FISH POND EFFLUENT EFFECTS ON YIELD OF FRENCH BEANS (*Phaseolus vulgaris* L.) AND KALE (*Brasica oleraceae* L.) IN CENTRAL KENYA.

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for the award of a Master of Science degree in Soil Science with our approval as the supervisors.

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DEDICATION

To all my teachers, friends and relatives who stood by me. To Valerie Mudibo thank you for who showing up on time to see me off to college!

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ABSTRACT.

The effects of pond effluent and its interaction with applied mineral fertilisers was assessed in a field experiment with application of mineral fertilisers at recommended rates and irrigation with pond effluent using french beans (*Phaseolus vulgaris* L.) and kale (*Brassica oleraceae*) as test crops over two growing seasons. Control treatments included unirrigated and unfertilised plots and irrigation with canal water. The treatments were arranged as complete factorial and laid out in randomised complete block design.

Plots receiving canal water and fertilisers at recommended rates had the highest yields of 9.1 tonnes of fresh pod ha^{-1} while those receiving no fertilisers or irrigation had the lowest yield of 1.3 tonnes fresh pod ha^{-1}. In the second season, significant difference ($P \leq 0.05$) were observed between treatments in fresh bean pod and fresh kale leaf yield. The fresh pod yield was observed in pond effluent irrigated and fertilised plots, while the lowest was observed in non irrigated not fertilised plots. The highest fresh kale leaf yield of 11.5 tonnes ha^{-1} was obtained with irrigation with canal water combined with fertiliser application, while the lowest yield of 4.2 tonnes ha^{-1} was recorded from the non irrigated or fertilised plots. Economic return from kale were significantly higher than from french beans due to a higher economic yield obtained from kale.

In the second experiment, the effectiveness of two types of soil occurring at Sagana, a Vertisol (black clay soil) and a Cambisol (red clay soil) in retaining nutrients from pond effluents was investigated. A laboratory experiment was conducted with soil columns containing red or black clay soil and 31, 81 and 161 mm day^{-1} effluent application intensities were tested on both soils. Both soils retained over 60% of total P from pond effluents, with red clay soil retaining 27% more P than black clay soil. At high effluent loading rate, low % N removal was observed in both soils. Total N removal efficiency declined with time and after 21 days, no N removal was observed where red clay soil was used. A significant difference ($P \leq 0.05$) was observed in N enrichment between soils. Black clay soil was more enriched by N more than red clay soil, while P enrichment was higher in red clay soil than in black clay soil. This leads to a conclusion that land application process of purifying pond effluents was more effective in P removal but less in N removal.

CHAPTER 1

1.0 Introduction

One of the major national objectives in Kenya's development policy is food self-sufficiency (Anon., 1993). Current population in Kenya is estimated at 28 million, and with a growth rate of 3.3% it is expected to reach 37 million by the year 2010 (Anon., 2000). Rapid population growth has resulted in increased demand for food and hence food security remains an important national priority. Attainment of this objective is constrained by diminishing productive land in the country with 78% classified as Arid and Semi-Arid Lands receiving inadequate and erratic rainfall.

Diversification and expansion of food production activities within traditional farming systems, and incorporating enterprises that result in more efficient recycling of organic and nutrient resources is a key to more efficient land management. Aquaculture is one such enterprise. Aquaculture is a rapidly expanding form of food production, and it has become a large world-wide industry, producing about 28.5 million tons of fin fish, shrimp, shellfish and aquatic plants in 1996 (Gross *et al.,* 1999). It is estimated that there are 46,000 fish ponds in Kenya (Seim, *et al.,* 1996). Effluents from the fish pond have a potential use as irrigation and fertilisation on crops (Al-Jaloud, 1993).

1.1 Integrated aquaculture farming

Aquaculture is concerned with the propagation and rearing of aquatic organisms under human control, and involves manipulation of at least one stage of an aquatic organisms' life cycle before harvesting in order to increase its production (Ghittino, 1995). It has also been defined as the science of production of aquatic plants, crustaceans, molluscs and fish in salt, brackish and fresh waters (Brankeret 1979). Fish provide 17% of the world's animal protein, and in some countries, the figure is as high as 50% (Anon., 1996). The majority of aquaculture throughout the world is conducted in ponds (Stickney, 1979). Pond culture for fin fish is the most widely practised type of operation in aquaculture (Rabanal and Shary, 1995). It is estimated that 3.7 million tons (75%) of the world production through aquaculture, covering 2.3 million hectares (90%) of the total area for aquaculture is derived from this type of system (Rabanal and Shary, 1995).

The agro-pisciculture production system integrates agriculture and fish culture and constitutes a complex man-made environment composed of organisms interacting with land and water environment in a given region. This ecosystem is characterized by optimal matter and energy transfers which maximize production of animal protein at the lowest possible cost (Pillay and Pill, 1997). Integration of fish farming and crops makes excellent sense for farmers in tropical countries, both in terms of intensification of land use and economic security. Fish provide meat for human consumption and the production practices enrich pond sediments and water which may then be used for crop production (Anon., 1991).

1.2 Justification

Integrated crop-livestock-fish farming has been suggested as one of the alternatives to large-scale monoculture farming (Brankeret, 1979). Adoption of new land use activities such as aquaculture into existing agroecosystems requires an understanding of their functional relationship with the existing land use (Elliot and Cole, 1987; Edward *et al.*, 1988).

The main objective of integrated systems is to enhance nutrient cycling and energy flow in the system to obtain maximum benefits in the production of food and fibre (Jamu and Piedrahita, 1995). Integration of aquaculture and agriculture through the use of pond sediment, organic matter as a crop fertiliser and pond water for irrigation establishes linkages between aquaculture ponds and crops (Jamu and Piedrahita, 1995), however, integrated systems have not been adequately studied because of their complexity. The plant-animal-fish production system has been deemed for long not to be genuinely integrated because it operated only in the plant and or animal to fish direction without the fish component making any contribution to the plant or animal component (Brankeret, 1979). To achieve genuine integration, the process needs to include another component such as the use of the pond, after draining, to grow a crop from which forage can be taken as a supplement animal feed (Brankeret, 1979) or use of pond effluents to irrigate or fertilize fodder or food crops.

Many livestock specialists and aquaculturalists believe integrated farming, as a type of eco-farming in which maximum utilization of resources including wastes, is proportionately related to minimum damage of the environment. Farm ponds can improve soil fertility by contributing enriched mud and water. One sustainable way to manage wetlands is their transformation into an agro-pisciculture by integrating agricultural and piscicultural production, thus allowing the optimization of food protein production for man at low cost (Symoens and Micha, 1995).

Little work has been done in East Africa on use of pond effluents as a source of irrigation water and plant nutrients for crop production. With rapid expansion of aquacultural activities in Kenya, there is a pressing need to better understand the benefits associated with improved resource integration. Results from this study could assist land managers to better use of pond effluents on the farm. They will also help aquaculturalists explore pond effluent treatment prior to disposal. As the number of farm ponds increase in Kenya, the quantity of enriched water with a potential agricultural benefit will also increase. It is advantageous to use one systems' refuse as another systems' resource.

1.3 Objective

The overall objective of the study was to investigate integrated fish-crop farming, with reference to the effects of fish pond effluents on yield of french beans (*Phaseolus vulgaris*) and kale (*Brassica oleraceae*) and the effectiveness of land application of pond effluents in removing excess nutrients from the effluents.

1.3.1 Specific objectives

The specific objectives were to:-

- Evaluate the suitability of pond effluent as a source of nutrients and irrigation water for high value vegetables using french bean and kale as test crops.
- Assess the effectiveness of soil to retain nutrients from fish pond effluents.

1.4 Hypotheses

The following hypotheses were tested.

1. Pond effluents can serve as an efficient source of irrigation water and nutrients to vegetable crops.
2. Pond waters may be purified within soils and serve as a source of nutrients to crops.

1.5 Thesis presentation.

This thesis consists of six chapters. Chapter One consists of the Introduction while Chapter Two serves as a general literature review. The Third Chapter describes the study area, and materials and methods used. Chapter Four consists of a report on experiment conducted to investigate the effects of pond effluents application on growth and yield of kale and French bean crop. The fifth chapter reports on the effectiveness of the soil in retention of total nitrogen and total phosphorus in land application treatment of pond effluents. The sixth chapter consists of a general discussion, conclusion and recommendations.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Integrated aquaculture - agriculture farming

Integrated aquaculture has been practised for many decades in Asia and Europe (Pullen and Shedadah, 1980; Hepher and Pruginin, 1981). Fish farming developed as a part-time activity of peasant farmers, who practised it alongside other farming activities as an efficient means of maximizing farm resources (Pillay, 1993). The basic principles involved in integrated farming are the utilisation of the synergestic effects of interrelated farm activities, and conservation, including the full utilisation of farm wastes.

Integrated fish farming is a system which is also practiced in Africa (Madagascar, Central African Republic, Zambia, Malawi) and South America (Panama and Brazil). Many developing countries have introduced this system on pilot or large scale basis, while some Eastern Europe countries (Hungary, Czech and Poland) have expanded and improved on the practice of integrating aquaculture with agriculture (Pillay, 1993). Farm wastes are used for fertilising and feeding fish and accumulations of silt in the ponds is used for fertilising agricultural crops, vegetables and fruit trees grown adjacent to the ponds. At the National Institute of Animal Husbandry, in Hanoi Vietnam, an integrated system has been applied on 11 ha. area using fish with pigs (use of pig manure and waste water), rice, vegetables and grasses for animal feed (Torskrisan, 1979). A comparison of the economic efficiency of fish culture only with that of combining fish with one crop of rice and vegetables on the same surface area suggests that there is benefit in intensive fish rearing and vegetable production in an integrated manner (Torskrisan, 1979). Such integrated farming can play a significant role in increasing the employment opportunities, nutrition and income of the rural populations, hence it deserves greater attention (Modadogou *et al.*, 1996).

2.2 Pond Fertilisation

Fertilisation of ponds and lakes for increased production of fish has its origin in antiquity, and for centuries it has been a common practice in Europe and parts of Asia to fertilise carp ponds (Bennet and Adams, 1972). The use of fertilisers to increase the biomass of fish and crustaceans has an agricultural analogy in the use of fertilisers to favour growth of pasture, which in turn allows increased production of livestock through the effect along the food chain (Hepher, 1963).

Inorganic nutrients released in the bacterial degradation of organic solids in organic matter are taken up by phytoplankton. Zooplankton graze phytoplankton and small detritus particles coated with bacteria, the latter also serving as food for benthic invertebrate detrivores. Plankton, especially phytoplankton, are the natural food within a fish pond (Pescod, 1992). Fertilisation results in a bloom of plankton algae that prevents development of filamentous algae and shades submerged aquatic vegetation (Bennet and Adams, 1972). It is well established that phytoplankton productivity is positively correlated with nutrient concentration and results in increased fish yield.

2.3 Chemical Fertiliser Application

Most fresh waters respond well to approximately 50 kg ha^{-1} of 16-20-0 NPK fertilisers (Boyd, 1985). Beveridge (1996) reported net tilapia (*Tilapia aurea*) production of 1109 kg ha^{-1} over 183 days in ponds that received 583 kg ha^{-1} of 20-20-0 fertiliser. Gross primary productivity in the same ponds averaged 6.3g organic carbon m^{-2} day^{-1}. Inputs of Nitrogen (N) and Phosphorus (P) fertilisers were 117 kg ha^{-1} and 51.1 kg ha^{-1} respectively and total dry matter production in photosynthesis was about 26,400 kg ha^{-1}. Under theoretical conditions, to maintain the gross productivity of 12 g carbon m^{-2} day $^{-1}$, 8 kg N and 0.8 kg P ha^{-1} day^{-1} would be required (Lin *et al.,* 1997). To reach fish yields of 3000-5000 kg ha $^{-1}$ $year^{-1}$, the ponds have to be maintained at a hypereutrophic state, by fertilising at a rate of 4 kg N and 1 kg P ha^{-1} day $^{-1}$. In most cases, maximum fish yields correspond to N loading rates of approximately 2 to 4 kg N ha $^{-1}$ day $^{-1}$ (Lin *et al.,* 1997).

2.4 Manure

Organic fertilisers or manure are animal wastes or agricultural by products which, when applied to ponds decompose slowly to release nutrients (Boyd, 1990). Organic fertilisers are used more extensively in Africa, Asia and the Far East. Use of domestic and farm wastes for fish culture is an age-old practice in Asia, especially in China, Malaysia and Indonesia (Pillay, 1993). Wastes from domestic animals are used to fertilize fishponds and these are supplemented with grass cuttings, rice bran, soybean meal. groundnut cake and other organic materials that may be available. The use of animal manures for fish culture is an extension of tradition land-crop cultivation, which uses available on-farm resources within reach of many small scale farmers (Edwards, 1993).

Culturing fish and rice together is an old practice and there is evidence that presence of fish increases rice yield when traditional farming methods are used (Grover, 1995). Many developing countries are adopting the system of fish farming in association with duck, pig or cattle production so as to utilize the wastes for fertilising fishponds (Rabanal and Shary, 1995). Duck and fish farming is an efficient means of cycling nutrients and has become widespread in Eastern Europe. Also the addition of fish feed to ponds increases the nutrient level, as do the excretory products of the culture animals. Organic manure in water upon decomposition releases nutrients which trigger the aquatic food chain. High levels of nutrients released from animal waste can support growth of extensive phytoplankton blooms and lead to high levels of secondary productivity in the zooplankton communities (Stickney, 1979).

2.5 Pond water enrichment

Nitrogen, phosphorus and occasionally potassium are the most limiting nutrients to phytoplankton production in natural waters and fish ponds (Lin *et al.*, 1997). Phosphorus is considered the key nutrient in pond fertilisation but N and other nutrients are also added (Boyd, 1990). Phosphorus is a limiting nutrient within many natural waters, as its source depends primarily on weathering of P rocks, which are not ubiquitous in the lithosphere (Lin *et al.*, 1997). Phosphorus and occasionally light are the principal factors limiting production in both temperate and tropical fresh waters, and thus the net addition or uptake of P or materials which greatly influence the light climate will alter productivity in ponds.

Phosphorus is an essential element required by all fish for normal growth and bone development, maintenance of acid-base regulation and lipids and carbohydrates metabolism (Takaech and Nakozoe, 1981 in Beveridge 1996). Phosphorus is also required for synthesis of RNA and DNA. Diets deficient in P can suppress appetite, normal food conversion and growth, and under extreme circumstances affect bone formation and lead to death (Lall, 1979). Phosphorus is a key metabolic nutrient and the supply of this element often regulates the productivity of natural waters. Experience with pond fertilisation also suggests that addition of P fertilisers increases pond production (Mortimer, 1954; Hickling, 1962).

Phosphorus is a required nutrient for plant growth and is usually present only in minute concentration in natural water because of its low mobility (Wetzel, 1975). Unless present in extreme abundance or in instances of another limiting factor operating, P is rapidly removed by primary producers. Researchers working in Israel found that inorganic nutrient concentration in pond water did not exceed 0.5 mg L^{-1} for P or 2.0 mg L^{-1} for N when large doses for fertilisers were added (Hepher, 1963). Phosphorus may be easily lost through combination with an excess of Ca^{2+} and Mg^{2+} to form tri-calcium phosphate. Iron may unite with P to form insoluble precipitate (Bennet and Adams, 1972). Phosphorus also may combine physically with micelles of ferric hydroxide or adsorbed directly on organic soil colloids on the pond bottom. Phosphorus added to pond or lake quickly goes out of solution, but still may be available on the pond bottom.

Unconsumed fish feed contributes a relatively large proportion of total waste output in most aquaculture operations (Cho and Bureau, 1997). In fishes such as salmonids which have size specific preferences for food, damaged pellets may not be ingested, but instead contribute nutrients to the water body. Food may also be washed out of the feeding cage by both natural currents and turbulence caused by fishes during feeding (Beveridge, 1984). For intensive trout culture, total feed losses are estimated to be 20% and estimates from various studies of 10-30% uneaten food. Some P is leached from the food prior to ingestion.

2.6 Fate of nutrients added to fish ponds.

Sediments are eventually the recipients of most of the nutrients added to aquaculture ponds. Laboratory studies have demonstrated that sediment P is the source of phytoplankton P and growth increases in relation to the P contents of the muds in the laboratory mud-water system (Chion and Boyd, 1974). Experiments conducted by Shrestha *et al.* (1996) to determine effective P fertilisation strategy in fish ponds, showed that the mean concentration of soluble reactive P in the water column increased with increasing sediment P saturation and P fertilisation rate. Sediments also contain organic P. Microbial decomposition of organic matter releases orthophosphate, which precipitates in equilibria established by the various iron aluminium and calcium compounds. Inorganic forms of P and N are processed into organic forms during passage through the pond (Teachert-Coddington *et al.,* 1995).

A large proportion of applied P is removed by sediments (Muskey and Boyd, 1986 in Shrestha *et al.,* 1996) that serve as the major sink for orthophosphate in fish ponds (Boyd and Musing 1981). Inorganic N and P effluents are higher in fertilised than unfertilised ponds (Boyd, 1990). The amount of P lost to sediments is varied e.g. 70% in mud water system in glass jars (Hepher, 1958), 44-46% in catfish raceway sediments (Worsham, 1975), 68% in an intensive carp pond (Avnimelich and Lachev, 1979), 70 to 90% in fertilised pond, 66% in cage fish culture (Ackefors, 1986), 75% in fertilised system (Bjork-Ramberg, 1984) and 55% in a channel catfish pond (Boyd, 1985). Sediments adsorb most P not harvested in fish reducing the P content in water column (Avnimelech and Lachev, 1979).

In a study conducted by Boyd (1990), shrimp harvested from ponds accounted for 10% of P removal. Almost one third of input P was not observed in the sum of P discharged with water and harvested with the shrimp, and was apparently fixed by the soils. Removals of N, P and organic matter in tilapia production accounted for 23.7% of N and 16.3% of P applied as fertilisers and 0.8% of the organic matter (O.M) fixed by grass photosynthesis (Boyd,1990). The surplus 26,176 kg ha.$^{-1}$ O.M, 89.3 kg N ha.$^{-1}$ and 42.8 kg P ha.$^{-1}$ either remained in the water, or in the mud, left the ponds in outflowing water or were transformed to gases (CO_2, NH_3, N_2,N_2O). Commercial size fish incorporated 17.55% of gross N input (Kroun *et al.,* 1985 in Shrestha and lin, 1996). Avnimelech and Lachev (1979) showed that fish harvested from an intensive carp culture pond with feeding accounted for 11% N and 32% P of that added in the feed. Each kilogram of fish harvested in this experiment required 1.32 kg of feed and released to the water in metabolic wastes 51.1g N, 7.2 g P and 1.1 kg chemical oxygen demand (COD).

When inorganic N is added to ponds in fertilisers, the initial high concentrations quickly declines. Some N present in water as metabolic wastes can be detected in solution and in particulate matter (Boyd, 1979). The N assimilated by plants in ponds is deposited in bottom muds as a component of organic matter when the plants die. Sediment clays accumulate approximately 2% of the total gross N input in the form of adsorbed KCl -extractable ammonium. Organic N accumulation in the sediment constitutes the greatest single N reservoir, accounting for 65% of the gross input (Avnimelch and Lachev, 1979).

An equilibrium exists between concentration of P ions in water surrounding the mud particles called interstitial water and the concentration of these ions adsorbed onto the colloidal particles. The net direction of the flux depends upon whether the water is above or below the equilibrium concentration of the ion in question (Boyd, 1990). Once the pond is filled with water, organic matter from uneaten feed, application of manure and fertilisers, dead plankton and fish excreta continually reaches the pond bottom. Organic matter does not degrade completely, and it tends to accumulate slowly in the ponds bottoms (Boyd, 1990).

2.7 Fish pond effluent pollution

The aquaculture industry produces large quantities of high strength waste water during production and processing of fish, shell fish and other organisms. The waste material from caged catfish were reported by Lin *et al.* (1997) to contain 30.9 kg N and 11.6 kg P given a fertilisation rate of 5.14 kg N and 1.94 kg P ha^{-1} day^{-1}. Fish farm effluents contain ammoniacal N as a by-product of the protein breakdown by fish and N brought in the pond by water (Solb'e, 1982). The average concentration reported is 0.17 mg L^{-1}. The concentration of undissociated NH_4 from an average of 51 fish farms in UK was reported to range between 1 μgL^{-1} to 11 μgL^{-1}. NH_3 concentration in pond water may reach levels of 0.5 mg L^{-1} upon a single input of NH_4 fertiliser at 5 kg N ha^{-1}. P is the major problem because it is the main factor determining the degree of eutrophy of water. In a survey conducted in Britain by Solb'e (1982), the concentration of P in the effluent of fish farms was 0.39 mg L^{-1}. It is estimated that in Finland about 240 tons $year^{-1}$ of N are discharged into water from fish farms, which was about 45% of the industrial N loading (Sumari, 1982). A survey conducted in UK indicated that for every ton of fish produced, 1.35 tons of solids are discharged to water ways increasing the total suspended solids by about two μgL^{-1} (Solb'e, 1982).

Eutrophication, as indicated by increase in plankton productivity may also cause changes in plankton community structure (Cornel and Whoriskey, 1993), leading to changes in fish community structure and function in the vicinity of the loading point (Ronnberg *et al.*, 1992). Sediment food and faeces stimulates microbial production, changing sediment chemistry, structure and function while the oxygen demand increases. There is an increase in release of N and P compounds into overlying waters leading to production of methane and evolution of hydrogen sulfide (Berge *et al.*, 1995, Beveridge, 1996). There tends to be a negative correlation between organic matter in estuaries and diversity of macrobenthos (Beveridge,1996), with heavily impacted sediments dominated by pollution tolerant species such as oligocheates and certain species of chironomid larval, while less tolerant taxa such as Ephemeroptera disappear.

2.8 Water application techniques

Water can be applied to crops by flooding it on the field surface, by applying it beneath the soil surface, by spraying it under pressure or by applying it through discrete emitters (drip irrigation). In the surface method of water application, water is applied directly to the soil surface from a channel. The method is suitable for irrigating closely spaced crops. Check basin irrigation involves construction of bunds or ridges around the cultivation areas forming basins within which the irrigation water is controlled. The basins are filled with water to desired depth and water is retained until it infiltrates into the soil (Michael, 1986). This method requires considerable land for construction of ridges and lateral channels. Precise land grading and shaping is also required. The method is not suitable for irrigated crops which are sensitive to wet soil conditions around the stems of plants. Furrow irrigation is used to irrigate crops where furrows are developed between the crop rows (Michael, 1986). This method offers better water control and utilization options compared to other surface application methods, however it requires precise land grading and additional land for furrow construction. Because of cracking, heavy black cotton soils can only be furrow irrigated, if combined with other irrigation methods.

In the sprinkler irrigation method, water is sprayed into the air and allowed to fall on the ground in a manner resembling rainfall. Sprinkler application achieves high irrigation efficiency if water is uniformly applied at a rate suitable to the infiltration rate of the soil. Fine textured soil, where infiltration rates are low and within a hot and windy climate, cannot be efficiently irrigated with sprinklers (Ross, 1989).

Trickle irrigation is mainly a technique whereby water and fertilisers can be placed at the direct disposal of the root zone, with the help of a specially designed emitter, calculated for significant low rates of flow. Water is delivered to the plants frequently and with a volume of water approaching the consumptive use of plants thereby minimising conventional losses as deep percolation, runoff and soil water evaporation. The system applies water slowly to keep the soil moisture within the desired range for plant growth (Hillel, 1980). Water application is accomplished by using small diameter plastic lateral emitters at selected spacing to deliver water to soil surface near the base of the plants. This emitter, the trickler, achieves a three dimensional differential spread of water, maintaining low levels of soil-water tension. Another high moisture regime prevails within the quite sharply defined boundaries of the wetted bulb which enables the development of closely knit root ramifications of live rootlets (FAO, 1973).

Drip irrigation was selected for this study due to its advantages of precision in measurement of applied water, ability to perform efficiently on heavy clay soil at the research site and low requirement for land shaping.

CHAPTER 3

3.0 RESEARCH APPROACH

3.1 Study area

The study was conducted between October 1998 and September 1999 at Sagana Fish Culture Farm of the Department of Fisheries, located in Sagana township of Ndia division, Kirinyaga District in Central Kenya. Sagana is situated at the southern foot of mount Kenya. The farm is located 2 km outside Sagana township about 105 km Northeast of Nairobi town at an elevation of 1210 metres above sea level between 39' South, and 37^{0} 12' East. The 50 hectare farm is located on a flat plain with 20 hactares of which are under ponds.

3.2 Climate

The study area is classified as lower midland 3 (LM3) with a semi-arid climate having a bimodal rainfall showing distinct dry and rainy seasons (Jaetzold and Schmidt, 1982) (Figure 3.1). Long rains are received from March to May while short rains are received from October to December. The average annual rainfall is 1166 mm year^{-1}. The air temperature ranges between a minimum average of $16.3^{o}C$ to a maximum average of $26.9^{o}C$. Humidity in the region surrounding the farm ranges from 90% in early morning to about 40% in the afternoon during dry season and from 50 to 60% in early rainy season (Nelson, 1984).

Low and poorly distributed rainfall was received at the station (Figure 3.1) as compared to the 25 year average in both seasons during study period. A total of

180 mm was received in the first season with 72% recorded in November. In the second season, a total of 143 mm was received with 78% recorded in June. (Figure 3.1).

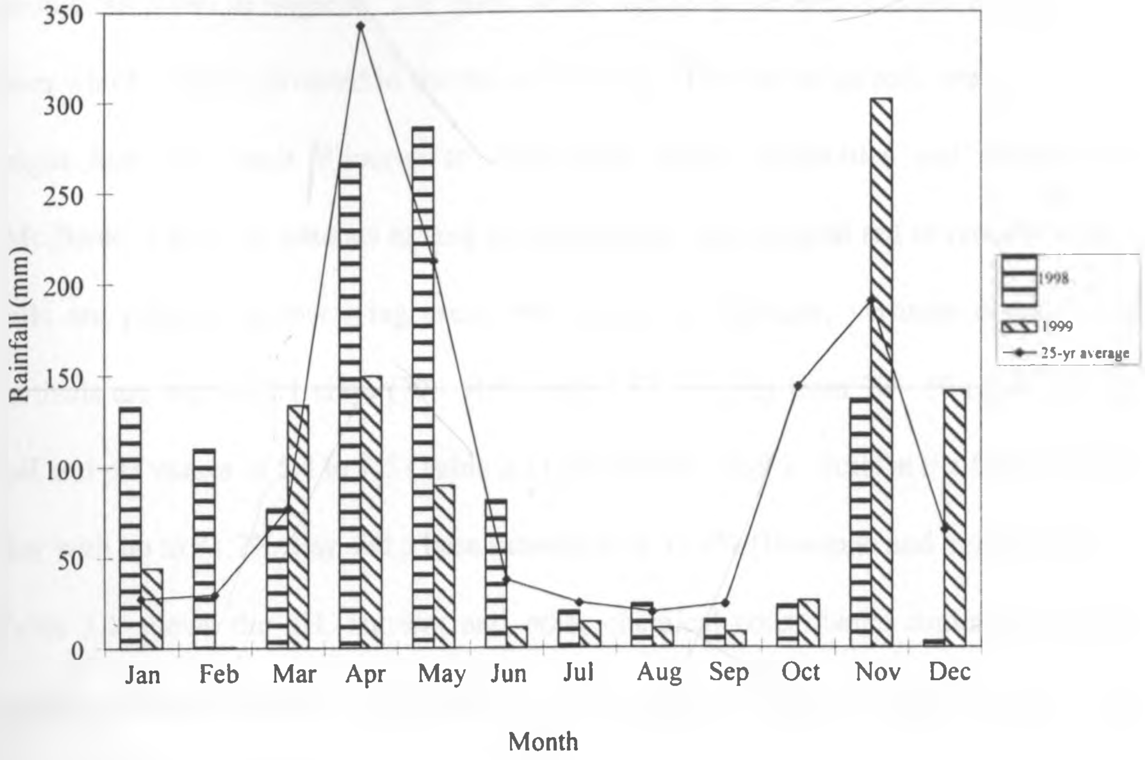

Figure 3.1 Monthly total rainfall for 1998, 1999 (bars) and the average over 25 years (line).

3.3 Vegetation and land use.

The site lies in an area characterized by trees that give way to cultivated fields and grasslands. The vegetation is dominated by *Pennisetum nigrum* grass inter-spaced by thickets of *Lantana camara.* Dominant trees species include *Jacaranda mimosifolia* and *Manginifera indica.* Other cultivated tree include *Grevillea robusta* and *Eucalyptus grandis.* Crops grown in the area are mainly food crops, such as *Zea mays* L., *Phaseolus vulgaris* L., *Ipomea batatus* and *Cajanus cajan* L.

3.5 Hydrology, geology and soils

The catchment area originates from the slopes of Mount Kenya and runs throughout Nyeri to Sagana. The main water supply to the area is from Ragati river from which water is diverted to the research ponds. The dominant soils are of volcanic origin from the latest Pliocene to Pleistocene basalt, phonolites and pyroclastics (McElwee, 1999). In patches having good drainage, laterittic and red to reddish brown soils are present. In low lying areas with restricted drainage, vertisols occur. The vertisols are high in 2:1 clays (70 - 90%) with CEC ranging from 30 - 50 cmol. kg^{-1} of soil and pH values of 5.4 to 7.5 (Table 3.1) (McElwee, 1999). Soils at the fish farm are clay with up to 81.7% clay and a base saturation of 76.4% (Bowman and Seim, 1996). Table 3.1 shows the pH, nutrient and other chemical constituents content, the bulk density and the hydraulic conductivity of the Vertisol (FAO/UNESCO) (black clay soil) and Cambisol (FAO/UNESCO) (red clay soil) used in both the crop irrigation and land application treatment of pond effluents experiments at the start of the trials.

3.6 The experiments

Two investigations were carried out in this thesis. The first study was conducted to investigate the potential benefits of applying pond effluents to horticultural crops and the effects of the effluents on the yield were assessed. The second experiment examined the potential use of land to purify fishpond effluents. Description of the procedures, results and conclusions from these experiments are in the subsequent chapters.

Table 3.1 Some 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 day^{-1}	kg m^{-3}	1:1.5	----------g kg^{-1}------		----------------------------mg kg^{-1}---------------------------				
Black Clay	0-15	0.98	1160	6.8	0.5	27	8.1	13.4	27.5	28.9	31.0
Black Clay	15-30	0.99	1260	7.3	0.4	20.8	6.2	11.4	25.2	11.3	9.6
Black Clay	30-45	-	-	8.2	0.3	15.7	8.3	13.6	33.2	20.9	7.9
Red Clay	0-15	466	1330	5.3	0.5	16.3	20.6	12.2	31.0	212.2	79.1
Red Clay	15-30	339	1373	5.0	0.4	12.1	7.3	10.7	26.7	110.4	57.9
Red Clay	30-45	-	-	5.0	0.2	11.7	3.7	10.4	25.2	102.6	44.7

CHAPTER 4

4.1 POND EFFLUENT AS A SOURCE OF PLANT NUTRIENTS AND IRRIGATION WATER FOR FRENCH BEAN AND KALE PRODUCTION

4.2 Introduction

Fertilisers are applied to ponds to increase inorganic nutrient levels that promote growth of phytoplankton that enhance production of fish and crustaceans through the effects along the food chain (Boyd, 1990). Where fish ponds were fertilized at a rate of 5.14 kg N and 1.94 kg P ha^{-1} day^{-1} fish pond water contained N and P nutrients capable of supplying fertiliser at rates of 30.9 kg N ha^{-1} and 11.6 kg P ha^{-1} respectively (Lin *et al.*, 1997).

Under optimal growth conditions, the average nutrient composition of phytoplankton biomass is approximately 45-50% C, 8-10% N and 1% P, giving a typical C:N:P ratio of about 50:10:1 (Goldman, 1980). The life span of an individual phytoplankton cell is approximately one to two weeks (Goldman, 1980) and the nutrients in dead phytoplankton are released very quickly through microbial degradation (De Pinto *et al.*, 1986). Phosphorus released in decomposition is readily adsorbed by mud (Shrestha, 1996). Increases in total P observed in water column when fertilisers are not applied is probably due to decay of dead plankton and the suspension of soil particles by rains and winds (Boyd, 1990).

Phosphorus requirements for different species of fish range from 0.29% to 0.90% of their diets. The majority of the currently available intensive fish feeds are largely derived from animal products, such as fish meal, meat meal, and bone meal, where most P is present in inorganic form, and the remainder is in the form of P complexes in proteins, lipids and carbohydrates (Lall, 1979). Nearly all of this P is readily available to carnivorous fishes. However, the availability of P in fish meal diets to omnivores and herbivores is highly variable (Beveridge, 1984). On the other hand, 60-80% of the total P in plant materials exists as Ca and Mg salt of phytic acid known as phytin (Beveridge, 1984) and is unavailable to fish as they do not possess the necessary enzyme to break down this component (Lall, 1979). Thus depending on the digestibility of the source, a significant proportion of P intake may be egested in faeces in undigested form.

Research indicates that net absorption of P by catfish from feeds derived from plant products range from 25% to 50% (Jonathan and Richard, 1997). Phosphorus surplus to dietary requirements is largely excreted (Lall, 1979). Beveridge (1996) reported an accumulation of between 20-70% of total N inputs in water column and plankton communities. The enrichment of discharge from fish farming is usually caused by added fertilisers and manure, unconsumed fish feed, fish feces and fractions of dissolved compounds (ammonia) excreted directly by fish.

Ponds are drained for harvest and considerable amounts of P and N are discharged from fish farms (Sumari, 1982). The effluents released from the ponds are allowed to run into the natural waterways. Effluents from fertilized ponds have high nutrient concentrations and can be potential sources of pollution and eutrofication of water in which they are disposed.

On one hand, the nutrients accumulated in fish ponds pose an environmental hazard when these waters are drained to harvest fish and service the ponds. However, these waters may provide a source of irrigation and plant nutrients to adjacent crop lands. This compatibility of objectives forms the basis for resource integration between agriculture and aquaculture systems.

To reduce the polluting effects of fish farming, pond effluents are collected when cleaning ponds and used for irrigation while the sludge is used for soil fertility management (Sumari, 1982) and crop fertilisation (Edwards *et al.*, 1986). In a study on rape seed production, application of 175 kg N ha^{-1} through irrigation water had a similar effect on yield as application of pond effluents containing 40 mg N L^{-1} (Al-Jaloud *et al.*, 1996).

Hussein and Al-Jaloud (1995) reported wheat biomass yield ranging from 4.3 to 14 metric tonnes ha^{-1} when well water was used for irrigation and 6.5 to 14.9 tonnes of biomass yield ha^{-1} when aquaculture effluent was used as a replacement with grain yield ranging from 0.8 to 5.0 tonnes ha^{-1} with well water and from 2.14 to 5.8 metric tonnes ha^{-1} with aquaculture effluents. Al-Jaloud *et al.* (1993), reported a wheat biomass yield of 5.5 to 18.7 metric tonnes ha^{-1} using well water, compared to a total biomass of 7.1 to 18.8 tons ha^{-1} using aquaculture effluents. Grain yield of 1.6 to 7.70 tons ha^{-1} with well water was obtained compared to 2.70 to 7.79 tons ha^{-1} with aquacultural effluents realized in the same study.

An improved water use efficiency (WUE) was also reported with aquaculture effluent irrigated crop having a WUE ranging from 11.3 to 30.0 kg ha^{-1} mm^{-1} whereas the well water had a WUE ranging from 6.8 to 22.2 kg ha^{-1} mm^{-1} (Hussein and Al-Jaloud, 1995). The grain yield and WUE obtained in treatments irrigated with well water and receiving 75% and 100% of N requirements were comparable with treatments irrigated with aquacultural effluents and receiving 25% and 50% of the N requirements implying that application of 150 to 225 kg N ha $^{-1}$ from well water irrigation and 75 to 160 kg N for aquaculture effluents irrigation containing 40 mg L $^{-1}$ was sufficient for optimum grain yield and resulted in improved WUE. A 50% saving in N application as an inorganic fertiliser could be achieved if crops were irrigated with aquacultural effluents containing 40 mg L^{-1} (Al-Jaloud *et al.,* 1993).

It appears that where the fish pond acts as a water reservoir, a high quality effluent for irrigation of crops, plus an additional crop of fish by the combined system is an economically sound system for consideration by farmers (Allien and Hepher, 1995).

The study reported in this chapter was conducted to evaluate the suitability of effluents from fertilised fish ponds as a source of plant nutrients and irrigation water for growing French bean (*Phaseolus vulgaris*) and kale (*Brassica aleraceae* conver acephala). This was to be achieved through testing the hypothesis that since fish pond waters are fertilized, they are likely to contain high levels of nutrients thereby when used for crop irrigation would result in increassed yield.

4.3 Materials and Methods

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.

4.3.1 Establishment of experiment

4.3.1.1 First season crop

4.3.1.1.1 Land preparation

Eighteen plots measuring 10m by 6m each were prepared on uncultivated star grass (*Digitaria scalarum*) grassland on the eastern side of the fish ponds (appendix 2b). The land was hand tilled and harrowed to the required tilth for French bean seeds. Drainage trenches were dug 0.3 m wide and 0.4 m deep, to drain out excess water after irrigation or rainfall incidence.

4.3.1.1.2 Treatments .

A total of six treatments were tested in the first season. These were;

1. No irrigation, no P nor N for bean (B –I,-F).
2. No irrigation plus 36 kg N and 40 kg P ha^{-1} on French beans (B –I,+F).
3. Irrigation at 0.3 mm day $^{-1}$ canal water, no P nor N for beans (B +IC, -F).
4. Irrigation at 0.3 mm day $^{-1}$ canal plus 36 kg N and 40 kg P ha^{-1} on French beans (B +IC, +F).
5. Irrigation at 0.3 mm day $^{-1}$ water from a pond effluent[*] providing to the plot 0.8 kg N and 0.5 kg P ha^{-1} for bean (B +IC&P1:1, -F).
6. Irrigation at 0.3 mm day $^{-1}$ water from a pond [**] effluent providing to the plot 1.6 kg N and 1.0 kg P ha^{-1} for bean (B +IP, -F).

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[*] The pond was receiving 20 kg N ha^{-1}week^{-1} and 8 kg P ha^{-1} for 17 week grow out period and the effluent taken from the pond to crop was diluted 1:1 with canal water

[**] The pond was receiving 20 kg N ha^{-1}week^{-1} and 8 kg P ha^{-1} for 17 week grow out period and the effluent taken from the pond to crop was not diluted with canal water

4.3.1.1.3 Field layout

The experiment consisted of six treatments laid out in a randomised complete block design (RCBD). The plots were blocked against the influence of water in a canal running between the ponds and the plots. Three blocks consisting of six plots where each block made a replicate were laid out. Six treatments were assigned in each block randomly (appendix 2c). A total of 18 experimental units were laid out. Plots receiving irrigation water were fitted with F1 ¾" filter (Lego Inco. Israel) and other drip irrigation equipment.

4.3.1.1.4 Irrigation water sampling and application procedures

Water samples were taken using a column sampler from the canal and pond and was analyzed for total N and P contents using the procedure described in appendix 2f. Irrigation water was applied from either pond or canal to a distribution bucket in each irrigated plot. Water was lifted to the buckets using another set of buckets. The distribution buckets for specific water source were linked to drip irrigation system that discharged water to the crops in individual plots. The amount of water applied to the crops was measured in a graduated bucket before introduction to the distribution tanks. Twenty litres of water were applied in split of 10 litres at 9.00 a.m. and 10 litres at 4.00 p.m every day giving an irrigation depth of 0.3 mm day $^{-1}$.

4.3.1.1.5 Test crops

French beans (variety Samantha) were used in this study during the first season. French bean seeds were sown out in the field on 30th October, 1998 at a spacing of 0.6

m by 0.1 m. They were sprayed with Antracol® and Ripcord® at a rate of 80 L ha^{-1} at 14 day intervals for pest and disease control. After 39 days, 90% of the beans had flowered.

4.3.1.2 Second season crop.

4.3.1.2.1 Land preparation

Twenty four plots measuring 5 m by 6 m each were prepared on the previous seasons' experimental site with additional twelve plots prepared on an adjacent uncultivated portion under stargrass (*Digitara scalarum*). The land was hand tilled and hand harrowed to the recommended tilth for French beans and kale crops.

4.3.1.2.2 Treatments .

A total of 6 treatments laid out in a randomised complete block design and replicated three times for each crop. The treatments were as listed below;

1. No irrigation no P nor N for kale (K –I,-F).
2. No irrigation no P nor N for beans (B –I,-F).
3. No irrigation plus and 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)..
4. No irrigation plus 36 kg N and 40 kg P ha^{-1} for French beans (B –I,+F).
5. Irrigation at 2.3 mm day $^{-1}$ with canal water, no P nor N for kale (K +IC,-F).
6. Irrigation at 2.3 mm day $^{-1}$ with canal water, no P nor N for beans (B +IC,-F).
7. Irrigation at 2.3 mm day $^{-1}$ with water from the canal and application 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).

8. Irrigation at 2.3 mm day $^{-1}$ with water from the canal and application of 36 kg N and 40 kg P ha^{-1} for french bean (B +IC,+F).
9. Irrigation at 2.3 mm day $^{-1}$ with water from a pond*** effluent providing to the plot 6.3 kg N and 2.6 kg P ha^{-1} for kale (K +IP,-F).
10. Irrigation at 2.3 mm day $^{-1}$ with water from a pond ***effluent providing to the plot 6.3 kg N and 2.6 kg P ha^{-1} for bean (B +IP,-F).
11. Irrigation at 2.3 mm day $^{-1}$ with water from a pond *** effluent providing to the plot 6.3 kg N 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).
12. Irrigation at 2.3 mm day $^{-1}$ with water from a pond*** effluent providing to the plot 6.3 kg N and 2.6 kg P ha^{-1} with application of 36 kg N and 40 kg P ha^{-1} for french beans (K +IP,+F).

4.3.1.2.3 Field layout

The experiment consisted of six treatments laid in randomized complete block design with three replicates for each crop (appendix 2d). Three factors namely, crops (kale and french beans), irrigation (0, canal water and pond effluent) and fertilisation (0 and recommended rates) were considered. Plots under French beans receiving irrigation water were fitted with an Alkal filter size 1.5" (which was bigger and more efficient than F1 ¾" used in first season) while those under kale were fitted with F1 ¾" filters used in the first season and other drip irrigation accessories.

*** The pond was receiving 20 kg N ha^{-1} week^{-1} and 8 kg P ha^{-1} for 17 week grow out period

4.3.1.2.4 Irrigation procedures

Water for irrigation was lifted to a 70 litre distribution barrel in each irrigated plot, using a pedal pump and applied daily at 11.00 a.m .

4.3.1.2.5 Test crops

Kale (*Brasicca oleraceae* conver Acephala) (variety gloria) and french beans (*Phaseolus vulgaris* L.) (variety samantha) were used as test crops in the second season. Kale seedlings were transplanted to the field on 9 June 1999, at a spacing of 0.9m by 0.3m and watered for seven days using a watering can to facilitate establishment. The crop was sprayed with Dimethoate® and Antracol® after 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 0.6m and line spacing of 0.1m. Other practices were done as in the first season.

4.3.1.2.6 Data collection

In the first season, french bean harvest began 46 days after planting and continued for 28 days. The green immature pods were harvested (Anon., 1989). 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 sheet for biomass yield records.

Kale harvesting began 22 days after transplanting and continued for 42 days by removal of the lowest three leaves per plant after every four days (Anon., 1989). Leaf samples were picked from the third leaf from the top of at least five plants per row excluding the two outer rows for nutrient analysis. Eighty days after transplanting, the crop was cut and the dry above ground biomass recorded.

Second season french bean harvest began 52 days after planting and continued for 28 days. After 81 days, the bean crop was uprooted and the above ground biomass dried out on polythene sheet for biomass yield records. The third leaf from the top was sampled and oven dried at 65°C for 24 hours, hand crushed using a mortar and pestle to smaller pieces and kept in plastic cans for analysis at Dr. C.W Wood laboratory in the Department of Agronomy and Soils at Auburn University Laboratory U.S.A. They were analysed using the procedure described in appendix 2g.

The weight of fresh french bean pods and kale fresh leaves harvested were measured at the desired harvesting period from each of the plots receiving different treatments. Leaf P and N levels were measured on French beans from the third leaf at flowering period while on kale it was done on the second leaf just before the harvesting period. The total above ground dry matter yield for the French beans and kale was determined from all the treatments at the end of the experiment.

4.3.1.2.7 Economic evaluation

A partial economic analysis was performed for all treatments relative to unirrigated unfertilised control treatments. Baseline information used is summarized as, cost of 1 kg of DAP Ksh 26, cost of 1 kg of CAN Ksh 24, cost of irrigation equipment in the first season Ksh 500 per 30 m^2 plot averaged over 6 seasons useful lifetime at Ksh 84 per season.

Cost of irrigation equipment in the second season Ksh 1590 per 30 m^2 plot averaged over 6 seasons useful lifetime Ksh 265 per season. Fertiliser inputs to receiving treatments were as recommended (Anon., 1989). Revenue from each treatment was computed by multiplying the mean yield from a particular treatment with the unit value of the crop (which was Ksh 30 per kg for French beans in the first season, Ksh 25 per kg in the second season and 10 per kg for kale).

Calculation of the net profit was performed relative to the control treatment. Additional cost and loss in revenue as a result of administration of a particular treatment relative to the control was summed up as cost (C), while additional revenue and saved cost was summed up as income (I). The net profit or loss was calculated as income less cost

$$I - C = NP \qquad (4.1)$$

4.3.1.2.8 Statistical analyses.

Yield data from the experiment was entered into the Microsoft excel spreadsheet with the various treatments as the rows and descriptors as the columns. Analysis of Variance was conducted using the General Linear Model of the Statigraphics (Statigraphics Inco., 1995), to determine the effects of irrigation source and fertilisation regimes on yield components at 0.05 level of significance (appendices, 3 -13.). The Least Significant Difference ($LSD_{0.05}$) at a probability of 0.05 was used to separate means (Zar, 1997). The statistical model employed may be summarised as;

$Y_{ijkl} = C + R_i + Cr_j + \text{fert.}_k + \text{irrig.}_l + \text{Cr x fert.}_{jk} + \text{Cr x irrig.}_{jl} + \text{irrig. x fert.}_{kl} + \text{Cr x Fert. x irrig.}_{jkl} + E_{ijkl}$

Where;

Y_{ijkl} = the measured parameter. C,R and E = constant, replicate and error terms.

Cr., Fert. and irrig. are the treatments i.e crop type, fertilisation rate and irrigation regime.

4.4 Results and discussion

4.4.0 Nutrient levels in irrigation water.

Two sources of water for irrigation which were investigated in this study showed a difference in total N and P contents and the levels of total suspended solids as shown in Table 4.1.

Table 4.1. 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}		----------------------
Canal	0.49	0.04	79.7	0.72	0.16	54
Pond	6.03	3.89	330.6	3.16	1.33	193

Total N and P contents were higher in pond water than canal water. After filling the pond with canal water and subsequent fertilisation, N and P contents in the pond water increased. Fish activities and their excreta increased the total suspended solids in pond water.

4.4.1. French bean crop production.

Fresh, dry pod and above ground biomass yields from french beans in the first season are presented in Figure 4.1 and 4.2.

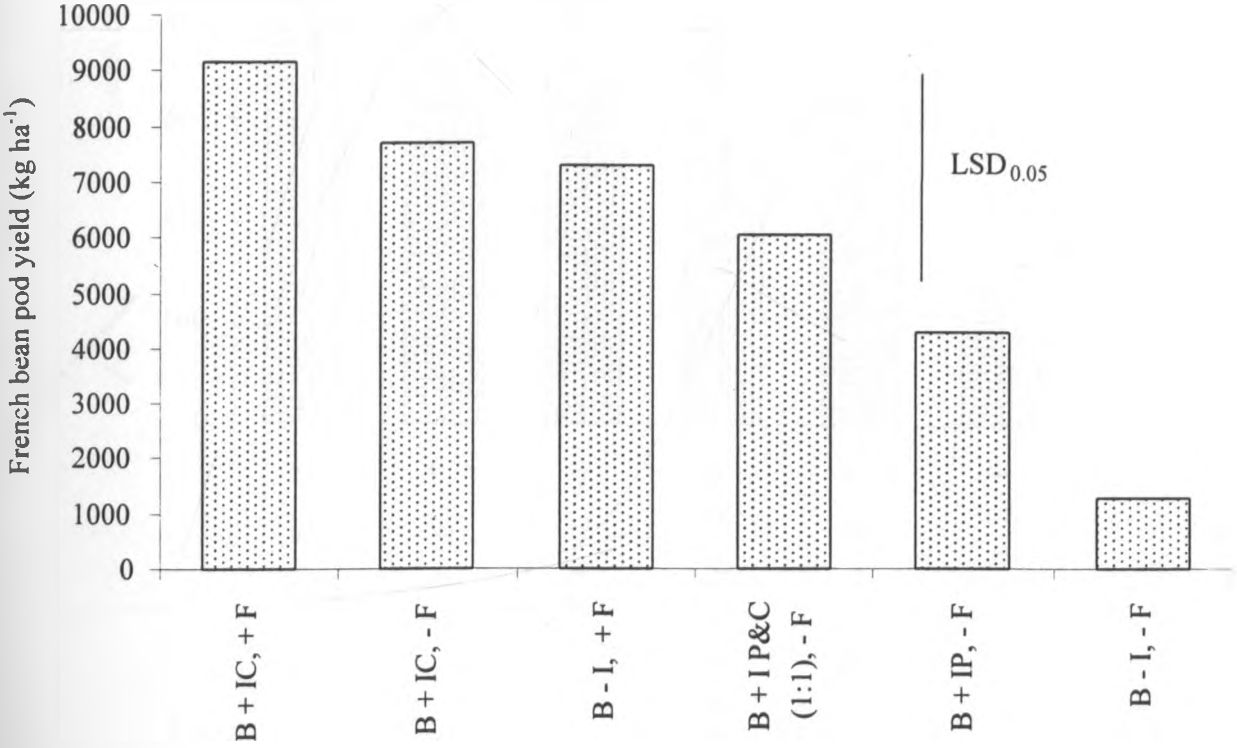

Figure 4.1 Mean fresh pod yield from french beans in the first season.

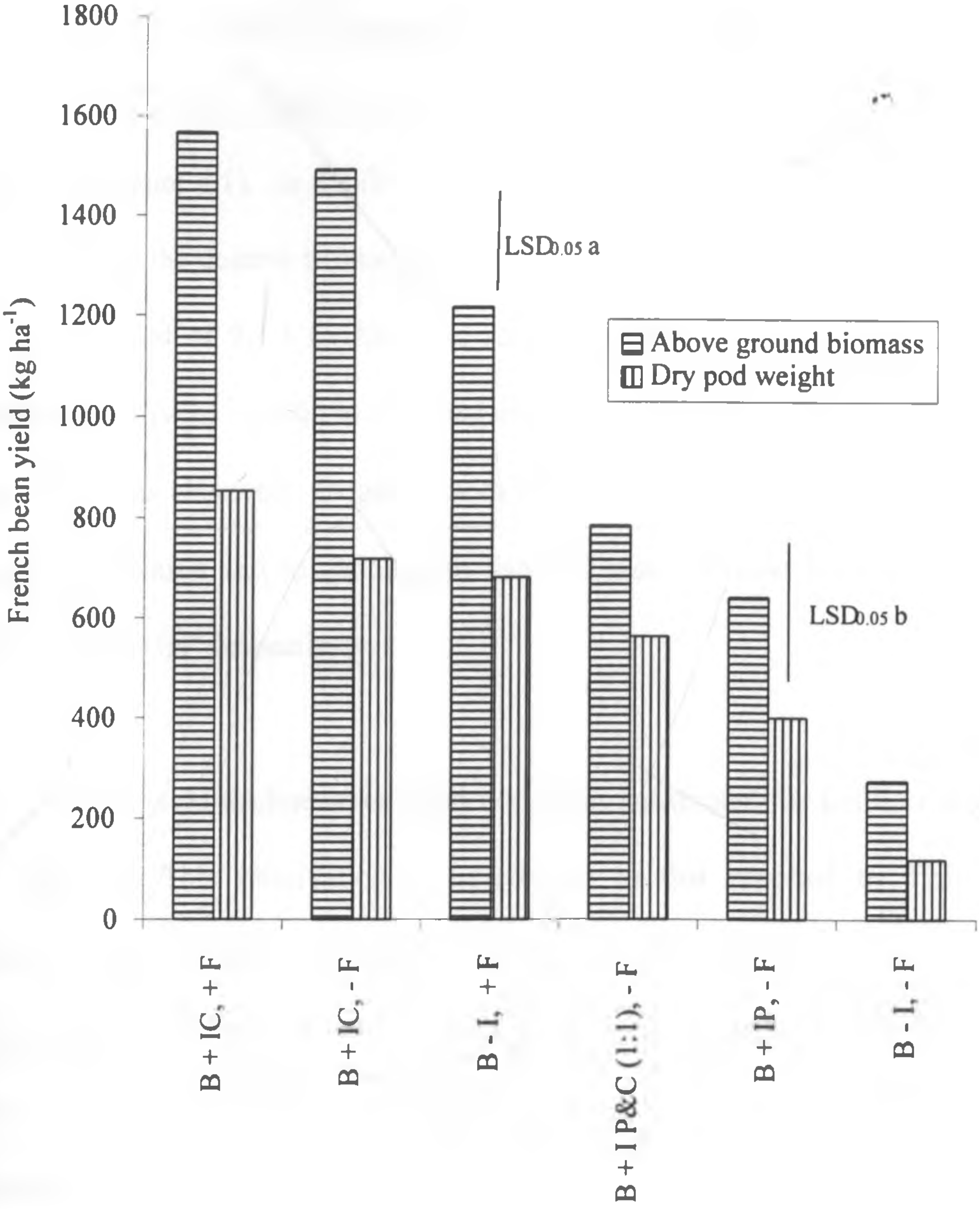

Figure 4.2. The aboveground (a) plant biomass and mean dry pod weight (b) from french beans in the first season.

Significant differences were observed in the mean fresh pod yield of the beans between treatments ($P \leq 0.05$). Separation of means using $LSD_{0.05}$ showed a significant difference between the yields obtained from B –I, -F treatment (control) and the other treatments (Figure 4.1). In the first season, all other treatments had higher mean fresh pod yield than the control treatment. When irrigation was combined with fertilisation 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 but a gradual decline as fish pond water was substituted for canal water was observed. Irrigation with fish pond and canal water at a ratio of 1:1 without fertilisation and irrigation with fishpond water without fertilisation provided 6.1 and 4.3 t fw ha^{-1} respectively.

A 53% yield decline when pond water was substituted for fertiliser application was observed. This observation is in contrast to that reported by Prinsloo and Schoonbee (1987) using flood irrigation on tomatoes, Al-Jaloud *et al.* (1993) with flood irrigated wheat and Hussein and Al-Jaloud, (1995) using flood and furrow irrigation on wheat who observed an increase in crop yield where pond water was used for irrigation instead of well water. The amount of nutrients supplied to the crop from pond water can be estimated from Figure 4.3.

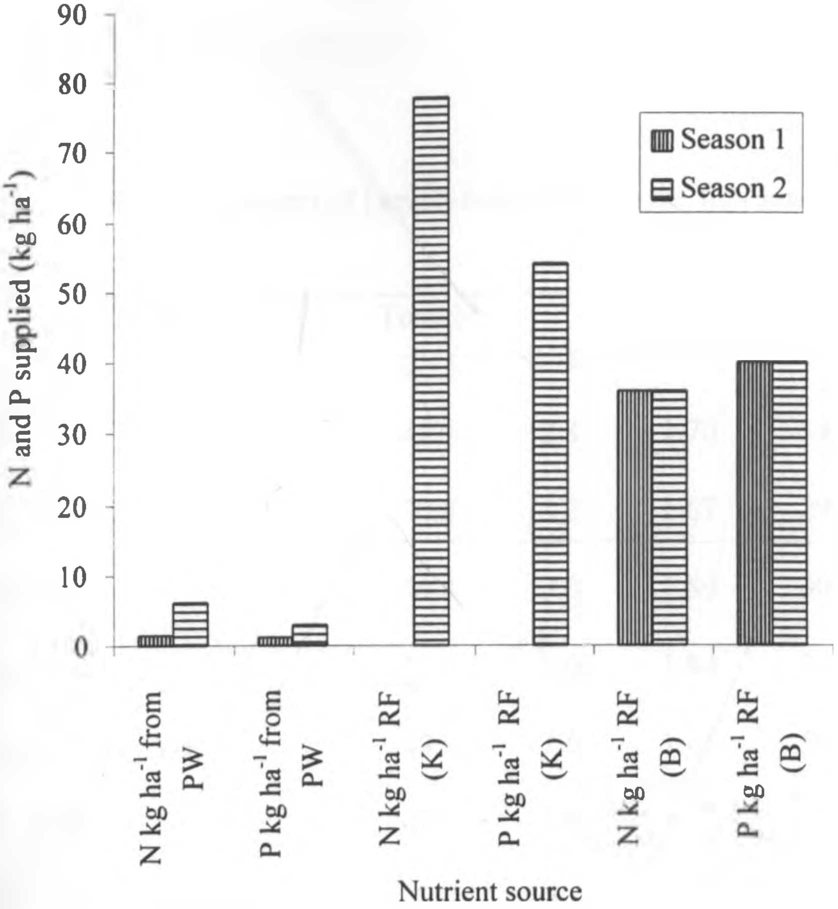

Figure 4.3 Amounts of total N and P supplied to the crop through pond water relative to the recommended rates.

Irrigation with pond water at 0.3 mm day^{-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 N and P nutrient. The 3.16 – 6.03 mg L^{-1} total N content in pond water was within the acceptable range as normal for any irrigation water (Tanji and Yaron, 1988) and could not therefore support similar yields as fertilisers. Using irrigation water as a way of spreading nutrients presented a disadvantage that the water distribution governed the uniformity of nutrient distribution. Nutrient uptake by french bean crop was estimated from the foliar nutrient levels as summarized in Table 4.2.

Table 4.2 Nutrient content 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	79.18
B -I,+F	50.0	3.2	1.67	298	146	115.96
B +IC,-F	44.4	3.0	1.89	302	166	144.64
B +IC,+F	52.5	4.0	1.84	274	134	97.28
B +IP&C(1:1),-F	43.3	2.6	1.65	296	152	125.01
B +IP-F	42.1	2.6	1.82	931	167	139.47
$LSD_{0.05}$	3.6	0.1	0.31	95.8	53.9	37.64
C.V.	9.5	16.8	10.4	15	23	26

Significant differences ($P \leq 0.05$) in mean leaf N and P contents were observed. Leaf N and P levels were higher in fertilized treatments than the unfertilized (Table 4.2), suggesting that availability of N and P as well as uptake by beans was higher in fertilized than unfertilized treatments. This explains the observed yield difference between treatments receiving fertilisers and those without. Pond water containing 6.03 mg N L^{-1} and 3.9 mg P $L^{-1}$when applied at rates used in this study did not supply sufficient amounts of N and P to French beans to support economical yields. It is apparent from this study that pond water cannot be a substitute to fertiliser application.

Beneficial effects of water application to crop yields are widely recognized (Anon., 1994; Michael, 1986; 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 in irrigation. The observed yield decline was due to insufficient water supplied to crops receiving irrigation water from the pond. Pond water was poorly distributed along the drip irrigation lines due to irregular clogging of the emitters resulting in patchey inadequate water supply to the crops. Clogging of emitters was a frequently encountered problem especially as the irrigation water had suspended particles and algae (phytoplankton). Some of these particles may have escaped the filtration system and ended up in the drip tapes.

Particles of organic matter, minute spores and separate cells of micro-organisms infiltrated through filters and reached emitters, where under conditions of reduced water velocity (as in bucket drip irrigation used in this study), oxidation - reduction potentials, favourable temperatures and aeration, they fluctuated and proliferated gradually plugging the outlets. When some emitters receiving water from the same bucket clogged, the 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 water logged or flooded, the portion of reduced soil conditions approached totality. Reducing conditions in saturated or periodically inundated rhizosphere may have resulted in increased soluble manganese concentration in soil solution and this had a direct importance in manganese toxicity to the beans and was shown by crinkled leaves (Bohn *et al.*, 1985) causing yield reduction. Generally most plants are affected by a foliar manganese content of about 300-500 ppm (Tisdale *et al.*, 1990). Mn in mature bean plant leaves is 40-50 ppm (Tisdale *et al.*, 1990) and the concentration above 500 ppm observed in this study resulted in toxicity (Knezek and Boyd, 1980). Foliar concentration of manganese (Table 4.2) in the pond water irrigated beans was at toxic levels.

Sporadic periods of over-irrigation under the functioning emitters occasioned by poor water distribution along the drip tapes led to inadequate water supply to some plants and excessive water supply to others, together resulting in yield decline.

Fresh and dry pod yield and aboveground biomass obtained in the second season are presented in figures 4.4 and 4.5.

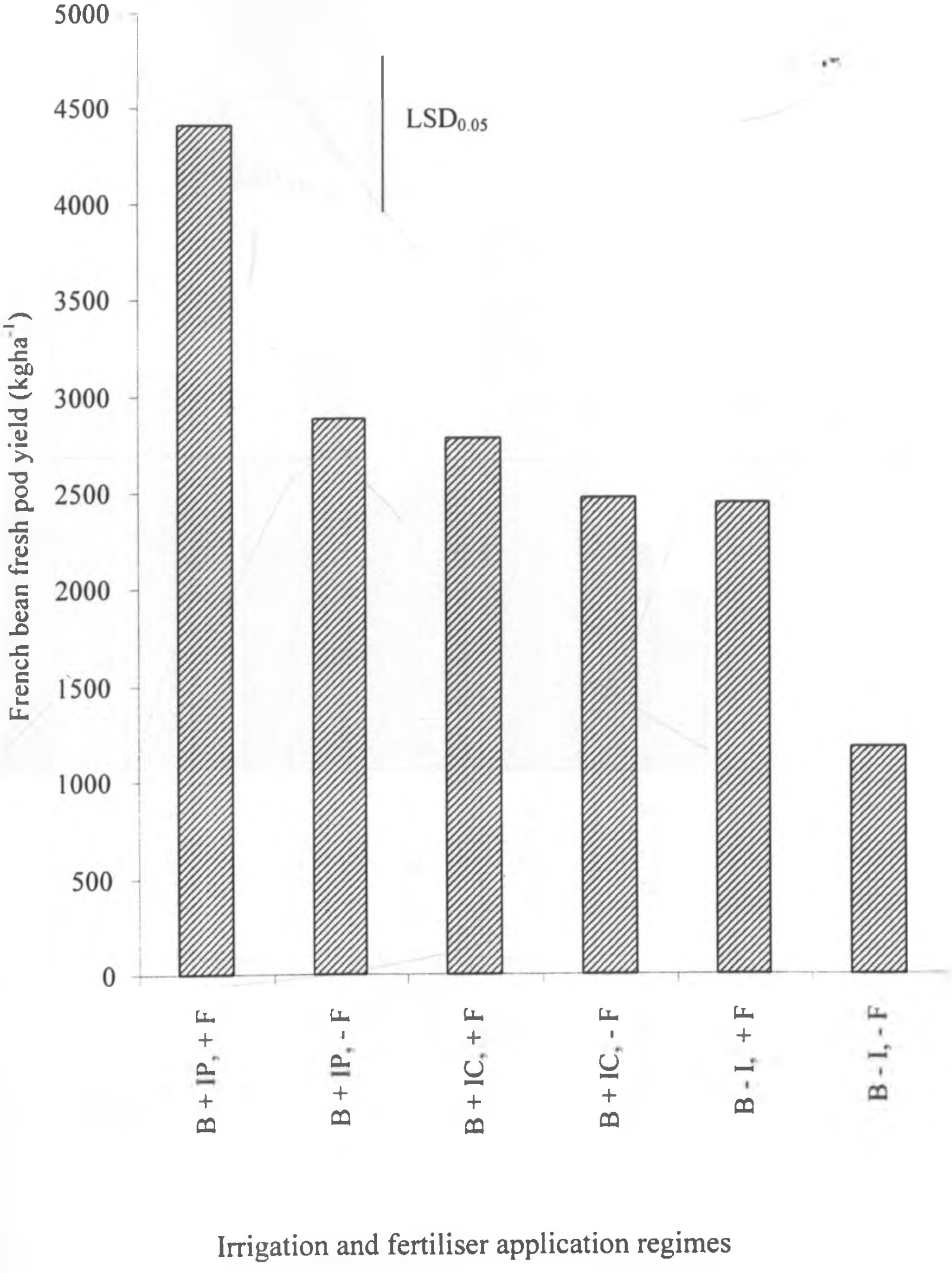

Figure 4.4. Mean fresh pod yield from french beans in the second season.

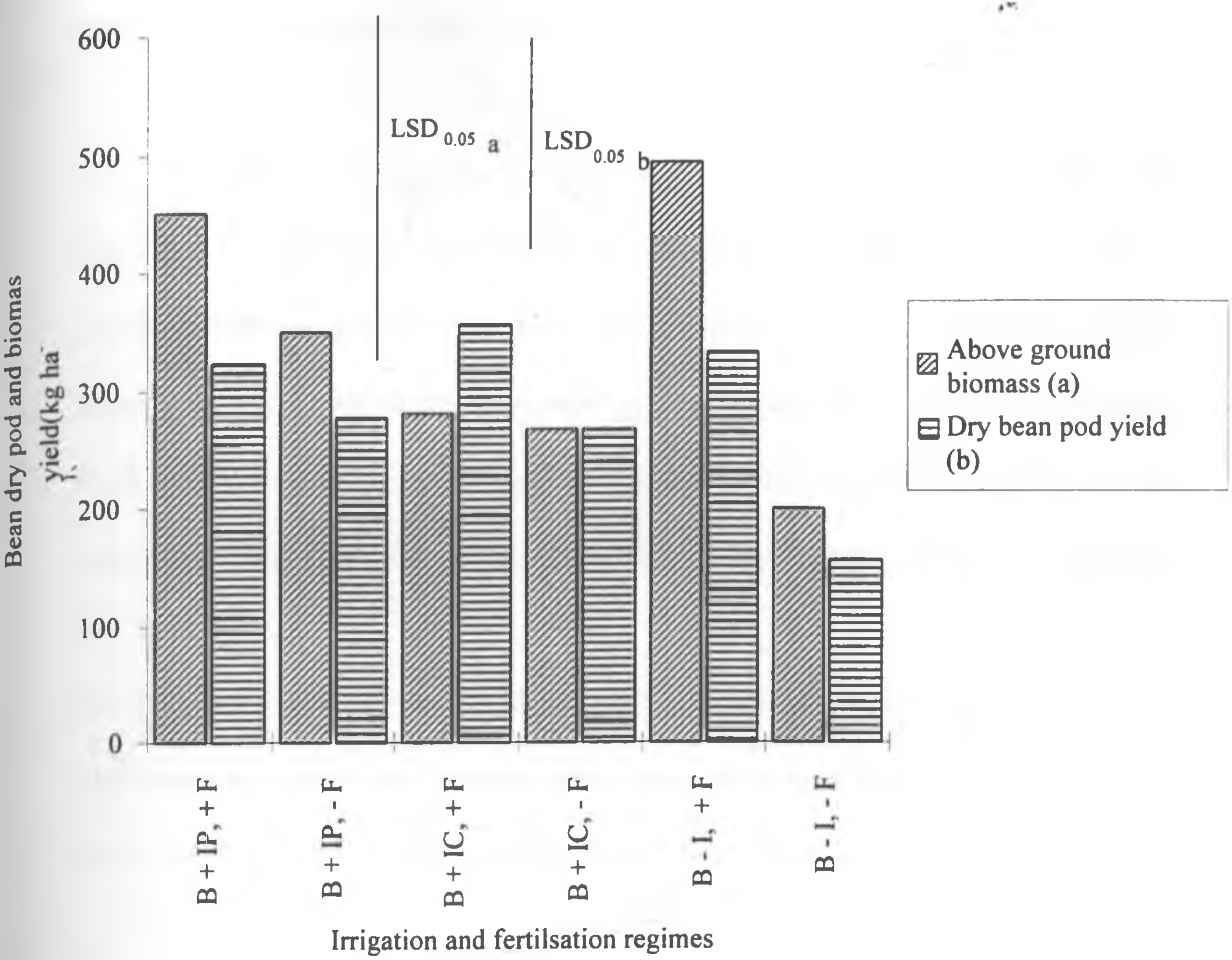

Figure 4.5 Mean oven dry pod weight and above ground biomass (dry weight basis) obtained from french beans in the second season.

There were statistically significant differences ($P \leq 0.05$) in mean fresh pod yield between treatments (Figure 4.4); however no significant difference was observed between the mean dry pod weight and the mean above ground biomass (Figure 4.5). The mean fresh pod yield from B +IP, -F was significantly different from that of control, B -I,-F and B –I,+F (Figure 4.5). The lowest yield weight of 1.2 t fw ha^{-1} was obtained from the control. Irrigation with pond water combined with fertilisation at the recommended rates resulted in the highest yield of 4.4 t fw ha^{-1}. Application of canal water combined with fertilisation had a mean fresh pod yield, which was not significantly different from pond water without fertilisation.

No significant change in fresh pod weight was observed when pond water was substituted for canal water contrary to observation made in the first season experiment. These observations were due to effects of improved distribution of pond water (using bigger filters) or the higher irrigation depth or their interaction. An increase of irrigation depth from 0.33 mm day^{-1} in the first season to 2.3 mm day^{-1} assured sufficient water supply to the root zone. Consumptive use of water was thus satisfied and better yields were obtained.

However increased water supply did not result in increased nutrient uptake by the crops. Estimate of nutrient N and P uptake from foliar nutrient content (Table 4.3) indicated a decline as pond effluents replaced fertilisers as source of nutrients.

Table 4.3. 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	17.2	30	41	51

Analysis of variance showed a statistically significant difference in mean leaf N ($P \leq 0.05$) (Table 4.3). No significant difference was observed on the mean leaf P, aluminum, iron, manganese, potassium, and magnesium concentration. Plots receiving fertilisers without irrigation had the highest foliar mean N content (55.3 mg kg^{-1}). Low foliar N concentration was observed in treatments irrigated with pond water without fertiliser application (45.2 mg kg^{-1}) and canal water without fertiliser application (47.3 mg kg^{-1}), suggesting a reduced availability of N in irrigated plots. High water application depth (2.3 mm day^{-1}) resulted in increased downward movement of N beyond the rooting zone. Nitrogen was leached beyond the rooting zone by the applied water. Appreciable loss of N in the top soil and reduction in the quantity of available N for plant uptake occurred. Hertermink *et al.*, (1996) reported a rapid decrease in top soil NO_3 with increase in precipitation received.

The mean total suspended solids (TSS) contents in pond water was 42% higher in the first season than in the second season (Table 4.1). In the second season, larger filters (Alkal filter 1.5" Lego Inc., Israel) were fitted on the drip irrigation system leading to an improved filtration. Low contents 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 overirrigation, soil saturation or insufficient water supply. Manganese levels remained low and no toxicity occurred.

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

4.4.2 Kale crop response to treatments

Mean fresh weight and the dry weight yield from the kale crop are shown in Figure 4.6and 4.7 respectively.

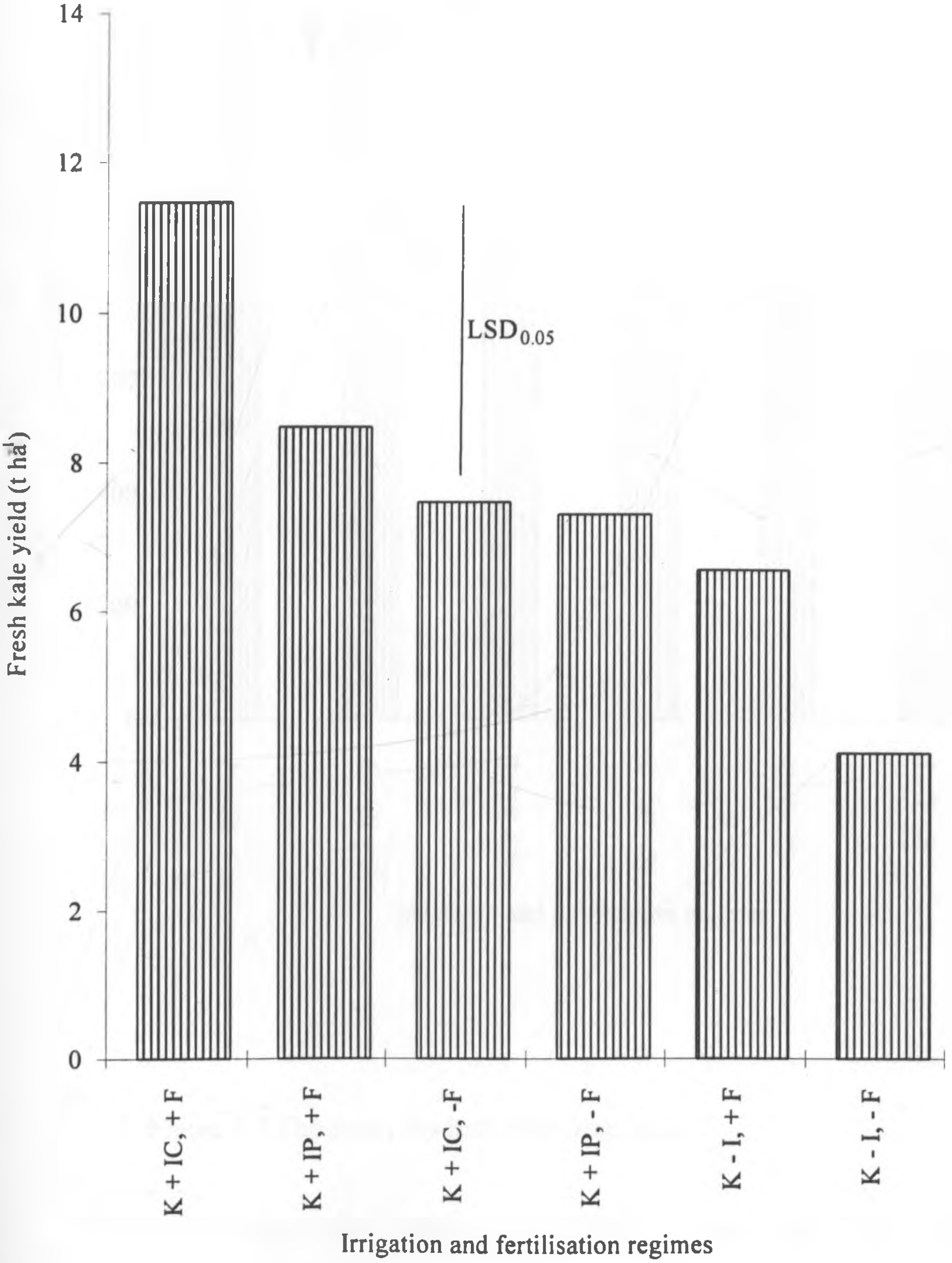

Figure 4.6 Kale leaf yield as influenced by irrigation and fertilisation effects

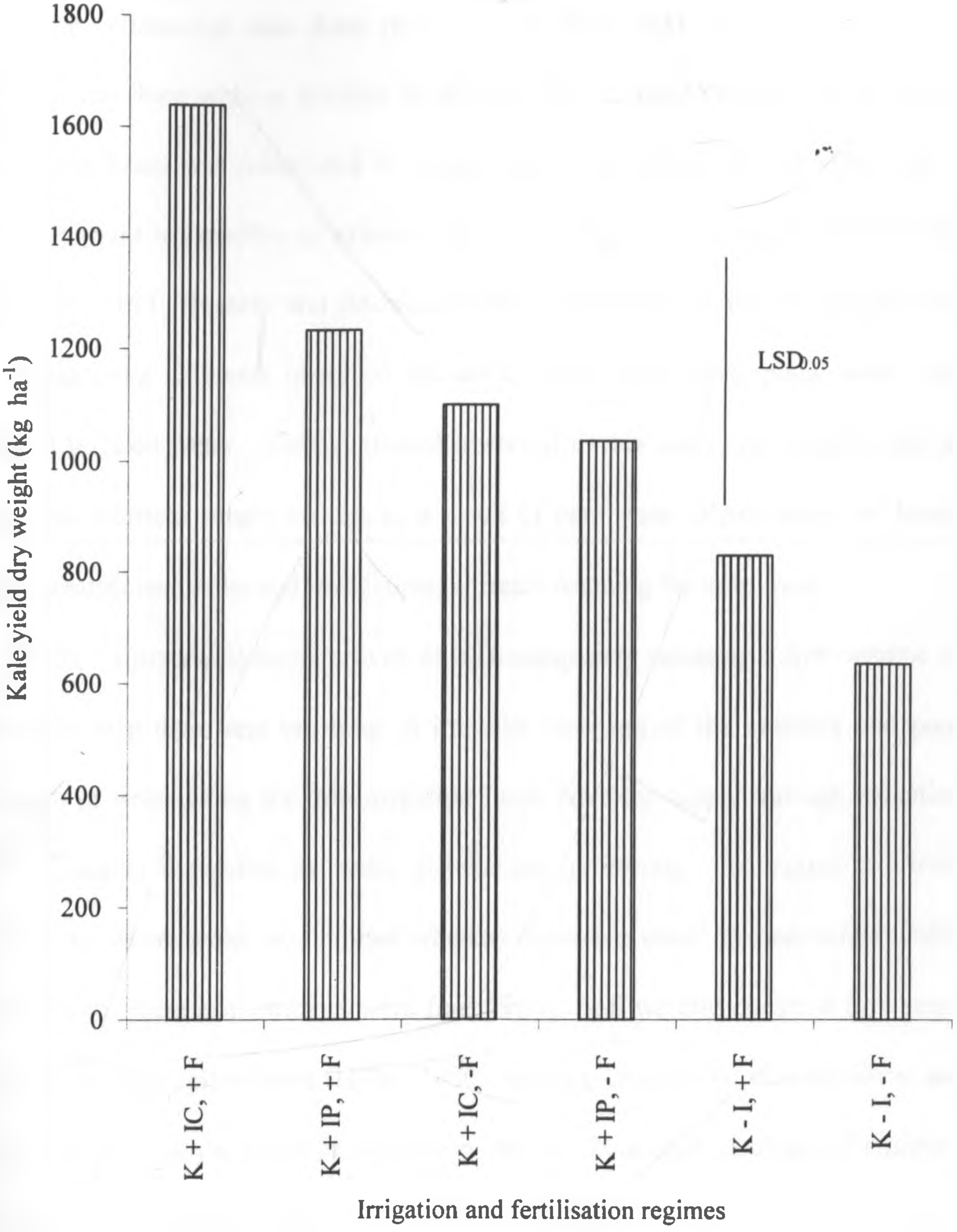

Figure 4.7 The mean dry leaf yield from kale.

There were significant differences ($P \leq 0.05$) in mean kale fresh leaf yield between the treatments (Figure 4.6). All treatments had higher fresh and dry leaf weight than the unirrigated, unfertilised treatment. Substitution of pond water for canal water where fertilisation was done resulted in a 26% yield decline. Where this substitution was done without fertiliser application a 2.5% yield decline was observed. When pond effluent was substituted for canal water in irrigation, the net effect was a reduction in yield irrespective of nutrient application. On contrary other workers (Al-Jaloud *et al.*, 1993; Hussein and Al-Jaloud,1995) using flood or furrow irrigation to apply aquacultural effluents observed increasing crop yield when pond water was substituted for well water. Yield reduction observed in this study was possibly due to moisture and nutrient supply effects, as a result of poor water distribution and hence excess or insufficient water and inadequate nutrients reaching the crop roots.

F1 ¾ " filtration systems proved to be inadequately 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. Nutrient supply through irrigation water was largely dependent on water distribution uniformity. Inadequate nutrients were received where water was limited whereas excessive water created unfavourable soil conditions where drip emitters were functioning. Soil wetting occurred in a small fraction of the total soil volume (Hillel, 1980), causing crops to be very sensitive and vulnerable to even slight irrigation disruptions due to occasional blockage of emitters. 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 system poses a disadvantage of moisture depletion and crop stress (Hillel, 1980). Table 4.4 shows foliar nutrient levels from kale.

Table 4.4 Mean nutrient content of kale leaves.

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
$LSD_{0.05}$	8.8	1.3	0.5	22.55	507	390
C.V	7.7	21.9	16.8	31.7	72	78

Significant differences ($P \leq 0.05$) were observed in mean leaf P (Table 4.4). No significant difference was observed on the mean leaf N, aluminum, iron, manganese, potassium, and magnesium contents. Irrigation with canal water with fertiliser application had the highest mean leaf P (0.52 ppm). Followed by pond water with fertiliser application (0.42 ppm). The lowest mean leaf P was observed in zero fertiliser with or without irrigation treatment, suggesting that the P taken up by kale crops was largely from applied fertilisers and not irrigation water. Phosphorus supplied by irrigation water was only a small proportion of the crop requirement (Figure 4.3).

This observation confirms the first season's data that showed that pond water did not supply water and nutrients to crops and substitute chemical fertilisation inadequately. The filtration system failed to filter and provide good quality pond effluent for drip irrigation on crops.

4.4.3 Partial Economic Analysis

Economic consideration in selection of an appropriate integrated system includes its potential for economic returns, its economic efficiency and ultimately its applicability among the farming communities in terms of resource requirements. Table 4.5 summarises economic returns from the second season crops.

Table 4.5 Economic returns from French beans and kale in the second season.

Treatment	Economic returns (Ksh ha^{-1})	
	French bean	Kale
-I,-F	29,440	61,970
-I,+F	60,960	98,330
+IC,-F	61,810	112,100
+IP,-F	68,570	109,340
+IC,+F	69,470	172,050
+IP,+F	110,280	127,167
$LSD_{0.05}$	17,700	37,000
C.V	46	35

Significant differences ($P \leq 0.05$) in economic returns were observed between french bean and kale, irrigated and non irrigated treatments. The crop by irrigation by fertilisation rates interaction had no effects on the economic returns. Significant yield increase upon application of fertilisers or irrigation water resulted in a significant increase in economic returns despite a lower unit price of kale (Ksh. 15 kg $^{-1}$) relative to french beans (Ksh 25 kg^{-1}).

Higher returns were obtained from kale than French beans (Table 4.5). Economic yield of kale constitutes a grater proportion of the above ground biomass of the crop. Whereas the foliar yield is harvested in kale, only fresh pods account for economic returns in French beans. This explains the higher mean economic yield in kale than the French bean crop. Results of partial budget analysis for French beans in the first and second seasons are summarized in Table 4.6 and 4.7 respectively and kale production economics is shown in Table 4.8.

Table 4.6 Partial budget analysis for French beans in the first season.

Treatment	Additional cost		Reduced cost	Additional revenue	Reduced revenue	Net change
			--------Ksh ha^{-1}--------			
B –I,+ F	Fertilisers	6400	-	179 700	-	173,300
B +IC,-F	Irrigation equipment	28,000	-	19,2330	-	164,330
B +IP,-F	Irrigation equipment	28,000	-	179,660	-	151,660
B +IP&C (1:1),-F	Irrigation equipment	28,000	-	142,660	-	114,660
B +IC,+F	Fertilisers Irrigation equipment	6400 28,000		235,330	-	200,930

Table 4.7 Partial budget analysis results for French beans in the second season.

Treatment	Additional cost	Reduced cost	Additional revenue	Reduced revenue	Net change
			Ksh ha^{-1}		
B –I,+ F	Fertilisers 6,660	-	31,500	-	24,840
B +IC,-F	Irrigation equipment 88,330	-	32,350	-	-55,980
B +IP,-F	Irrigation equipment 88,330	-	39,330	-	49,000
B +IP, +F	Fertilisers 6,660 Irrigation equipment 88,330	-	80,830	-	-14,160
B +IC,+F	Fertilisers 6,660 Irrigation equipment 88,330	-	40,000	-	-54,990

During the first season a 44% yield decline in bean yield was observed as pond water was substituted for canal water corresponding to a loss of KSh 102,000 ha^{-1} (approximately US$ 1400). The highest gross income of KSh 273,000 ha^{-1} was achieved when canal water was supplemented with fertiliser while the lowest gross income of KSh 34,000 ha^{-1} was realized from the control treatment. Partial economic analysis showed a net profit in production of French beans in the first season.

Despite the high capitalization in terms of irrigation equipment, benefits related to combination of irrigation and fertilisation justify such investment (Table 4.5). However where pond water was substituted for canal water, an investment in the irrigation system resulted in reduced profits despite the savings on fertiliser inputs.

In the second season, the French bean was harvested and sold at a price of KSh 25 per kg. The highest gross income was KSh 110,000 ha^{-1} with pond water combined with fertiliser, while the lowest return of KSh 29,500 ha^{-1} was obtained with control treatment. Irrigation with pond water without fertiliser application gave a gross income of KSh 68,500 ha^{-1} while irrigation with canal water combined with fertilisation had a gross income of KSh 69,500 ha^{-1}, suggesting a 1.4% decline when substituting the former for the later.

The decrease in gross income when compensated for by the saving on fertiliser cost may result in increased net profit related to substitution of pond effluents for canal water in irrigation, if better filtration and application of large quantities of effluents are achieved. However in the second season, low french bean yield coupled with increase in the cost of filtration process resulted in net loss in all treatments receiving irrigation water. The increased cost of irrigation equipment together with reduced income from unfertilized crop resulted in a greater net loss (Table 4.7).

The increase in yield as a result of improved water distribution did not offset the additional cost due to improved water filtration equipment. Unless a less expensive filtration system is available, this study suggests that improving filtration at the existing cost may not be justified by the additional output. Alternatively a cheaper irrigation system such as furrow or flood need to be considered to replace drip irrigation.

Table 4.8 Partial budget analysis results for kale

Treatment	Additional cost		reduced cost	Additional revenue	Reduced revenue	Net change
			KSh ha^{-1}			
K –I,+ F	Fertiliser	7670	-	24,240	-	16,570
K +IC,-F	Irrigation equipment	49,330	-	32,350	-	-16,980
K +IP,-F	Irrigation equipment	49,330	-	31,580	-	-17,750
K +IP, +F	Fertiliser	7670	-	43,460	-	-13,540
	Irrigation equipment	49,330				
K +IC,+F	Fertiliser	7670	-	73,400	-	16,400
	Irrigation equipment	49,330				

Kale leaves were harvested and sold at a price of KSh 10 per kg. Irrigation with canal water combined with fertilisation generated KSh 115,000 ha^{-1} while –I,-F resulted in the lowest income of KSh 41,000 ha^{-1}. Substitution of pond water for canal water led to yield decline of both crops which was estimated at KSh 30,000 ha^{-1} and KSh 4,600 ha^{-1} with or without fertilisation respectively. With kale production, the highest net income was achieved where fertilisers were applied at the recommended rates without irrigation. Application of canal water without fertilisation resulted in a net loss, whereas application of fertilisers made it profitable. Investment in irrigation equipment without provision of fertilisers is uneconomical. Farmers interested in using pond effluents for irrigating horticultural crops should be prepared to invest in supplemental fertilisers.

4.5 Conclusion

It is beneficial to apply pond effluents to kale or french bean as a supplemental source of nutrients, but where pond effluents are used as the main supplier of N and P to crops supplemental N and P fertilisers is recommended. Increasing irrigation depth from 0.3 mm day^{-1} to 2.3 mm day^{-1} enhanced bean response to irrigation with pond water. However caution should be exercised when doing this since larger amounts of water may cause negative effects including water logging and accumulation of toxic micronutrients such as manganese in the heavy black cotton (vertisol) soils.

Nutrient rich pond water support growth of phytoplankton and other organisms in the pond. Phytoplankton bloom and the high total suspended solids in pond water due to activities of fish increase turbidity of water caused clogging of the distribution pipes, drip lines and water emitters. This resulted in poor water distribution leading to nonuniform crop stand and low yields. Improving filtration using Alkal 1.5" in place of F1 ¾" filters led to increased bean yield response with pond effluent application. Improved filtration is therefore essential. Higher economic benefits were realised on kale than on French beans.

CHAPTER 5

5.0 EFFECTIVENESS OF FIELD SOIL IN PURIFICATION OF POND EFFLUENT

5.1 Introduction

Waste effluents from intensive fish culture have been a major concern to environmentalists because they are a source of pollutants to natural waters (Edwards, 1993). Solb'e (1982) reported ranges of nitrite N concentration in fish farm effluents of between 0.02 to 12.9 mg L^{-1} with the net output of total N amounting to an annual output of 67.5 kg ton^{-1} of fish produced. Alligator waste water resembles domestic waste water in Biochemical Oxygen Demand (BOD) (452 mg L^{-1} and 400 mg L^{-1} respectively), and total soluble P concentration (10.9 mg L^{-1} and 15 mg L^{-1} respectively) but contains twice the N content (153 mg L^{-1} and 85 mg L^{-1} respectively) (Pardue *et al.*, 1994).

During draining, nutrients are released from sediment solids (Hall *et al.,* 1990) and it has been estimated that as much as 60% P and 80% N from a fish pond end up in the water column (Hall *et al.,* 1992). Changes in recipient fresh water may be apparent in dissolved oxygen (DO), BOD, chemical oxygen demand (COD), turbidity and secchi disc depth (Beveridge, 1996). There is a strong correlation between fish farm effluent loading and dissolved nutrients levels, especially between total N and P loading from farms and inorganic N and P concentrations in surface water (Wallin and Hakanson, 1991). Discharges of untreated or partially treated agricultural and aquacultural wastes water into water bodies may result in reduced water quality and accelerated eutrophication (Pardue *et al.,* 1994).

One of the oldest techniques of purifying wastewater is to spread it over the soil surface and then allow it to percolate through the soil profile (Pell and Nyberg, 1989a). Various soil processes attenuate many of the contaminants present in high-strength waste water. The soil is reported by Pardue *et al.,* (1994) to remove on average about 59% BOD, 46% NH4-N, 70% organic-N and 25% total soluble P. Organic N is reported to be consistently removed by the system while removal of the total soluble P becomes less efficient with time (Pardue *et al.,* 1994). The effectiveness of land application depends primarily on the time allowed for the soil and soil micro-organisms to react with the effluent water (Pardue *et al.,* 1994). Application of waste water on land as a treatment has been shown to be a viable treatment option for high strength aquaculture waters, and most efficient at removing total soluble P however, it depends on the finite capacity of the soil to adsorb P (Pardue *et al.,* 1994).

Sagana fish farm has 20 hectares of ponds which are regularly drained for fish harvest releasing on average 100,000 m^3 of enriched effluents into Sagana River. Total N concentration in the effluents ranges from about 3 - 6 mg L^{-1} while total P ranges from 1 - 4 mg L^{-1}, resulting in a possible 450 kg of N and 250 kg of P loading into the river. The feasibility of purifying the effluents by land application on the farm prior to releasing in the recipient water was explored in two sites with different types of soils (Table 5.0). In well drained parts of the farm, a red clay soil is common, while the lower lying, poorly drained portions are covered with black clay soils (vertisols).

This study was carried out to assess the effectiveness of two soil types from to retain nutrients from fish pond effluent. The hypothesis tested was that the soil can remove sufficient amounts of N and P from pond effluents, hence reduce pollution while at the same time raising levels of these plant nutrients in the soil for crop production.

Table 5.0 Chemical properties prior to effluent application

Soil type	Depth	pH (water)	N	P	K	Ca	Mg	Fe	Al	Mn
Black clay	(cm)					g m^{-2}				
	0-15	8.2	173	1.96	7.21	411	195	3.64	21.4	3.6
	15-30	8.3	133	2.14	3.63	466	230	5.28	23.0	4.9
	30-45	8.2	156	3.20	3.73	422	254	4.18	19.3	2.2
Red clay	0-15	5.3	90	3.53	11.93	53	30	2.58	29.2	13.2
	15-30	5.0	82	1.32	6.90	54	33	2.54	25.9	10.2
	30-45	4.9	73	0.85	3.66	53	31	2.55	32.1	12.1

5.2 Materials and Methods

5.2.1 Soil column filters

A laboratory experiment 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 (Hillel, 1980; Pell and Nyberg, 1989a). Columns simulating a 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 stargrass (*Digitara scalarum*) for the Vertisol (black clay soil) and the other batch from a field previously cultivated with soyabean (*Glycine max*) which was a 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 0-0.15 cm, 0.15-0.30 cm, and 0.30-0.45 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 P and N were determined from the sub samples taken from each of the soil type using the procedure described by Page *et al.*, 1982 (Appendix 2 g).

In the same fields, undisturbed samples were obtained using the core ring method (Page *et al.*, 1982). Four positions were selected randomly on the experimental site. Mini pits were dug to a depth of 0.50 cm and steps demarcated at 0-0.15 cm, 0.15-0.3 cm, 0.3-0.5 cm. Three cores were carefully placed at random on each step and driven into the soil using a core driver. The cores were then dug out using a sharp knife, wrapped in aluminum foil and taken to the laboratory for analysis.

5.2.2 Soil column packing.

Three portions of a pipe were used to simulate a soil profile of three layer depths: 0-0.15 cm, 0.15-0.30 cm, and 0.30-0.45 cm. Each portion of 0.15 cm length was filled with a soil sample taken from a specific soil layer. Based on the determined bulk densities, 1.56 kg of the red clay soil and 1.93 kg of the black cotton soil from the 30-45 cm soil layer was packed 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 30-45 cm 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 was 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 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 was 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 as shown in Appendix 2e. Pond water to be purified was then collected from the pond receiving 20 kg N ha^{-1} $week^{-1}$ 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.

5.2.3 Treatments in soil column filters

Four treatments were administered as the depths of water corresponding to varying loading rates of pond effluent to land as shown in table 5.1

Table 5.1 Treatments in the soil column filters

Treatment	Irrigation intensity (mm day^{-1})	Application period (days)	Water (m^3) / land (m^2)	Pond :Land
1	0	0	0	0
2	31	32	1	1:1
3	81	62	5	5:1
4	161	62	10	10:1

Three replicates of the soil column filters were randomly arranged on the laboratory floor in a completely randomized design.

5.2.4 Data collection on soil and water from the soil column filters

At the end of experiment, soil was retrieved from soil column from the three 15 cm layers, prepared and analysed for total N, acid extractable P and micronutrients (Hue and Evans, 1996). The through-flow water from soil columns was collected on Tuesdays and Fridays and stored at 4 °C for chemical analysis.

5.2.5 Soil and water analysis

Pond effluents and through-flow water were analyzed for total N and P using the procedure described in Appendix 2f. Soil samples were analysed for total N and available P using the procedure described by Hue and Evans (1986) (Appendix 2g). The difference between the concentration of total N and P 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 from the effluents was calculated as;

$$\%NR = (\text{Conc. } X - \text{Conc. } F) \times 100 / \text{Conc. } X \qquad (5.3)$$

Where,

%NR is the % nutrient removal, conc. X is the particular nutrient concentration in the pond effluent, conc. F is the particular nutrient concentration in the filtrate.

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

$$dX = X_1 - X_2 \qquad (5.4)$$

Where,

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

5.3.8 Statistical analyses

Data on soil nutrient content from the columns were entered into a spreadsheet with the various treatments as the rows and the nutrient levels as the columns. Analysis of variance was performed using the general linear model of the Statigraphics (Statigraphics Inc. 1995) 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 (Zar, 1997).

Model used was as follows;

$Yijk = C + Ri + Sj + \text{Irrig}\,k + \text{depth}\,l + (S \times \text{Irrig})jk + (\text{Irrig} \times \text{depth})\,il + (S \times \text{depth})\,jl + (S \times \text{Irrig} \times \text{depth})\,jkl + Eijk.$

Where $Yijk$ = The measured nutrient level.

C,R and E are constant, replicate and error terms.

S, Irrig and depth are the treatments, i.e. the soil type, irrigation depth and soil layer .

5.3 Results and discussion

5.3.1 Nitrogen removal

Applying pond effluent at a rate of 31 mm day $^{-1}$ to both red and black clay soils resulted in enrichment with nutrient N. When the rate was raised to 81 and 161 mm day^{-1} black cotton soil was enriched with N while the red clay soil was leached through the column. Removal of total N from fish pond effluent at varying irrigation depths through the soil are shown in figure 5.1.

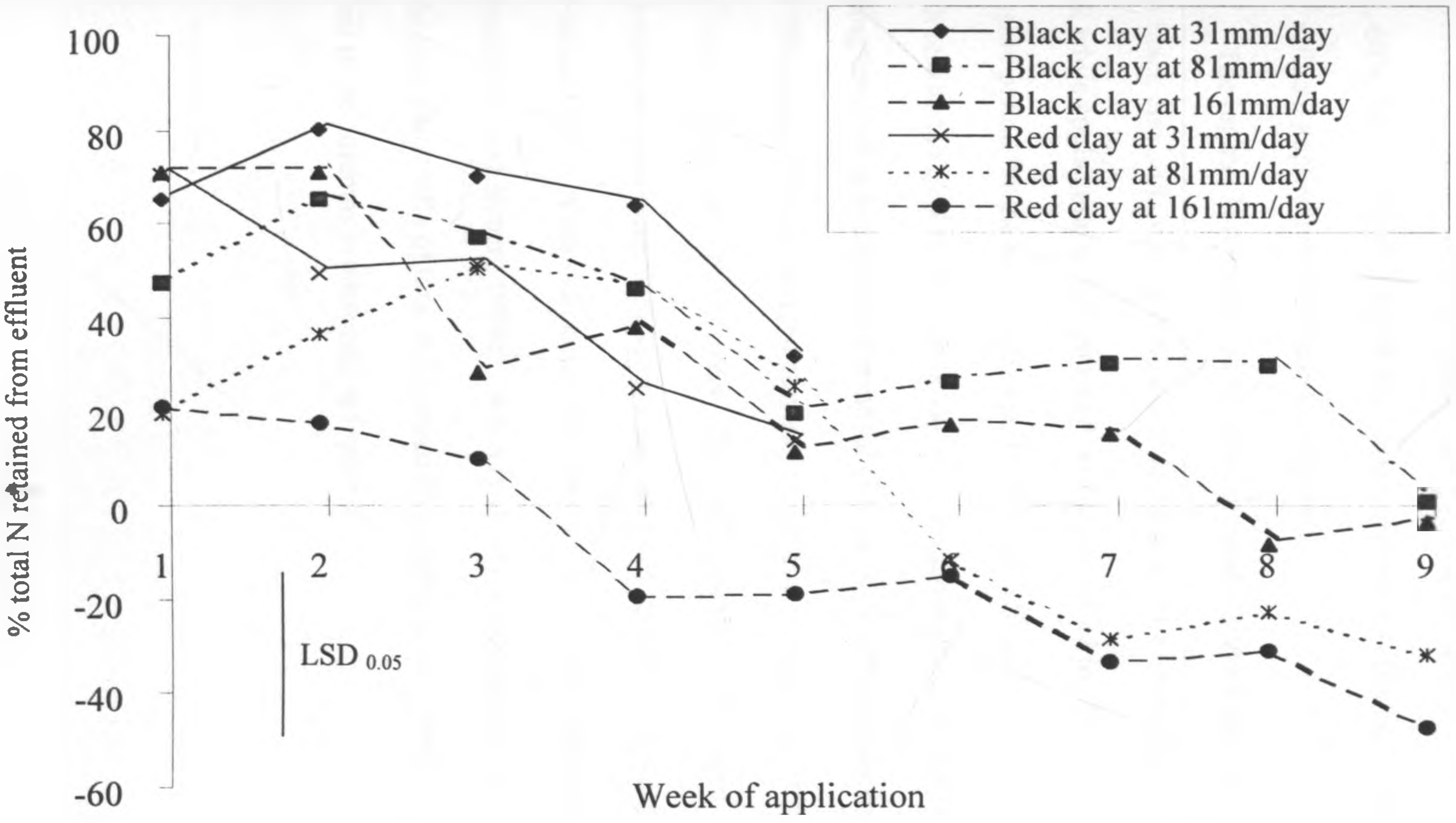

Figure 5.1 Nitrogen removal by soil in the columns at varying pond effluent applications intensities

In the first two weeks over 50% of applied total N was removed from the effluents, through 31 mm day^{-1} irrigation depth resulting in 75% removal. Effluent application at a rate of 161 mm day^{-1} and 81 mm day^{-1} led to a 72% and 60% applied N removal respectively within the black clay soil columns (Figure 5.1). In the red clay soils, 60%, 35% and 20% total N was removed from the effluent at 31, 81 and 161 mm day^{-1} effluent application intensities respectively.

The highest N removal, which was recorded at 70% from red clay soil and 84% from black clay soil, were observed with application of 31 mm/day during the first week while application at 161 mm day^{-1} effluent resulted in 20% mean N removal in the same period for the same type of soil. The intermediate 81 mm day^{-1} irrigation depth resulted in 37% mean N removal from the added pond effluent. High effluent loading resulted in less effective removal of total N. The black clay soil was 20%, 42% and 72% more effective than red clay soil in removal of total N at 31 mm day^{-1}, 81 mm day^{-1} and 161 mm day^{-1} respectively. Total N removal declined rapidly to less than 30% after the third week with 81 mm day^{-1} and 161 mm day^{-1} application intensities. The initial high % N removal rates were possibly due to adsorption by the charged colloids (Pell and Nyberg 1989a). When relatively small amounts of NO_3 were added to the soil, about 60% of total N is sorbed (Hertemink *et al.,* 1996). Mean total soil N in soil in the columns is presented in Figure 5.2.

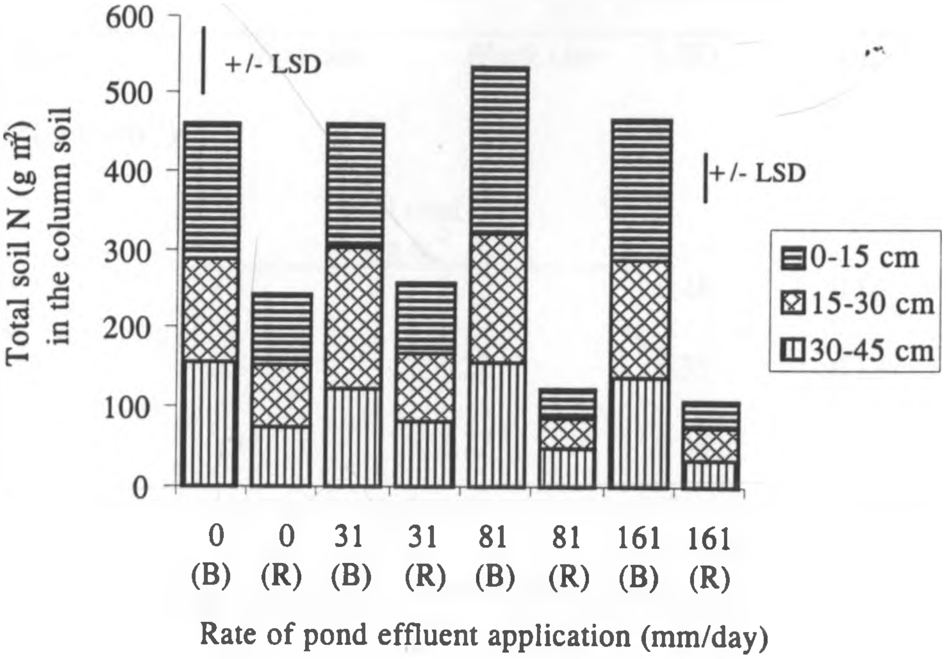

Figure 5.2 Mean total soil N levels in soil columns before (0mm day^{-1} irrigation intensity) and at the end of the experiment.

There were significant differences ($P \leq 0.05$) between mean total soil N at different effluent irrigation depths in the red clay soil while no significant differences were observed at different depths in all effluent application intensities. In black clay soil significant differences were observed between the mean soil total N content at different depths at all levels of effluent application intensities; however, no significant differences were observed between different effluent irrigation depths or irrigation depth by depth interaction. Table 5.2 shows total N enrichment (g m^{-2}) in soil after passing pond effluents through.

Table 5.2 Increase in total N content in the soil after pond effluent application

Application intensity (mm day^{-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

Black cotton soil retained 2.7%, 145% and 155% more N than red clay soil at 31, 81 and 161 mm day^{-1} rate of effluent application respectively. Positively charged ammonium ions in pond effluent were presumably attracted to the negatively charged surfaces of clay and humus where they were held in exchangeable form and prevented from leaching (Brady and Weil, 1999). Ammonium ion, because of its size, could have been entrapped within cavities in the crystal structure of the 2:1 montimorillonitic clays leading to their retention in an unexchangeable state (Brady and Weil, 1999). Interlayer fixed NH_4^+ is reported to account for 5-40% of the total N held by soils high in 2:1 clay minerals. The highly weathered red clay soils low in 2:1 clay mineral could not retain as much N as the black clay soils.

The low saturated hydraulic conductivity (K_{sat}) (Table 3.1) of black soil reduced the rate of downward movement of water increasing contact time between N in effluent with the soil exchange surface, resulting in higher N adsorption. Water was probably transported through the small pores in the soil profile, thereby enhancing the adsorption of ammonia and NO^-_3 (Hertemink *et al.*, 1996). With high pH values recorded, black cotton soil retained more total N than red clay soil. Sorption of NO^-_3 - N was reported to typically increase with increased soil pH (Black and Waring 1978). The location and rate of movement of NO^-_3 front was determined primarily by water movement and adsorption and solubility reactions in the two soils (Bond, 1984). Transportation of NO^-_3 was slow in black clay since the displacement of the soil solution was less rapid. Due to expansion of the black cotton soil upon wetting, volumetric water content was high (Russell, 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 N were displaced further in red clay soil and the NO^-_3 front advanced faster than in black clay soil.

The concentration of total N in pond effluent was equal to that in the through-flow water from the soil columns implying a zero N removal after 23 days and 40 days of operation in the 161 mm/day and 81 mm day^{-1} effluent application intensities respectively. This was not observed where a 31 mm day^{-1} application intensity was tested (Figure 5.1). In black clay soils zero % N removal was observed at 161 mm/day application intensity after 54 days, the other two application intensities continued to retain N from the pond effluent. Any further application of the pond effluents after these days resulted in higher levels of total N in soil column through-flow than in pond effluent. This negative N budget implies N addition by the soil in the columns to the through-flow water could be attributed to the arrival of NO_3 front at the bottom of the soil column. These observations agree with those reported by Lance and Whishler (1972) and Pell and Nyberg, (1989a).

Dynamics in microbial population in the soil may have affected N retained in various pools in the soil (Pell and Nyberg, 1989a). Initially, the growth of aerobic bacteria may have been high leading to immobilisation of high proportion of the N in pond effluents (Pell and Nyberg, 1989b). High loading could have led to the development of anaerobic conditions and to the production of toxic compounds such as hydrogen sulphide beyond 15 cm depth (Beveridge, 1996). Organic matter and ammonia in pond effluent may have further disturbed the oxygen status in the soil columns restricting proliferation of aerobic bacteria and therefore reducing the quantity of N retained in the soil at high effluent application intensity (Beveridge, 1996). This environment may have resulted in decline in population of aerobic bacteria (Lance and Whishler 1972). Mineralization of the organic N bound in dead bacteria probably resulted in high levels of N in the soil column through-flow. The capacity of the soil exchange complex to adsorb the various N ions may have been saturated by and the percentage of NO_3 not retained in the soil was reasonably high (Hertemink *et al.,* 1996). Soil columns when continuously flooded with secondary wastewater, loose their capacity to remove N gradually which ceases finally (Pell and Nyberg, 1989a).

5.3.2 Phosphorus removal.

Both black and red clay soils were enriched with P at 31, 81 and 161 mm day^{-1} effluent application ratio. Red clay soils retained more P than black clay soils and P retention was dependent on the amount supplied from the effluent. Black clay soil with lower saturated hydraulic conductivity allowed less effluent through-flow as compared to the red clay soil. Figure 5.3 shows the removal trends of total P from the black clay and red clay soils

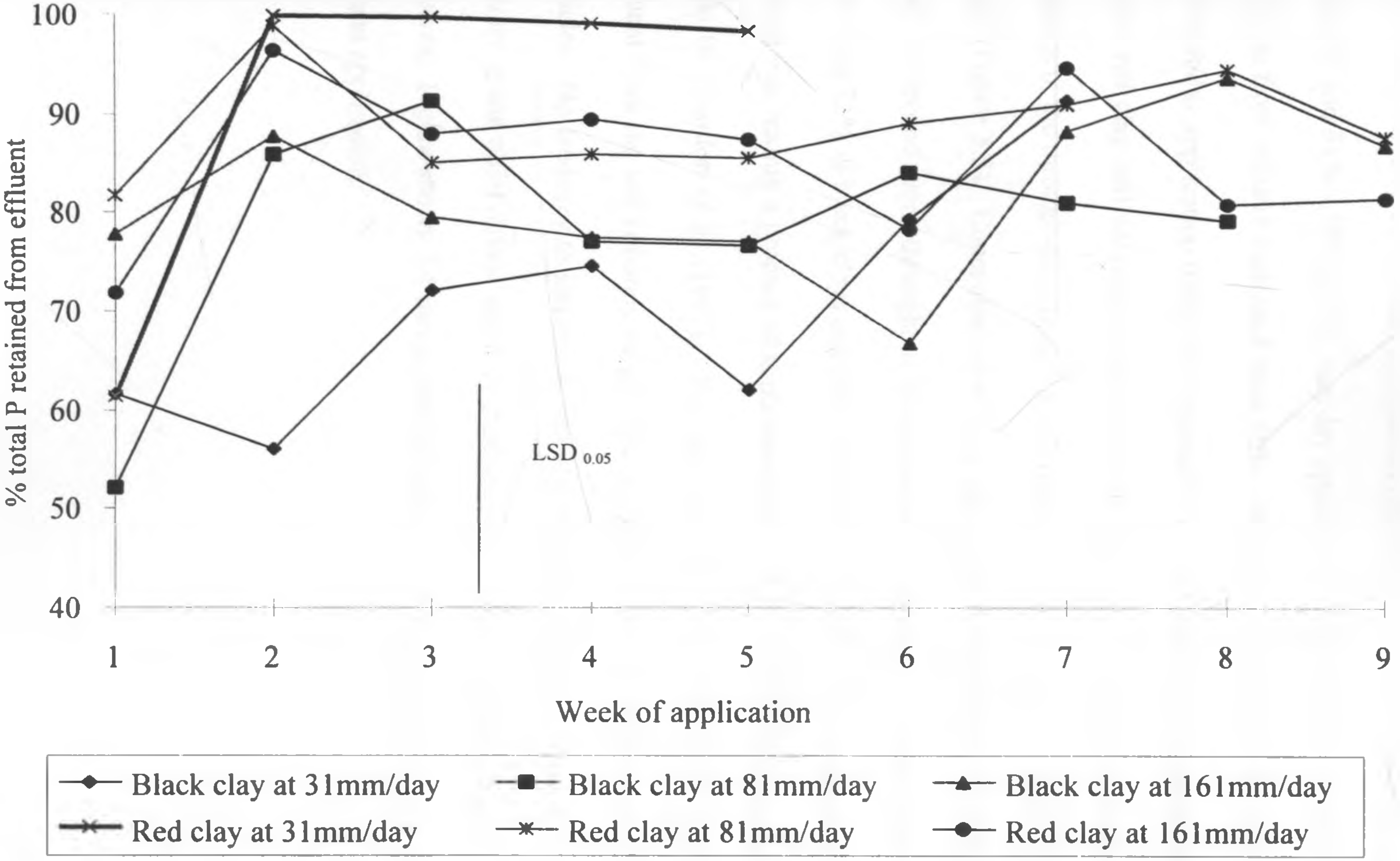

Figure 5.3. Phosphorus removal trends by black clay soil at varying pond effluent application rates.

Over 60% of total P applied in effluent was removed at all application intensities, with the efficiency of removal in black clay soil increasing from 78% - 81% from the first to the ninth week in 31 mm/day application intensity, 52% - 78% in 81 mm/day application intensity and 61% - 86% in 161 mm/day application intensity. In red clay soil column , P removal from effluent increased from 60% - 98%, 80% - 94% and 70 - 95% in 31, 81 and 161 mm/day application intensities respectively. Low percent P removal from the effluent by the red clay soil columns observed in the first week may have resulted from high P contents in the through-flow from the columns due to initial high P content in the 0 - 15cm depth (Figure 5.3). Concentration of P in through-flow from soil columns remained low from the second week throughout the experimental period. The efficiency of P removal was about 75% in black clays and 80% in red clays at all loading intensities. P retained in the soil was mainly a product of application rate and P content, similar observations were made by Chardon *et al.*,(1997). The fact that very low levels of P were found in the effluent from the soil columns suggest that most of the P was rapidly adsorbed to the soil particles. No tendency to saturation was observed at the loading rates used in this study, contrary to the observations made by Pardue *et al.*, (1994) who used higher concentration effluents. Figure shows 5.4 mean total phosphorus in soil columns before and after pond effluent application.

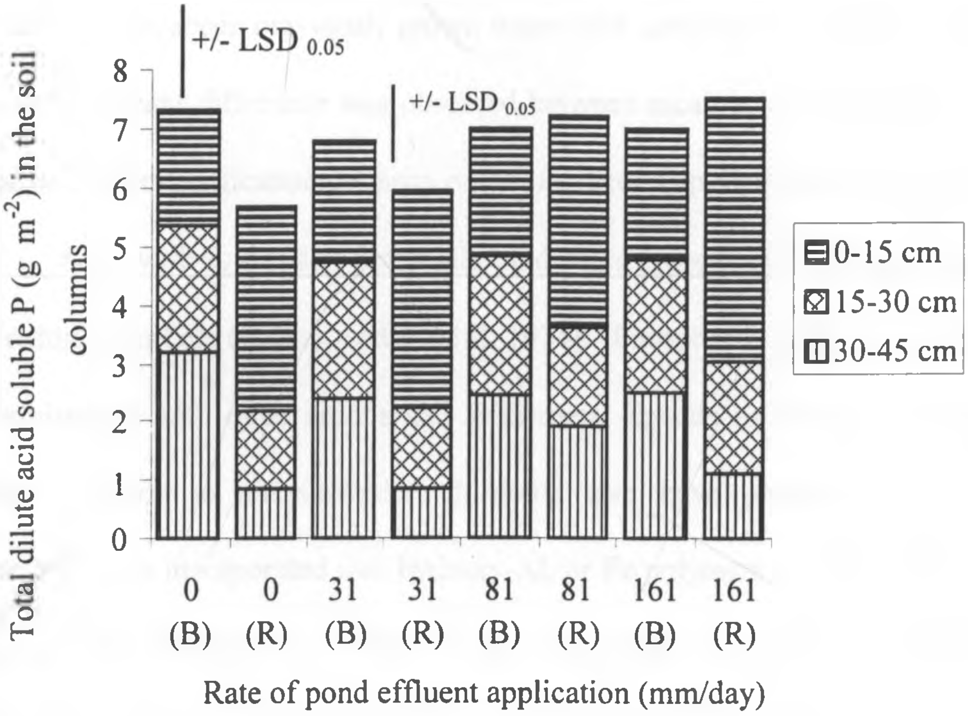

Figure 5.4 Mean dilute acid extractable phosphorus in the column soil before (0 effluent application intensity) and after pond effluent application.

Significant differences (P=0.05) were observed between mean soil dilute acid extractable P at different depths at all effluent application intensities in red clay soil, however, no significant difference was observed between the mean soil dilute acid extractable P at varying or application intensities or the interaction between the mean soil dilute acid extractable P at different depth and effluent application intensity. A high amount of P was retained within 0 - 15cm depth. Only a reduced amount of P moved further down the profile. In addition, high initial P in 0 – 15 cm layer was due to fertiliser application to soyabean previously grown where trial samples were obtained. In black clay soil, no significant difference was observed between mean acid extractable P at different depths or effluent application intensity or the interaction application intensity and depth.

Soils with low redox potentials bind more P from soil solution than soils with high redox potentials (Patrick and Khalid, 1974). Phosphorus sorption occurred where P was exchanged with other anions and with metal ligands in the soil, or changed from physical sorption to chemisorption. It could also have precipitated as insoluble P compounds, was incorporated into hydroxy-Al, or Fe polymers or diffused into the crystal lattice of soil minerals (Ross, 1989). Data on column soil enrichment with dilute acid extractable P (g m^{-2}) pond effluent application are presented in Table 5.3.

There was no significant difference ($P< 0.05$) in total P retention between the two soils as shown by increase in the dilute acid extractable P, however red clay soil retained 4%, 45% and 31% more P than black clay soil at 31, 81 and 161 mm day^{-1} rate of effluent application respectively (Table 5.3).

Table 5.3 Increase in dilute acid extractable P content in the column soil after pond effluent application

Application intensity (mm day^{-1})	Red clay	Black clay	LSD$_{0.05}$	C.V
		Soil total N		
		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

The ability of red clay soil to remove P from waste water may have been due to high Al content (Table 5.0). As reduced conditions approached totality, pE (redox potential) values decreased leading to instability and dissolution of adsorbents binding metals and ligands causing a marked increase in solubility of metals and ligands (Sposito, 1989). In presence of Al and Fe hydroxyls in the soil solution at pH values below 6.5, phosphate ions are likely to have replaced hydroxyl groups and reorganised into very stable bridge between the cations (Bohn, *et al.*, 1985) P sorption capacity of red clay soil may also have increased due to formation of $Fe(OH)_3$ which served as sorption surface. Phosphorus was removed from soil solution by reacting with the hydrous oxides of iron and aluminum to form insoluble compounds such as potassium and ammonium taranakites (Ross, 1989). Furthermore, the high organic matter in black soil (Table 3.1) could have complexed Al and Fe (Marshall, 1977) thereby reducing the effects of the cations on P retention.

Use of pond effluent that contain low plant nutrient (N & P) concentration additions such as those observed in this experiment, a continuous adsorption is observed (Bache and Williams, 1971). Adsorption probably remained on the straight line portion of the Langmuir adsorption isotherm curve where further addition of P resulted in adsorption (Bache and Williams, 1971).

5.4 Conclusion.

Removal of total N in soil columns was high in the first three weeks of application but this declined rapidly with time upon continuous application. Continuous application of pond effluents at a rate of 81 and 161 mm day^{-1} for a period of forty and twenty three days respectively saturates the soils ability to retain total N from pond effluents with total N concentration ranging from 1.33 mg L^{-1} to 6.30 mg L^{-1}. No further removal of the total N in the effluents by the red clay soil was achieved thereafter. Passing pond effluent through the soil column did not remove N from the effluents applied at rates above 81 mm day^{-1} since excessive through flow as a result of the high hydraulic conductivity causes a rapid movement of N down the profile. Increase in the amount of N retained in the soil was significantly higher in the black clay (Vertisol) soil than in red clay soil (Cambisol), primarily because the rate of nitrogen movement and wash out in through flow water was more rapid in red clay soil.

As the effluents pass through the soil, enrichment with N is higher in black than in red clay soil due to a longer residence time of the effluent allowing adsorption. Application of pond effluents with total P concentrations ranging from 1.33 mg L^{-1} to 3.9 mg L^{-1} resulted in removal of 80% of the total P from the effluents, if they are applied at any of the rates used in this study for up to ten weeks. Pond effluent application at a rate of 81 mm day^{-1} in red clay soil resulted in the highest P (4.52 g kg^{-1}) enrichment while an application at a rate of 31 mm day^{-1} in black soil had the least enrichment (3.00 g kg^{-1}). Phosphorus was removed from the effluent by the red soil by complexing with the aluminum and iron oxides while removal of P by black soils was mainly through formation of insoluble complexes with calcium and magnesium. To supply P to crops effluent application at 81 mm day^{-1} on red clay soil seems to be more effective.

CHAPTER 6

6.0 GENERAL DISCUSSION AND CONCLUSION

6.1 General discussion

Application of fertilisers in to the fish pond caused an accumulation of N and P in water. Ponds receiving fertiliser exhibited higher nutrient levels than the canal water. Fertilizers added to pond water increased pond soil nutrient levels, which in turn contributed to the nutrients in water column. Withdrawal of the enriched pond water and their use for irrigation caused 0.01% and 0.1% water reduction in the ponds. This loss was relatively low as compared to 19% and 28% losses to seepage and evaporation as reported by Mwau (2000). The nutrient content in pond water was not high, and when applied at a rate of 0.11 to 1.05 mm day^{-1}, the amounts of N and P supplied to the root zone are inadequate to supply the crops with these nutrients sufficiently.

Suspended particles clogged the tapes and impaired water distribution in the plots through the drip irrigation system. Crops under functioning emitters were over-irrigated, waterlogged and suffered manganese toxicity as indicated by the levels in the leaves, while those under clogged emitters received insufficient water, showed water stress and a depressed yield. Improvement of the water supply system led to a sufficient water supply and higher bean yields.

High rates of pond water application enriched the soil with N, however, enrichment with P was not significant. Levels of P in the effluents did not cause a significant increase in the soil extractable P when applied upto a rate of 161 mm day^{-1}.

6.2 Conclusion

Accumulation of N and P in pond water during aquaculture production activities is insufficient to meet the nutrient requirements for optimum production of French beans and kale. Additional fertilisation with N and P were necessary to obtain economic yields of these crops. Due to low nutrient levels in pond effluents for the purpose of crop fertilisation, larger amounts of the effluent need to be applied to increase the nutrient supply to the crops however the soil column experiment suggest that the nutrient contained in large volumes of water washed through the soil especially for red clay soil. Increased suspended matter in pond effluents necessitates application of a complex filtration system if the pond effluent is to be delivered through a drip irrigation system. A pre-treatment filtration is therefore a requirement before drip irrigation system can be used to apply pond effluents on crops.

Returns from cultivation of kale irrigated with pond effluents through drip irrigation are higher than when French bean crop is cultivated. The relatively poor returns in the second season was mainly due to overcapitalisation in the irrigation system over reduced irrigation plots. The integrated system demonstrated positive returns to shared water resources. The study provided an insight into the benefits related to shared water use between aquaculture and horticulture and demands of the drip irrigation water delivery system to capital.

It is apparent that, where access to capital is limiting, farmers should apply water at rates used in the first season, or alternatively increase the area under irrigation and use the rates tried in the second season after improving on the pond effluent filtration facility. In this study, the fish subsystem did not benefit from the crop subsystem, thereby breaking the linkage in the integrated system mainly because the fish were exclusively on commercial feeds, and the total crop biomass was carried off the field. Production of an irrigated crop and a crop of fish simultaneously is feasible and therefore inclusion of an irrigated crop in an integrated crop- fish farming system is a viable option.

6.3 Recommendations

1. Effluents should be evaluated in terms of their nutrient concentration prior to being considered as sources of plant nutrients. Pond effluents low in nutrients cannot be a substitute for fertilisers in kale or french bean production.
2. Appropriate irrigation technique should selected when applying pond effluents on crops. Further research should be carried out to investigate the most beneficial and technically feasible method of applying pond effluents to crops. Research should be carried out to find out the most efficient way of water distribution, owing to the limited availability of the pond effluents.
3. Where drip irrigation is selected as a method of water application to crops, improved filtration system which is affordable should be used. Improvement of the filtration

reduces clogging of drip lines. Alternatively, culture of filter feeding fish species in polyculture where pond water is to be used for irrigation should be considered. Concentration of particles that are liable to clog an irrigation system will be reduced in reservoirs if stocked with filter feeding fish. The fish reduces the concentration of filamentous algae, prevents blue green algae blooms and also reduces the concentration of zooplanktoon in reservoirs. The presence of filter feeding fish is also reported to reduce large suspended particles.

4. Required investment in irrigation is large and to offset this cost, higher value crops with an established market should be grown. Further research should be conducted to come up with high value crops with a higher water use efficiency to enable production with limited quantities of water.
5. Lagoons should be constructed for holding effluents and thereafter applying them to crops over the growing period. The suspended solids will settle out and since no water will be added to the lagoon, the nutrient concentration may be high.
6. Red or black clay soil can be used and effectively retain P from pond effluents, however removal of N is not achieved by passing the effluents through these soils. An alternative method of cleaning N from large volumes of pond effluents should be identified.

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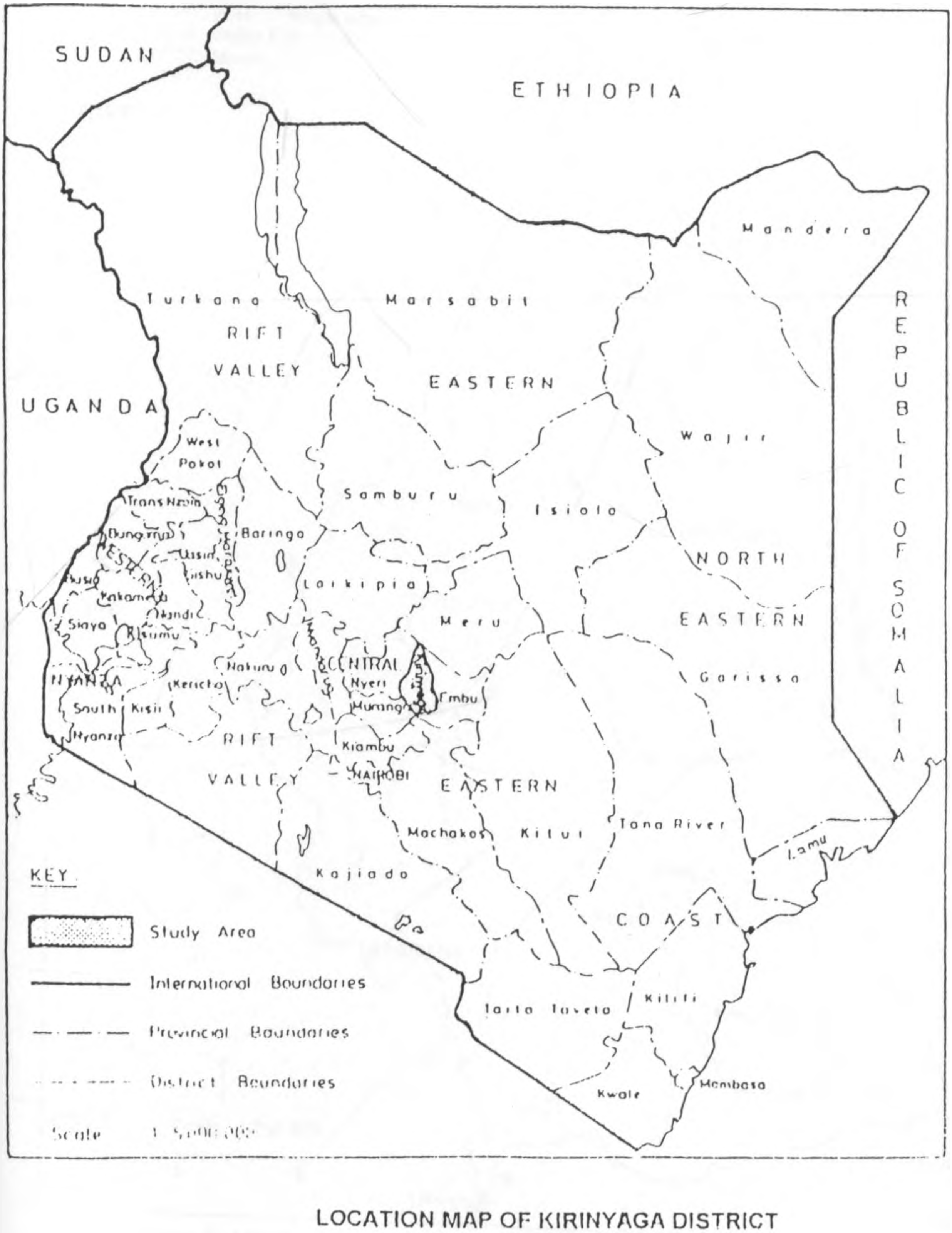
Appendices.

Appendix 1. Map of Kenya showing Kirinyaga district.,



LOCATION MAP OF KIRINYAGA DISTRICT

SOURCE: Survey of Kenya, 1981

Appendix 2a. Map of Kirinyaga showing Sagana fish farm

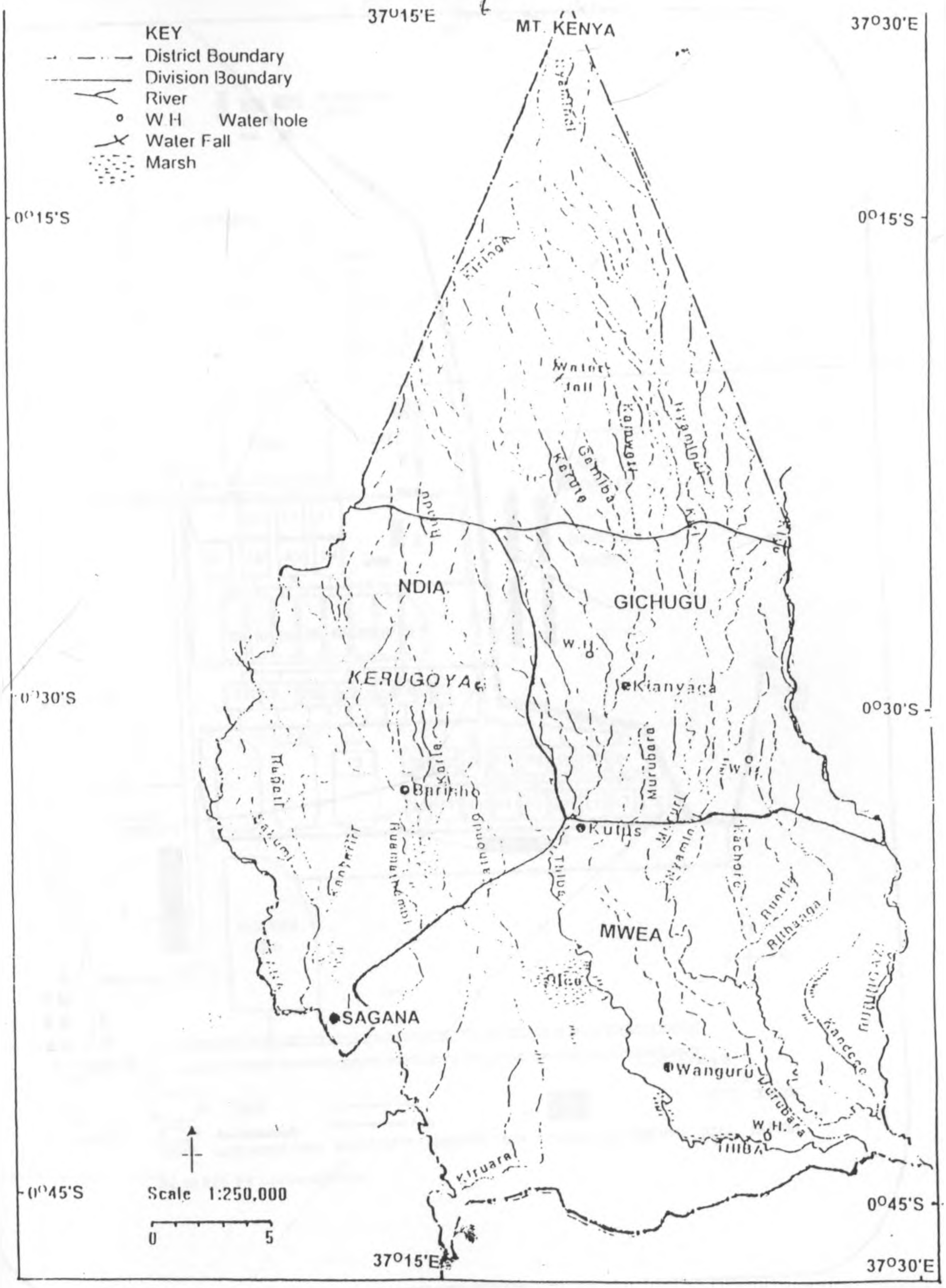
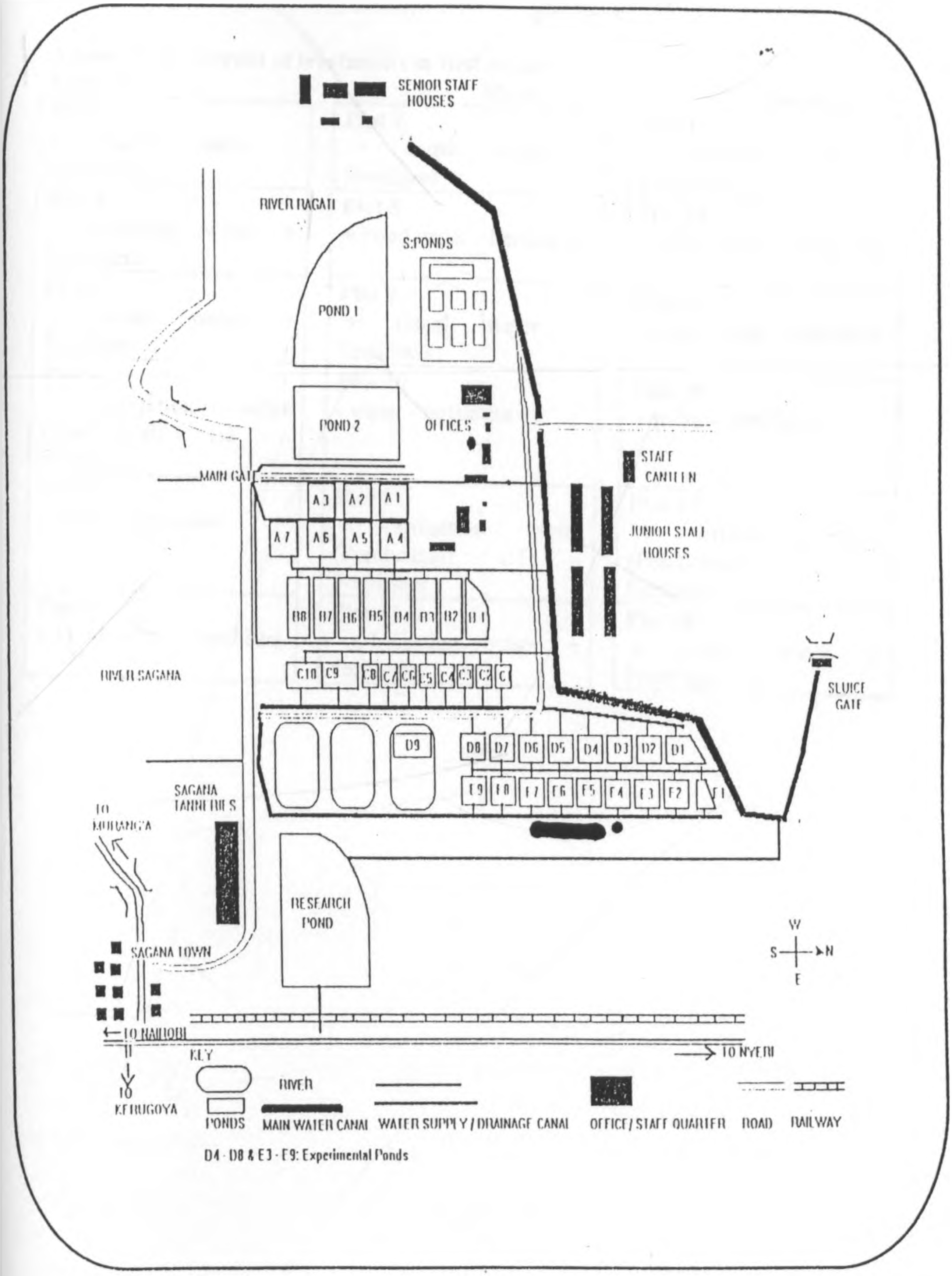


Figure 5: **Location map of Sagana Town in Ndia Division, Kirinyaga District**

SOURCE: survey of Kenya, 1981

Appendix 2b Layout of ponds in Sagana fish farm showing the research site.



Sagana Fisheries Station

Source: PD/A CRSP 1998

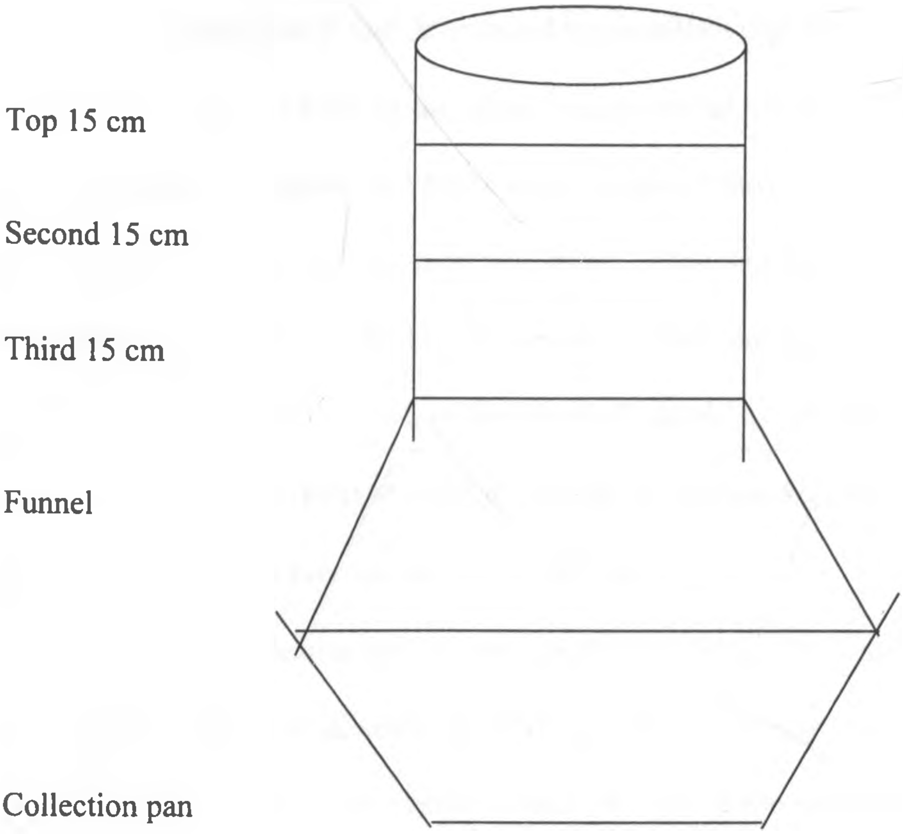
Appendix 2c Layout of treatments in first season.

Block 1	Block 2	Block 3
Plot 1 + Canal water + Fertilisers	**Plot 7** + canal water – Fertilisers	**Plot 13** - Irrigation water + Fertilisers
Plot 2 - Irrigation water + Fertilisers	**Plot 8** + Pond water - Fertilisers	**Plot 14** + Pond water - Fertilisers
Plot 3 + canal water – Fertilisers	**Plot 9** + Canal water + Fertilisers	**Plot 15** + canal water - Fertilisers
Plot 4 + irrigation water (Pond:canal) 1:1 – Fertilisers	**Plot 10** - water - fertilisers	**Plot 16** - water – fertilisers
Plot 5 - water – fertilisers	**Plot 11** + irrigation water (Pond:canal) 1:1 – Fertilisers	**Plot 17** + irrigation water (Pond:canal) 1:1 – Fertilisers
Plot 6 + Pond water – Fertilisers	**Plot 12** - Irrigation water + Fertilisers	**Plot 18** + Canal water + Fertilisers

Appendix 2d Layout of treatments in the second season

Block 1		Block 2		Block 3	
Plot 1 Bean + canal water + Fertilisers	**Plot 7** Beans Pond water + Fertilisers	**Plot 13** Kale + Pond water + Fertilisers	**Plot 19** Kale - water - fertilisers	**Plot 25** Bean + canal water + Fertilisers	**Plot 31** Beans + canal water - Fertilisers
Plot 2 Kale + Pond water - Fertilisers	**Plot 8** Kale -Irrigation water + Fertilisers	**Plot 14** Bean + canal water + Fertilisers	**Plot 20** Beans - water - fertilisers	**Plot 26** Kale + canal water + Fertilisers	**Plot 32** Beans -water- fertilisers
Plot 3 Kale + canal water - Fertilisers	**Plot 9** Bean + Pond water + Fertilisers	**Plot 15** Bean + Pond water + Fertilisers	**Plot 21** Beans + canal water - Fertilisers	**Plot 27** Kale -Irrigation water + Fertilisers	**Plot 33** Kale - water - fertilisers
Plot 4 Kale - water - fertilisers	**Plot 10** Beans + canal water – Fertilisers	**Plot 16** Beans + Pond water + Fertilisers	**Plot 22** Kale + Pond water - Fertilisers	**Plot 28** Kale + Pond water + Fertilisers	**Plot 34** Bean + Pond water + Fertilisers
Plot 5 Kale + Pond water + Fertilisers	**Plot 11** Kale + canal water + Fertilisers	**Plot 17** Kale -Irrigation water + Fertilisers	**Plot 23** Kale + canal water + Fertilisers	**Plot 29** Bean + Pond water + Fertilisers	**Plot 35** Kale + canal water - Fertilisers
Plot 6 Beans- water - fertilisers	**Plot 12** Beans -Irrigation water + Fertilisers	**Plot 18** Beans -Irrigation water + Fertilisers	**Plot 24** Kale + canal water - Fertilisers	**Plot 30** Kale + Pond water - Fertilisers	**Plot 36** Beans -Irrigation water + Fertilisers

Appendix 2e Schematic diagram of soil columns arrangement.



Appendix 2f Water analyses method

Total N and Total P was determined by persulfate digestion procedure described by Eaton, *et al.*, (1995). 10 mL of the water sample was pipetted in a digestion tube. 5 mL digestion reagent was added, and the tube was capped tightly. The sample was mixed with the reagent by inverting the digestion tube twice. The tubes were put in a pressure cooker and heated at a pressure of 15 psi for 30 minutes. After cooling to room temperature, 1 mL borate buffer was added. 10 mL of the digested sample was pipetted into 50 mL conical flask and topped with deionised water to volume. 25 ml was kept for total N determination while the remaining 25 mL was used for total P determination.

Total N was determined by the szechrome NAS (Diphenylamine sulfonic acid chromogene) method as directed by Skekely (1975). Briefly, 5ml of szechrome NAS reagent was pipetted in 50 mL conical flasks. 0.5 mL of the sample was pipetted into the flask and mixed with the reagent. Violet colour developed after 5 minutes. The colour intensity was read off on the spectrophotometer (Spectronic 21) at a wavelength of 570 nm.

Total P was determined by ascorbic acid method (Boyd and Tucker, 1992). 10 mL of the digest was pipetted in 50mL conical flasks. The sample was topped off to 50 mL by deionised water. 25 mL of the sample was pipetted in 50 mL conical flasks and 4.0 mL of combined reagent added. After 10 minutes, blue colour developed. The intensity of the blue colour was read off on the spectrophotometer (Spectronic 21) at a wavelength of 880 nm.

Total suspended solids were determined following the procedure described by Boyd and Tucker, (1992). Briefly oven dry filters were tared out. 100 mL water sample was passed through the tared dry filters. The filters were then dried for 24 hours at 103 °C, cooled in a desiccator and weighed to precision. Total suspended solids were calculated as

$$\text{TSS (mg L}^{-1}\text{)} = [(F - T) \times 1000] / V \qquad (4.1)$$

Where

F = Final weight of filter and residue in milligrams.

T = Tare weight of filter in milligrams

V = Volume of the sample in milliliters

Appendix 2g Soil and plant tissue analyses

Soil analyses.

Preparation of soil samples for analyses

Samples were subjected to standard preparatory procedures. About 1.5 kg of the representative soil samples were spread on a clean polythene sheet and air dried on the laboratory benches for 7 days. About 1 kg of the air dry samples was lightly crushed using a clay mortar and pestle (Page *et al.,* 1982). The samples were sieved through a 2 mm mesh sieve and kept in plastic bottles awaiting nutrient analyses.

Chemical analyses

Determination of soil pH

Soil pH was determined by the glass electrode pH meter method described by Sparks *et al.*, (1996). 10 g of air dry soil was put in a plastic bottle and 10 mL of deionised water added and mixed thoroughly. The mixture was allowed to stand for 10 minutes , then swirled and electrode tip was inserted. The pH was read off. The electrode was rinsed and dried with blotting paper between sample reading.

Total carbon and nitrogen

Total C and N in soil and plant tissue were determined by dry combustion with a LECO CHN-600 analyzer (LECO Corp., St. Joseph, MI) (Hue and Evans, 1986).

Available P, K, Fe, Mn and Al.

Available P, K, Fe, Mn, and Al, in a 5 g soil or plant tissue sample or were extracted with 20 mL of a dilute double acid mix of 0.05 N HCl and 0.025 N H_2SO_4 (Hue and Evans, 1986). This extract was analyzed by Jarrell-Ash inductively coupled argon plasma (ICAP) spectroscopy (ICAP 9000, Thermo Jarrell Ash, Frankllin, MA).

Physical analyses

Determination of bulk density.

Bulk density was determined by the core ring method described by Blake and Hartige, (1986). Soil cores were weighed on an electronic scale and this recorded as the wet sample weight (W/w). The cores were placed in an oven and maintained at a temperature of 105 °C for twenty four hours. They were retrieved and weighed on an electronic scale, and this was recorded as the sample oven dry weight (Wd). Soil was then pushed out of the cores, and each core was washed clean with tap water, oven dried at 105 °C for four hours to get rid of water on their surfaces and weighed on an electronic scale. This was recorded as the empty core weight (Wc). The internal diameter and the length of the cores was then determined using a vernier calipers. This was used to compute the volume of the soil (Vs). The bulk density was calculated as,

Bulk density = (sample oven dry weight-empty core weight)/volume of the soil.

$$Pb = (Wd-Wc)/Vs \qquad (5.1)$$

5.3.1.2 Determination of the saturated hydraulic conductivity of the soil.

Saturated hydraulic conductivity was determined by the constant head method (Klute *et al.*, 1986). Constant head apparatus were assembled as described by Klute *et al.* (1986). Soil samples in cores were then put on a funnel mounted on stand. Water was allowed to run through the sample while maintaining a constant head (h in cm). Using a stop watch, the time (t in minutes) required for a given volume (v in cm^3) of water to pass through the sample was recorded. Using venier calipers, the internal diameter and the length of the cores was measured. The internal diameter was used to compute the cross sectional area (A in cm^2) of the soil, while the length was used to measure the soil sample length (H in cm) which was used to compute total head (h+H in cm).

The saturated hydraulic conductivity was calculated as,

$$K_{sat} = VL/[At\,(H_2 - H_1). \qquad (5.2)$$

Where V is the volume of water that flows through the sample of cross sectional area A in time t, and $(H_2 - H_1)$ is the hydraulic head difference imposed across the sample.

Appendix 3. Analysis of variance table for the effects of irrigation and fertilisation regimes on yield of fresh pods of French beans in first season.

Fresh bean pod

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Treatment	1.19782	5	2.39563	9.53	0.0015
Reps	3.823371	2	1.91185	0.76	0.4925
Residual	2.51256	10	2.51256		
Total	1.48731	17			

Oven dry bean pod

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Treatment	1.04273	5	2085452	9.53	0.0015
Reps	3346.42	2	16731.7	0.760	0.4910
Residual	218907	10	21890.7		
Total	1.2951	17			

Appendix 4. Analysis of variance table for the effects of irrigation and fertilisation regimes on economic returns of kale and french bean in the second season

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Reps	12.02	2	6.01	0.008	0.99
Crops	19661.57	1	19661.57	26.45	0.00
Irrigation	13560.90	2	6780.45	9.12	0.001
Fertilisation	9508.36	1	9508.36	12.79	0.002
Crops X irrigation	4025.44	2	2012.72	2.71	0.09
Crops X Fertilisers	276.47	1	27647	0.37	0.55
Irrigation X fertilisers	33.76	2	16.88	0.02	0.98
Crops X irrigation X fertilisers	2219.62	2	1109.81	149	0.47
Residual	16350.87	22	743.22		

Appendix 5. Analysis of variance table for the effects of irrigation and fertilisation regimes on kale and french bean yield in the second season

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Reps	12.02	2	6.01	0.008	0.99
Crops	19661.57	1	19661.57	26	0.00
Irrigation	13560.90	2	6780.45	9.12	0.001
Fertilisation	9508.36	2	9508.36	12.79	0.002
Crops X irrigation	4025.44	2	2012.72	2.71	0.09
Crops X Fertilisers	276.47	1	276.47	0.37	0.55
Irrigation X fertilisers	33.76	2	16.88	0.2	0.99
Crops X irrigation X fertilisers	2219.62	2	1109.81	1.49	0.247
Residual	16350.87	22	743.22		

Appendix 6. Analysis of variance table for the effects of irrigation and fertilisation regimes on kale and french bean dry matter yield in the second season

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Reps	29003.13	2	14501.56	0.33	0.72
Crops	4912101.75	1	4912101.75	112.75	0.00
Irrigation	529312.86	2	264656.43	6.08	0.008
Fertilisation	4522161.19	1	452161.19	10.38	0.004
Crops X irrigation	751224.50	2	375612.28	8.62	0.002
Crops X Fertilisers	69905.53	1	69905.53	1.650.30	0.22
Irrigation X fertilisers	26269.26	2	13134.63	1.76	0.74
Crops X irrigation by fertilisers	153694.87	2	76847.44		0.20
Residual	958455.33	22	43566.15		

Appendix 7. Analysis of variance table for the effects of pond effluent application on total N in soil in columns.

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Soil	177445.66	1	177445.66	361.10	0.00
Irrigation	6193.99	3	2064.67	4.20	0.01
Depth	6061.77	2	3030.87	6.17	0.004
Soil X irrigation	15909.62	3	5303.21	10.79	0.000
Irrigation X depth	3450.49	6	575.08	1.17	0.34
Soil X depth	3260.55	2	1630.28	3.31	0.45
Soil X irrigation X depth	4217.86	6	702.98	1.43	0.223
Residual	23588.08	48	491.41		

Appendix 8. Analysis of variance table for the effects of pond effluent application on available P in soil the columns.

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Soil	0.36	1	0.36	0.70	0.41
Irrigation	1.21	3	0.40	0.78	0.511
Depth	17.66	2	8.83	1710	0.00
Soil X irrigation	1.48	3	0.49	0.95	0.42
Irrigation X depth	1.74	6	0.29	0.56	0.75
Soil X depth	32.93	2	16.46	31.87	0.00
Soil X irrigation X depth	2.13	6	0.35	0.69	0.66
Residual	24.80	48	0.51		

Appendix 9. Analysis of variance table for the effects of pond effluent application on total N enrichment in soils in the columns.

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Soil	3.27	1	3.27	19.17	0.00
Irrigation	0.99	2	0.46	2.78	0.8
Depth	0.81	2	0.40	2.36	0.11
Interactions					
Soil X irrigation	1.31	2	0.65	3.83	0.03
Irrigation X depth	0.76	2	0.38	2.3	0.12
Soil X depth	0.11	4	0.03	0.16	0.96
Soil X irrigation X depth	0.6	4	0.04	0.23	0.92
Residual	6.14	36	0.17		

Appendix 10. Analysis of variance table for the effects of pond effluent application on total N enrichment in soils in the columns.

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Soil	1.04	1	1.04	3.97	0.54
Irrigation	0.59	2	0.30	1.13	0.34
Depth	0.08	2	0.04	0.15	0.86
Soil X irrigation	0.44	2	0.22	0.83	0.44
Irrigation X depth	1.00	2	0.50	1.93	0.16
Soil X depth	0.86	4	0.21	0.82	0.52
Soil X irrigation X depth	0.97	4	0.24	0.93	0.46
Residual	9.39	36	0.26		

Appendix 11. Analysis of variance table for the effects of irrigation and fertilisation regimes on above ground dry biomass of French beans in second season.

Source	Sum of squares	D F	Mean Square	F - Ratio	P - Value
Main Effects					
Treatment	77543.6	5	15508.7	2.65	0.0891
Reps	20217.4	2	110108.7	1.73	0.2270
Residual	58553.9	10	5855.39		
Total	1563158	17			