapes. Particles of organic matter, minute spores, and separate cells of microorganisms probably infiltrated through filters and reached emitters. Under these conditions of reduced water velocity, oxidation-reduction potentials and favorable temperatures and aeration allowed microorganisms to proliferate, gradually plugging the outlets. When some emitters receiving water from the same bucket clogged, the remaining functioning emitters supplied excess water, resulting in excessive through-flow and leaching which took place directly under the drip tapes. As wetness increased below the emitters to the point of being waterlogged or flooded, reduced soil conditions likely occurred. Reducing conditions in a saturated or periodically inundated rhizosphere may have resulted in increased soluble manganese concentration in soil solution, promoting manganese toxicity to bean that was expressed as crinkled leaves (Bohn et al., 1985) and yield reduction. Generally, plants are affected at a foliar manganese concentration of about 300 to 500 mg kg^{-1}, and manganese concentration in mature bean leaves is typically 40 to 50 mg kg^{-1} (Tisdale et al., 1990). Thus, the concentration above 500 mg kg^{-1} observed in this study (Table 4) resulted in toxicity.

Table 5. Nutrient concentration of French bean leaves in the second season.

Treatment	Total N	P	K	Mn	Fe	Al
	(g kg^{-1})			*(mg kg^{-1})*		
B: –I, –F	45.9	2.4	1.52	62.5	671	551
B: –I, +F	55.3	3.6	2.05	55.5	614	473
B: +IC, –F	47.3	2.7	1.87	65.6	666	574
B: + IC, +F	48.4	3.0	1.72	81.7	894	806
B: + IP, –F	45.2	2.5	1.41	60.3	553	435
B: + IP, +F	50.2	2.9	1.99	85.1	769	664
$LSD_{0.05}$	4.7	0.9	0.37	30.2	549	586
C.V.	9.7	21.4	17.20	30	41	51

Figure 3 shows fresh pod yield obtained from French bean in the second season. There were statistically significant differences (P = 0.05) among treatments for fresh pod yields but not for dry pod weight and above-ground biomass (data not shown). Separation of means showed that fresh weight yield of bean pods from B: +IP, –F was significantly different from the yields of the control (B: –I, –F), B: +I, –F, and B: –I, +F treatments (Figure 3). The lowest yield, 1.2 t fw ha^{-1}, was obtained from the control. Irrigation with pond water combined with fertilization at the recommended rate resulted in the highest yield, 4.4 t fw ha^{-1}. Application of canal water combined with fertilization (B: +IC, +F) had a fresh pod yield that was not significantly different from application of pond water without fertilization (B: +IP, –F).

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 the effects of improved distribution of pond water, the greater irrigation amount, or their interaction. An increase of irrigation amount from 0.33 mm d^{-1} in the first season to 2.3 mm d^{-1} assured sufficient water supply to the root zone. Consumptive use of water was thus satisfied and better yields were obtained.

Table 5 shows nutrient concentration of bean leaves collected in the second season. Analysis of variance showed a statistically significant difference in leaf nitrogen concentration (P = 0.05). No difference was observed for leaf phosphorus, potassium, magnesium, aluminum, iron, and manganese concentrations. Treatments receiving fertilizers without irrigation had the highest foliar nitrogen concentration. Low foliar nitrogen concentrations were observed in treatments irrigated with pond water without fertilizer application and canal water without fertilizer application, suggesting a reduced availability of nitrogen in irrigated plots or a dilution effect owing to greater biomass production.

TSS in pond water was 42% higher in the first season than in the second season (Table 3). In the second season, larger filters (Alkal filter 1.5-in Lego Inc., Israel) were fitted on the drip irrigation system, leading to improved filtration. Low concentrations of TSS in pond water coupled with improvement of 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. Leaf manganese concentrations remained low and no toxicity occurred.

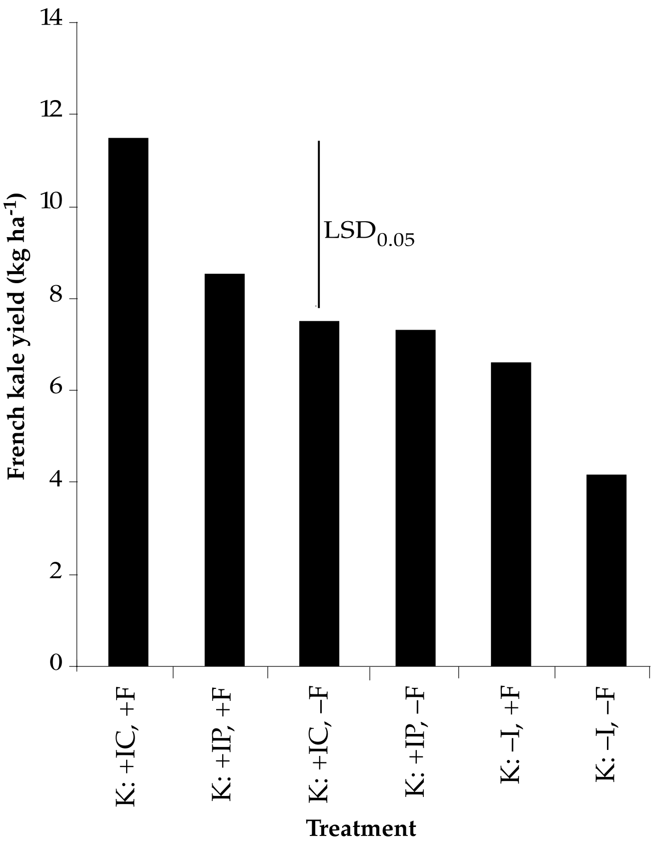

Figure 4. Fresh leaf yield of kale as affected by irrigation and fertilization.

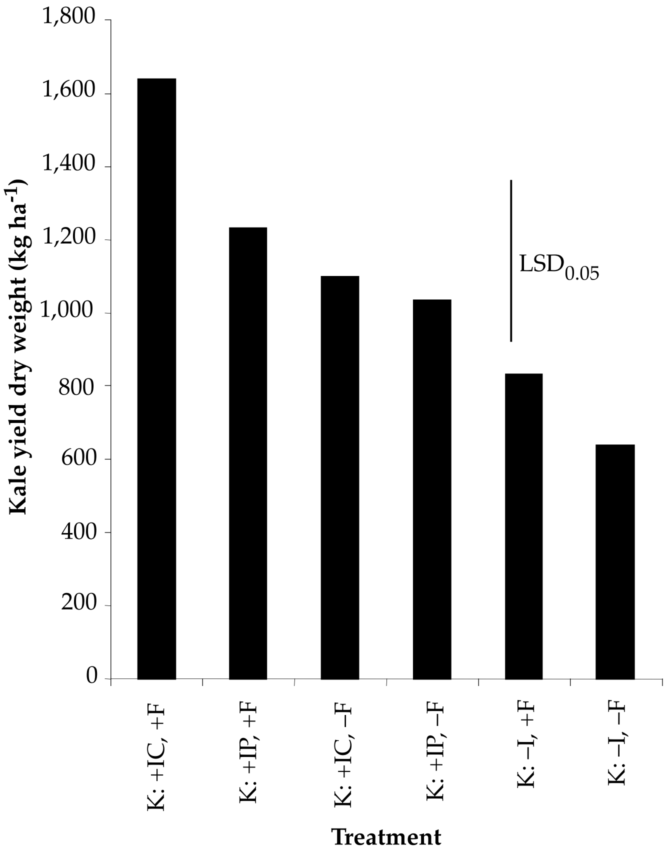

Figure 5. Leaf dry matter yield of kale as affected by irrigation and fertilization.

No other crops were grown in the neighborhood of the trial plots, and a higher pest incidence on the trial plots was witnessed. Therefore, lower yield in the second season bean compared to the first season could be due to the effects of pests and diseases that occurred due to late planting in the second season.

Fresh weight and dry weight yields of kale are shown in Figures 4 and 5. There were significant differences ($P = 0.05$) in kale fresh leaf yield among treatments. All treatments had higher fresh leaf weight and dry leaf weight than the non-irrigated, unfertilized control. When pond effluent was substituted for canal water, the net effect was a reduction in yield irrespective of nutrient application. A similar trend was observed for French bean in the first season. Yield reduction in kale owing to use of pond effluent observed in this study was related to moisture supply, probably due to poor water distribution and, hence, excess or insufficient water and inadequate nutrients reaching the kale crops. The F1 0.75-in filtration systems proved to be inadequate, releasing a low volume of water to the drip tapes and resulting in irregular clogging of the emitters and poor distribution of water along the drip irrigation lines. An imperfect and discontinuous drip irrigation system resulted in a continuous water stress as the moisture reservoir available to crops was extremely small. Discontinuously operated drip irrigation systems pose a disadvantage of moisture depletion and crop stress (Hillel, 1980).

Table 6. Leaf nutrient concentration of kale.

Treatment	Total N	P	K	Mn	Fe	Al
	g kg^{-1}			*mg kg^{-1}*		
K: –I, –F	56.1	3.9	2.34	34.1	358	303
K: –I, +F	57.6	3.8	1.54	46.9	310	186
K: +IC, –F	58.2	3.8	2.09	33.2	258	157
K: +IP, –F	57.6	5.6	1.83	43.7	550	330
K: +IC, –F	54.0	4.2	2.00	31.7	232	151
K: +IP, +F	54.7	5.2	1.99	52.4	389	172
LSD	8.8	1.3	0.50	22.5	507	390
C.V.	7.7	21.9	16.80	31.7	72	78

Table 6 shows foliar nutrient concentrations in kale leaves. Significant differences ($P = 0.05$) were observed in leaf phosphorus concentration. No significant differences were observed for leaf nitrogen, aluminum, iron, manganese, potassium, and magnesium concentrations. Irrigation with canal water with fertilizer application had the highest leaf phosphorus concentration, followed by pond water with fertilizer application. The lowest leaf phosphorus concentration was observed with zero fertilizer with or without irrigation, suggesting that the phosphorus taken up by kale was largely from applied fertilizers and not irrigation water. Similar to first season French bean results, it is apparent that pond water supplies inadequate nutrients to kale and that a larger filtration system is required to provide good quality pond effluent for drip irrigation.

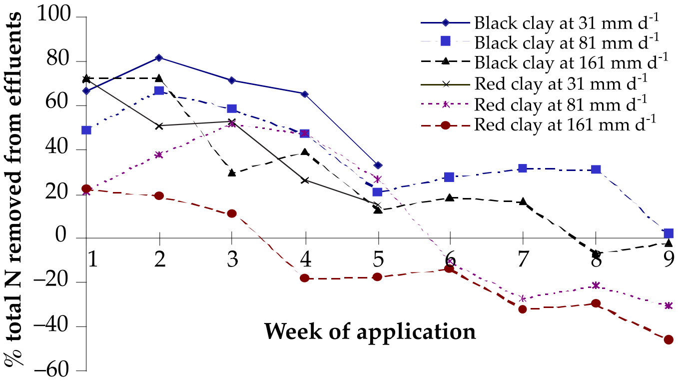

Figure 6. Nitrogen removal trends by soil in the columns at varying pond effluent application intensities.

Pond Effluent Nutrient Removal by Soil Experiment

Removal of total nitrogen from fish pond effluent via irrigation to soil columns at varying irrigation amounts is shown in Figure 6. In the first two weeks, 75% of applied nitrogen was removed from effluents in the 31 mm d^{-1} irrigation treatment by the black clay soil, followed by the 161 mm d^{-1} (72%) and 81 mm d^{-1} (60%) treatments. Within the same period, 60% of total nitrogen was removed from the effluent by red clay soil at the 31 mm d^{-1} effluent application intensity, 35% in the 81 mm d^{-1} effluent application intensity, and 20% in the 161 mm d^{-1} application intensity.

The highest percent nitrogen removal (70% for red clay soil and 84% for black clay soil) was observed with application rates of 31 mm d^{-1} during the first week, while the 161 mm d^{-1} effluent application rate resulted in 20% nitrogen removal in the same period for red clay soil. The intermediate 81 mm d^{-1} irrigation treatment resulted in 37% nitrogen removal from pond effluent added to red clay soil. High effluent loading resulted in less effective nitrogen removal. Black clay soil was 20%, 42%, and 72% more effective than red clay soil in nitrogen removal at 31, 81, and 161 mm d^{-1} effluent application intensities, respectively. Total nitrogen removal declined rapidly to less than 30% after the third week in the 81 mm d^{-1} and 161 mm d^{-1} application intensities.

Table 7 shows total nitrogen enrichment in soil after passing pond effluents through. Black clay soil retained 2.7%, 145%, and 155% more total nitrogen than red clay at the 31, 81, and 161 mm d^{-1} rates of effluent application, respectively. Low saturated hydraulic conductivity of black soil (Table 1) reduced the rate of downward movement of water, increasing contact time between nitrogen in effluent and the soil exchange surface, resulting in higher nitrogen adsorption. Water was probably transported through the small pores in the soil profile, enhancing adsorption of ammonia and nitrate. With alkaline pH (Table 1), black soil retained more total nitrogen than red clay soil; sorption of NO_3 was reported to increase with increased soil pH (Black and Waring, 1979). Sorption of NO_3 on positively charged surfaces delayed downward movement of NO_3. The location and rate of movement of the NO_3 front was determined primarily by water movement and adsorption in the two soils (Bohn et al., 1985). Transport of NO_3 was slow in black clay since displacement of the soil solution was less rapid. Due to expansion of the black soil upon wetting, volumetric water content was high (Russel, 1988), and assuming that the incoming water displaced the resident soil solution, the downward movement of the soil solution was less in black than red soil. For an equal quantity of effluent applied, dissolved forms of nitrogen were displaced farther in red clay soil and the soluble nitrogen front advanced faster than in black clay soil.

For red clay soil, total nitrogen in pond effluent was equal to that in the through-flow water from the soil columns after 23 days and 40 days of operation in the 161 mm d^{-1} and 81 mm d^{-1} effluent application intensities, respectively, implying zero nitrogen removal. However, zero nitrogen removal was not observed in the 31 mm d^{-1} application intensity (Figure 6). In black clay soil, zero nitrogen removal was observed at 161 mm d^{-1} application intensity after 54 days; the other two application intensities did not attain zero removal. Any further application of the pond effluents after reaching zero nitrogen removal resulted in higher levels of total nitrogen in soil column through-flow than in pond effluent. This negative nitrogen budget implies nitrogen addition by the soil in the columns to the through-flow water, which can be attributed to the arrival of the NO_3 front at the bottom of the soil column. This observation agrees with those reported by Lance and Whistler (1972) and Pell and Nyberg (1989).

Figure 7 shows phosphorus removal trends from black and red clay soils. Over 60% of total phosphorus applied in effluent was removed at all application intensities. Concentration of phosphorus in through-flow from soil columns remained low from the second week throughout the experimental period. The efficiency of phosphorus removal was about 75% in black clays and 80% in red clays at all loading intensities. Phosphorus retained in the soil was mainly a product of application

Table 7. Increase in total N content in the soil after pond effluent application

Application Intensity (mm d^{-1})	Red Clay	Black Clay	$LSD_{0.05}$	SE	C.V.
	Soil Total N ($g\ m^{-2}$)				
31	1.1	1.13	0.48	0.16	40
81	0.51	1.25	0.35	0.12	52
161	0.44	1.12	0.38	0.13	44

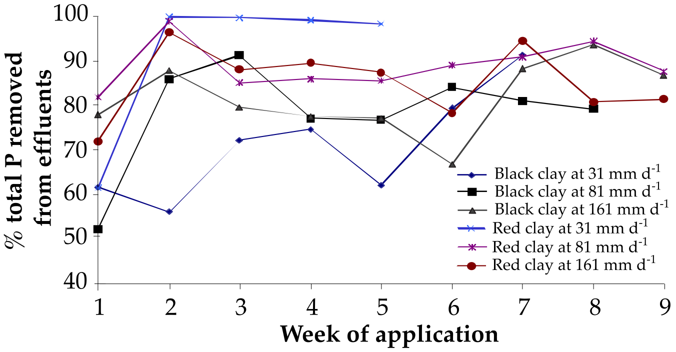

Figure 7. Phosphorus removal trends by soil in the columns at varying pond effluent application intensities.

Table 8. Increase in dilute-acid-extractable phosphorus content in the column soil after pond effluent application.

Application Intensity (mm d^{-1})	Red Clay	Black Clay	$LSD_{0.05}$	C.V.
	Soil Extractable P (g m^{-2})			
31	1.03	0.99	0.16	14
81	1.5	1.03	0.83	46
161	1.34	1.02	0.24	23

rate and phosphorus concentration; similar observations were made by Chardon et al. (1997). The fact that very low levels of phosphorus were found in effluent from the soil columns suggests that most of the phosphorus was rapidly adsorbed to soil particles. No tendency for phosphorus saturation was observed with the loading rates used in this study, contrary to observations made by Pardue et al. (1994), who used higher concentration effluents.

Phosphorus sorption onto soil from pond effluents occurred where phosphorus was exchanged with other anions and with metal ligands in the soil or was changed from physical sorption to chemisorption, precipitated as insoluble phosphorus compounds, incorporated into hydroxy-aluminum or iron polymers, or diffused into the crystal lattice of soil minerals (Bohn et al., 1985). Data on column soil enrichment with dilute-acid-extractable phosphorus (g m^{-2}) pond effluent application are presented in Table 8. There was no significant difference ($P = 0.05$) in total phosphorus retention between the two soils as shown by an increase in dilute-acid-extractable phosphorus; however, red clay soil retained 4%, 45%, and 31% more phosphorus than black clay soil at the 31, 81, and 161 mm d^{-1} rates of effluent application, respectively.

CONCLUSIONS

Fish pond effluent applied as irrigation and as a supplemental source of nutrients is beneficial for French bean and kale growth and yield. However, pond effluent should not be used as the primary source of nitrogen and phosphorus for crops owing to its low concentration of these elements. Moreover, the small amount of nitrogen and phosphorus in pond water does not justify adjustment of recommended nitrogen and phosphorus rates for crops.

Nutrient-rich pond water supports growth of phytoplankton and other organisms in the pond. Phytoplankton and suspended solids present in pond water due to activities of fish increase turbidity of the water, causing clogging of distribution pipes, drip lines, and water emitters. The resulting poor water distribution leads to nonuniform crop stands and low yields. Improving filtration using Alkal 1.5-in in place of F1 0.75-in filters led to better French bean yield response to pond effluent application. Improved filtration via larger filters is therefore essential. Similar conclusions are apparent for growing kale under drip irrigation.

In the soil column study, removal of nitrogen from pond effluent was high in the first three weeks of application, but rapidly declined with time. Continuous application of pond effluent at rates of 81 and 161 mm d^{-1} for periods of 40 and 23 days, respectively, saturates the soil's ability to retain total nitrogen from pond effluent with total nitrogen concentrations ranging from 1.33 mg l^{-1} to 6.30 mg l^{-1}. As effluent leaches, soil enrichment with nitrogen is higher in black than in red clay soil due to a longer residence time of the effluent, allowing adsorption. Soil treatment resulted in an average 80% removal of total phosphorus from pond effluent for up to ten weeks. Pond effluent application at a rate of 81 mm d^{-1} in red clay soil resulted in the highest soil phosphorus enrichment, while an application at a rate of 31 mm d^{-1} in black soil had the least enrichment. Black and red clay soils in the Sagana, Kenya, area are able to retain substantial amounts of nitrogen and phosphorus from pond effluent and are most effective in removing phosphorus.

ANTICIPATED BENEFITS

When fish are recovered from ponds, the effluent is often drained, presenting both an environmental challenge and an agricultural opportunity. Application of chemical fertilizers in ponds and activities of fish increase the 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 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. The soils in the Sagana, Kenya, region are capable of removing substantial quantities of nitrogen and phosphorus from pond effluent that otherwise would contribute to eutrophication of receiving water bodies.

LITERATURE CITED

Al-Jaloud, A.A., G. Hussain, A.A. Alsadon, A.Q. Siddiqui, and A. Al-Najada, 1993. Use of aquaculture effluent as a supplemental source of nitrogen fertilizer to a wheat crop. Arid Soil Res. Rehab., 7(3):233–241.

Black, A.S. and S.A. Waring, 1978. Adsorption of nitrate, chloride and sulfate by some highly weathered soils from southeast Queensland. Aust. J. Soil Res., 17:271–272.

Bohn, H., B.L. McNeal, and G.A. O'Connor, 1985. Soil Chemistry, Second Edition. John Wiley and Sons, New York, 341 pp.

Boyd, C.E., 1990. Water Quality in Warm Water Fish Ponds. Alabama Agricultural Experiment Station, Auburn University, Alabama, 482 pp.

Chardon, W.J, O. Oenema, P. del Castilho, R. Vreisema, J. Japenga, and D. Blaauw, 1997. Organic phosphorus in solutions and throughflows from soils treated with animal slurries. J. Environ. Qual., 26:372–378.

Government of Kenya, 1997. National Fisheries Statistics Bulletin. Department of Fisheries, Ministry of Natural Resources, Nairobi, Kenya.

Hillel, D., 1980. Applications of Soil Physics. John Wiley and Sons, New York, 301 pp.

Hue, N.V. and C.E. Evans, 1986. Procedures Used for Soil and Plant Analysis by the Auburn University Soil Testing Laboratory. Alabama Agricultural Experiment Station, Auburn University, Alabama, 31 pp.

Hussein, G. and A.A. Al-Jaloud, 1995. Effects of irrigation and nitrogen on water use efficiency of wheat in Saudi Arabia. Agric. Water Manage., 27(2):143–153.

Klute, A., G.S. Campbell, R.D. Jackson, M.M. Mortiland, and D.R. Nielson, 1986. Methods of Soil Analysis. Part 1. Physical and

Mineralogical Methods, Second Edition. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, 810 pp.

Lance, J.C. and F.D. Whistler, 1972. Nitrogen balance in soil columns intermittently flooded with secondary sewage effluent. J. Environ. Qual., 1:80–86.

Pardue, J.H., R.D. De Laune, W.H. Patrick, Jr., and J.B. Nyman, 1994. Treatment of alligator farm wastewater using land application. Aquacult. Eng., 13:129–146.

Pell, M. and F. Nyberg, 1989. Infiltration of wastewater in a newly started pilot sand-filter system: III. Transformation of nitrogen. J. Environ. Qual., 18:463–467.

Prinsloo, J.F. and H.J. Schoonbee, 1987. Investigations into feasibility of a duck-fish-vegetable integrated agriculture-aquaculture system for developing areas in South Africa. Water S.A., 13(2):109–118.

Russel, T., 1988. Soil Conditions and Plant Growth. Oxford University Press, London, 720 pp.

Sumari, O., 1982. Report on fish farm effluents in Finland. In: J.S. Alabaster (Editor), Report of the EIFAC Workshop on Fish-Farm Effluents, Silkeborg, Denmark, 26–28 May 1981. European Fisheries Advisory Commission (EIFAC) Tech. Paper 41. Food and Agriculture Organization, Rome, pp. 21–28.

Tisdale, S.L., W.L. Nelson, and J.D. Beaton, 1990. Soil Fertility and Fertilizers. MacMillan, Inc., New York, 480 pp.

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