EFFECTS OF RICE-FISH INTEGRATION ON THE PRODUCTIVITY OF IRRIGATED PADDIES IN EAST KANO IRRIGATION SCHEME, WESTERN KENYA

BY

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ABSTRACT

Rice-fish integration is practiced in many places in the world with varied success. Carps, milkfish and tilapias are traditionally used. One other potential fish, particularly for Africa, is the African catfish (*Clarias gariepinus*). Whereas adoption of rice-fish integration technology would potentially increase aquaculture fish production in Kenya, local trials have not adequately been undertaken resulting in knowledge gaps including number of fish species involved under integration and the yields of both fish and rice, that this study sought to bridge. The present study integrated Basmat rice variety with African Catfish (*Clarias gariepinus*) and Nile tilapia (*Oreochromis niloticus*) at Ahero Rice Research Station in Western Kenya ($0^0 08'$ S and $34^0 56'$ E) with a view to assessing the viability of such integration in Western Kenya. Three treatments with varying fish stocking densities were tested in triplicate - rice-catfish low density (4 fish/m^2), rice-catfish high density (8 fish/m^2) and rice-catfish-tilapia polyculture (4 fish/m^2 per species). The paddies were fertilized but no supplementary feeding was done to the fish in all the treatments. After a 122days' trial, the mean weight of catfish had increased from the initial weight of 16.6±0.2g to 136±11.2g in RCH, 16.0±0.1g to 150.3±6.4g in RCL and 16.2±0.4g to 156.9±9.09g in RCT. For tilapia mean weight had increased from the initial of 10.0±0.1g to 105.4±7.05g. The catfish yields were 373.16 kg/ha in the RCT, 288.88 kg/ha in RCH and 236.26 kg/ha in RCL. Catfish grown under RCL recorded lowest growth rates, which was significantly different (ANOVA; $p<0.05$) from the other treatments. Rice yield over the same period was 3350 kg/Ha in RCT, 2898 Kg/Ha in RCL and 2696 Kg/Ha in RCT. Both yield of catfish and rice were significantly higher (ANOVA; $p<0.05$) in RCT compared to RCH and RCL. The differences observed between the different treatments with respect to the environmental parameters were however not significant (ANOVA, $p > 0.05$). This study demonstrated highest productivity with rice-fish polyculture integration, giving highest yields for both the fish species – catfish and tilapia, and rice. Although carried out in a new environment, these findings showed potential for success and are suggested for up-scaling and adoption in East Kano. The impact of giving supplementary feeds to fish in a rice-fish polyculture integrated system is recommended for further investigation.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Integration of rice with fish (ricipisciculture) is an efficient way of using the same land resource to produce both carbohydrate food and animal protein concurrently. Successful integration of rice with fish requires good soil and water quality principally to promote growth and production of both rice and fish (Rothuis, Nhan, Richter and Ollevier, 1998a; Yaro, Lamai and Oladimeji, 2005). The aim of the culture system should be to optimize the use of resources and improve production efficiency through increased recycling of nutrients and matter, and to avoid overuse of agro-chemicals (Yaro *et al*, 2005; Frei and Becker, 2005a).

Rice fields are temporary man-made aquatic habitats that are planted and harvested once or twice a year. They cover a range of irrigated, rainfed lowland, flood-prone, and up-land ecosystems and can be integrated with fish farming (Rothuis *et al.* 1998a; Yaro *et al*, 2005). Production of fish in rice fields is almost as old as the practice of paddy rice culture itself. It is most likely that fish and other aquatic organisms would have come in with the floodwater, made the rice field their temporary habitat within the duration of the rice farming cycle to become an additional rice field product for the farmers (FAO, 1987). However, The earliest records of fish culture in rice fields is from China where it can be traced to as early as the year 220 AD followed by India, 1500 years ago. It has been successfully practiced for centuries by most tropical Asian countries. As reported by Xiuzehn, (2003), China had over 4% of the total rice cultivation area integrated with fish production in the year 2001and the country's fish production was estimated at 377,000 tonnes for the year 2003 (Table 1). China and Egypt are the world's leaders in integrated rice-fish culture production. India, Indonesia, Thailand, Vietnam, the Philippines, Bangladesh and Malaysia follow with high rice-fish production and different types of rice-fish culture systems (Halwart and Gupta, 2004). Many reports on rice-fish culture note increasing rice yields (5-48%) in integrated systems compared to rice monoculture (Frei and Becker, 2005b; Pant, Demaine and Edwards, 2004; Fernando and Halwart, 2000; Halwart, 1998; Rothuis *et al*, 1998a; Lightfoot, Dam and Costa-Pierce, 1992). The factors that have been put forward to explain the increase in rice yields in the integrated rice-fish culture are: fertilizing effect from the fish droppings that greatly increases nutrient availability to the rice crop; weeds and pests control by the fish that could otherwise reduce rice crop yield; and better management of water flow in the integrated system.

Table 1: Leading countries in rice-fish production (Extracted from GAFRD, 2004)

Country	Area of rice-fish (ha)	Yield (kg/ha/yr)	Total production (tonnes)
China	1.2 million	3,183	377,000
Egypt	172,600	115	19,863
Indonesia	94,309	670	63,187
Thailand	3.1 million	25	77,500
Vietnam	40,000	_	_

In addition to increasing rice yields and controlling vectors, rice-fish integrated system provides a second source of income from fish, thereby resulting in ecological and increased economic benefits. Yaro *et al.* (2005) observed that rice-fish farming provides a suitable alternative to rice monoculture, if the farmer takes full advantage of the natural productivity of the rice field ecosystem.

1.2 Aquaculture in Kenya

In comparison to the other parts of the world, fish culture is a relatively new practice in Kenya. It dates back only to about 1912 when trout was introduced as sport fish to stock rivers in the Mt. Kenya region (Ngugi, 1999). It later evolved into pond culture of tilapine fishes in the 1920s. Later fish farming in the country adopted other fish including the African Catfish and Common carp (FAO, 2004). This culminated into proper fish farming in the 1948 as indicated by Owiti (2000). For rice-fish culture, however, there are hardly any cases reported for Kenya except for a recent and isolated case of an experimental research in West Kano Irrigation Scheme (Rasowo and Auma, 2006).

Fish polyculture concept is based on the utilization of different trophic niches by the different fish cultured species. The African catfish (*Clarias gariepinus*) and Nile tilapia are among the most important tropical fish species that have been considered for polyculture owing to their biology and economic considerations as pointed out by De Graaf and Janssen (1996), Kangmin (1998) and Okechi (2004). The two species can also be sustained in flooded rice fields. The present study attempted polyculture of *C. gariepinus* and *O. niloticus* and a monoculture of *C. gariepinus* in a rice irrigation scheme with a view to contributing new knowledge towards improving rice field productivity through rice-fish integration in Kenya.

1.3 Statement of the problem and justification

In Kenyan, fish production from the capture fisheries has been dwindling while demand for the commodity has steadily been increasing thereby creating a gap between supply and demand for fish. This situation poses the challenge of finding adoptable and sustainable technologies for improved fish production to satisfy the growing demand. As a way of boosting fish production in Kenya, emphasis has recently shifted to fish production from different aquaculture systems. An aquaculture system that has long been successfully practiced in a number of Asian counties is rice-fish integration. This system, that brings together rice farming and fish culture into one in the rice field, increases production of both commodities. The irrigated rice environment can therefore be a contributor to the much-needed future increase in fish production and, in turn, food security in Kenya. However, the technology of culturing fish in irrigated rice fields is not yet adopted in Kenya because farmers have not yet been exposed to the culture system coupled with the existence of knowledge gaps since local trials of the technology have not been adequately undertaken. It is against this backdrop that this study was carried out in East Kano rice fields in Nyando Sub-County to seek to contribute to the knowledge that could see increased productivity of rice fields in Kenya through the adoption of rice-fish integration technology.

1.4 Aim and objectives

The aim was to evaluate the effects of rice-fish integration on the productivity of irrigated paddies in East Kano Irrigation Scheme.

The specific objectives were to:

i) Assess the growth performance of fish raised under rice-fish integration;

ii) Determine the effects of rice-fish integration on production of rice.

1.5 Hypothesis

Integrating catfish and Nile tilapia with rice cannot increase the production from rice paddies, thereby giving higher yields to rice farmers in East Kano Irrigation Scheme.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice-fish culture

Irrigation systems such as rice fields, provides a big potential for the culture of fish. Harvesting fish from irrigation systems has been practiced for a long time. It is probable that once rice farming progressed to involve puddled fields with standing water, fish must have been an additional product. FAO (1987) and FAO (2000) point out that whenever water is stagnated within bunds for rice culture, fish that naturally occur in the irrigation water enter the paddy fields and grow there until harvest, along with the rice. Thus, fish production in rice fields dates from very early days. It is widely acknowledged that aquaculture started early in China, where pond culture of common carp (*Cyprinus carpio*) began at the end of the Shang Dynasty (1401-1154 BC) (Li 1992). It is noted that rice-fish farming also started in China. Archaeological and written records trace rice-fish culture from rice fields in China in the year 220 AD, and the practice may have started when fish farmers with excess fry released them in their rice fields (FAO, 1987; Li 1992; Cai and Wang 1995; Rothius, 1998; Frei and Becker, 2005a), followed by India, 1500 years ago (Rothius, 1998). FAO (1987) notes that around the year 1900 this type of fish culture begun in Madagascar and in Italy towards the end of 19th century. Rice-cum-fish culture is well established in other rice growing countries, especially in Thailand, Taiwan and Japan (FAO, 1987). Although seldom recorded, this practice seems to have been widespread in the tropics and subtropics, especially in rice fields of many countries in the Asian Continent (Halwart and Fernando, 1998). Frei and Becker (2005a) reported that rice-fish culture optimizes utilization of available resources (water and the inundated rice paddies) thus providing the additional opportunity for fish production without compromising resource availability to other food producing sectors.

According to Halwart and Gupta (2004), rice acts as a nitrogen sink and helps to reduce the ammonia that may be released by fish metabolism and, in so doing, helps make the water cleaner for the fish. Complementary manuring and fertilization of rice fields increases the production of plankton as food for fish and thereby leading to higher yields. In rice-fish culture, fish growth is influenced by increasing the food available to fish and, by increasing the amount of dissolved oxygen in the aquatic environment (Vromant, Nam and Ollevier, 2002). A major source of dissolved oxygen in the water column is the photosynthetic activity of the aquatic plant biomass. Halwart and Gupta (2004) point out that dissolved oxygen concentration is largely a result of photosynthetic activity that uses up carbon and reduces the dissolved carbon dioxide effectively raising both dissolved oxygen as well as pH levels.

The rice field environment is also characterized by large fluctuations in temperature (Kangmin, 1998; Rothuis, 1998; Rothuis *et al.*, 1998a) that sometimes combine to make the water quality conditions adverse. This means that only tolerant species can be cultured successfully in the rice fields. Hence, one of the main characteristics for the choice of fish species for the rice-fish culture must be determined by their tolerance towards the wide fluctuations in water temperature and the other water quality conditions. The rice-fish integration would, to some extent, stabilize the adverse effects of the water quality through self-purification and therefore provide an environment that is conducive for both organisms. Part of the stabilizing effect, as earlier mentioned, is the fish manuring effect in relation to rice plant acting as nitrogen sink. Fish farming in rice irrigation systems in the past and at present is integrated in such a way that the habitats created by irrigation and the accompanying agricultural activities are put to use in fish farming (Fernando and Halwart, 2000).

Many reports on rice-fish culture note increased rice yields from 5% to as high as 48% when compared to rice monoculture (Lightfoot, Dam-van & Costa-Pierce, 1992; Halwart, 1998; Rothuis, 1998; Rothuis, Nam, Richter and Ollevier 1998b; Fernando and Halwart, 2000; Pant *et al.*, 2004; Halwart and Gupta, 2004; Frei and Becker, 2005a). The increase in rice yields in the rice-fish culture systems, particularly on poorer soils and of unfertilized crops, is probably because of the fertilization effect from fish droppings that improve soil fertility (Sule, Bello and Diyaware, 2007).

2.2 Concurrent and rotational rice-fish production systems

Rice-fish production systems can be grouped into concurrent and rotational schemes (Halwart and Gupta, 2004; Frei and Becker, 2005a). The concurrent culture is an agricultural cropping system that integrates fish culture into rice culture. Rice and fish are cultivated simultaneously with the growing rice plants. In the rotational culture, rice and fish are raised independently on a rotational basis on the same piece of land. Of the two modes, concurrent system is more efficient as per the reports by Halwart and Gupta (2004); Frei and Becker (2005a). Concurrent riscipisciculure can be practiced under both irrigation and rainfed conditions (Halwart and Gupta, *op cit*). In this system, fish have full access to the entire inundated field (Vromant, Chau and Ollevier *et al.*, 2001) although about 10% of the area is usually constructed to serve as fish refuge (Halwart and Gupta, 2004; Frei and Becker, 2005b).

Fish yields in a rice-fish culture vary according to the fish species cultured and the stage at which they are harvested. Apart from tolerance to adverse physical and chemical conditions in the rice field, additional required qualities of the animal organism are; desirable herbivorous or omnivorous feeding habits and desirable growth rate (Kangmin, 1998; Fernando and Halwart, 2000; Frei and Becker, 2005a). Two groups of fish stand out in rice-fish farming; these are the cyprinids and the tilapines. The cyprinids - particularly the common carp - have the longest documented history in the rice-fish culture, having been described by early Chinese writers (Halwart and Gupta, 2004). The Mozambique tilapia (*Oreochromois mossambicus*) used to feature prominently in early literature, but the species was increasingly replaced by the Nile tilapia (*O. niloticus*) in many places. The Nile tilapia is now as widely used as the common carp in rice-fish farming (Halwart and Gupta, *op cit* and Sule *et al*, 2007). For Kenya, Rasowo and Auma (2006) pointed out that the rice paddies are potential fish ponds that are yet to be exploited in Kenya.

Rice-fish farming may either be the culture with only one species of fish (monoculture) or a combination of two or more species of fish (polyculture). With their long history of aquaculture, Chinese farmers are aware of the advantages of polyculture over monoculture so that polyculture of various species seems to be the rule. Polyculture makes it possible to take advantage of the available food niches in the rice field ecosystem (Halwart and Gupta, 2004). If the different types of natural food organisms available in a rice field ecosystem are fully exploited by stocking a proper combination of fish species, Halwart and Gupta (*op cit*) estimated that fish production per crop, without supplementary feeding, can range from 100 to 750 $kg \cdot ha^{-1} yr^{-1}$. A model developed by FAO/UNDP/LDBA (1999) on fish farming in Lake Victoria region predicted an average body weight of 200g of tilapia and 250g catfish attained in 198 days and a yield of 9 tonnes per hectare. Rasowo and Auma (2006) working in West Kano observed a mean harvest weight of 56.8g after 77 days of culture for Nile tilapia. During that study, Rasowo and Auma (2006) observed a total yield of 132.4 kg/ha.

2.2.1 Fish polyculture in rice-fish culture system

The motivating principle in fish polyculture is that fish production in ponds may be maximized by raising a combination of species that have different food habits and thus can effectively utilize natural foods thereby resulting in higher yields than monoculture (Halwart and Gupta, 2004). Combinations of three Chinese carps (bighead, silver and grass carp) and the common carp are most common in polyculture in China. In the tropics, Bocek (1982) noted that efficient polyculture systems produce up to 8,000 kg of fish per hectare per year in the Philippines. Sule *et al*, (2007) noted that growth performance of *Heterotis niloticus, Clarias gariepinus* and *Oreochromis niloticus* species under semi-intensive polyculture systems in Nigeria exhibited an increase in fish production within the ponds. Halwart and Gupta (2004) and Frei and Becker (2005a) recommend adoption of a polyculture system using species that occupy different feeding niches.

In the case of rice-fish polyculture, fast growing compatible fish species are grown together in rice fields to increase total production of both rice and fish from the same body of water and land (Halwart and Gupta, 2004). This has long been practiced in China, India and Israel (Sule *et al*., 2007). Halwart and Gupta (2004) noted that polyculture is applied in most rice-fish culture systems where the most commonly used fish species are Common carp (*Cyprinus carpio*), Grass carp (*Ctenopharyngodon* *idella*), Crucian carp (*Carassius auratus*), NileTilapia (*Oreochromis niloticus*), and the African catfish (*Clarias gariepinus*).

2.2.2 African catfish in rice-fish culture systems

The African catfish (*C. gariepinus*) has a phenomenal natural distribution ranging from east to west and from north to south of the African continent (Clay, 1979; Teugels, 1986; Bruton, 1988; De Graaf and Janssen, 1996). It inhabits a variety of freshwater environments many of which are subject to seasonal drying (Gunder and Fink, 2004). It is both a bottom dweller and bottom feeder, in addition to being obligate air breather (De Graaf and Janssen, 1996; Gunder and Fink, 2004). This species is very adaptive to extreme environmental conditions and can live in poorly oxygenated waters with pH range of 6.5-8.0 (Kampong *et al.*, 2002). They are able to live in very turbid waters and can tolerate temperature ranges of 8-35°C (Teugels, 1986).

The African catfish is an opportunistic omnivore capable of switching feeding modes, depending on prey availability. It feeds on insects, plankton, snails, crab, shrimp and other invertebrates. It is also capable of eating dead animals, small mammals, other fishes, and plant matter. Because it is mobile on land, it is able to prey on terrestrial organisms (Gunder and Fink, 2004). According to Kangmin (1998) and De Graaf and Janssen (1996), *C. gariepinus* is one of the most important tropical catfish species for aquaculture. Huisman and Richster, (1987) point out several attributes that make *C. gariepinus* preferred choice of species for culture in Africa. These include its high consumer preference ranking and its ability to utilize atmospheric oxygen as well as dissolved oxygen. d'Oultremont and Gutierrez, (2002) pointed out that this species is important in nutrient recycling in rice fields explaining that the transfer of nutrients takes place from the pond to the rice via fish feces, which increases rice yields.

2.2.3 The Fish Condition

The degree of well-being of a fish is expressed by the coefficient of condition of the fish also known as the condition factor. Variations in fish condition factor reflect the state of degree of nourishment, sexual maturity, and in some instances, the age (Williams, 2000).

The condition factor is used as an indicator of the well-being of individual organisms. It compares the wellbeing of a fish based on the hypothesis that heavier fish of a given length are in better condition (Abowei, Davies and Eli, 2009). Further, Abowei op cit note that the condition factor decreases with increase in fish length and influences the reproductive cycle in fish. Because it integrates many levels of sub-organismal processes, condition factor may signify the overall condition and nutritional status of fish community (Adams *et al.*, 1992).

For the purpose of condition factor, weight determinations are made on live or freshly killed fish. This factor is calculated from the relationship between the weight of a fish and its length, with the intention of describing the condition of that individual. The value varies directly with nutritional status and inversely with disease (Schmitt and Dethloff, 2000). Greenfields, Hrabik, Harvey and Carpenter, (2001) observed that body condition changes rapidly in response to environmental perturbation and is more indicative of prevailing environmental constraints to growth than measures of past growth. Condition factor is known to vary with seasons, possibly as a response to changing food resources, metabolic efficiency, or gonadal status (Owiti, 1986; Doyon, Downing, and Manin, 1988).

2.3 Rice culture

Rice, an annual grass (Gramineae), belongs to the genus *Oryza* that includes twenty wild species and two cultivated species, *O. sativa* (Asian rice) and *O. glaberrima* (African rice) with three subspecies, or races that are recognized, namely: *japonica, indica* and *javanica* (Kouko, 1997). These two species are respectively native to tropical and subtropical southern Asia and southeastern Africa (Halwart and Gupta, 2004). *O. sativa* is the most commonly grown species of rice throughout the world today (Kouko, 1997).

Rice is grown in irrigated, rainfed lowland, flood-prone, and upland ecosystems (Halwart, 1998; Halwart and Gupta, 2004; Kega. and Maingu 2010). The irrigated rice ecosystem, with approximately 81 million hectares worldwide, accounts for 53% of the world's harvested area of rice and produce 76% of the global rice (Halwart, 1998). In Kenya, rice is an important staple crop, ranking third after maize and wheat and most of its production is by small-scale farmers as food and commercial crop (Kimani, Tongoona, Derera, and Nyende, 2011).

Globally, farmers select rice varieties for their suitability to agroclimatic conditions. Past increases in rice yields was noted by Halwart (1998) to have mainly come from use of the high yielding varieties that are short, stiff-strawed, fertilizer responsive, and have short to medium growth duration (100-130 days). This poses a challenge to rice-fish culture that requires the use of long-stemmed and long-maturing varieties to allow for a higher water level and an extended period for fish farming.

The area under rice cultivation in Kenya ranged from 13,200 hectares in the year 2003 to 23,106 hectares in 2006 (GOK, 2009) with between 80% - 84% of this area being under irrigated rice (Mati, No Date; GOK, 2005/06; Theuri, 2007; GOK, 2009; Kimani, *et al*, 2011; Emongor, Mureithi, Ndirangu, Kitaka and Walela, 2013). The total annual rice production, that Kimani *et al*, (2011) notes to have stagnated at around 45,000 - 80,000 metric tonnes, is therefore in favour of irrigated rice (95%) with a yield of about 4-6 metric tonnes ha^{-1}. Within Nyanza Region irrigated rice cultivation cover 3520 hectares in East Kano (Ahero) and West Kano Irrigation Schemes (Emongor *et al.*, 2013) where the average yield (tonnes ha^{-1}) is 2.63 for East Kano and 2.73 for West Kano (GOK, 2010).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The study was conducted at Ahero Rice Research Station situated within the East Kano Rice Irrigation Scheme in Nyando District of Western Kenya (0^0 08' S and 34° 56' E; Fig. 1). The East Kano Rice Irrigation Scheme has a total area of 1,538 Ha, of which approximately 880 Ha are under irrigated rice cultivation. Commercial rice cultivation is the main activity in the scheme. The irrigation water is pumped from Nyando River from a point approximately 7 km from the rice research station. The rainfall pattern of the area is bi-modal; with the first season being in the months of March, April and May while the second is in September to November. The mean annual maximum temperatures range from 25°C to 30°C and the mean annual minimum temperatures from 15°C to 18°C. The area was selected due to its commercial rice cultivation system that can allow for integration with fish culture.

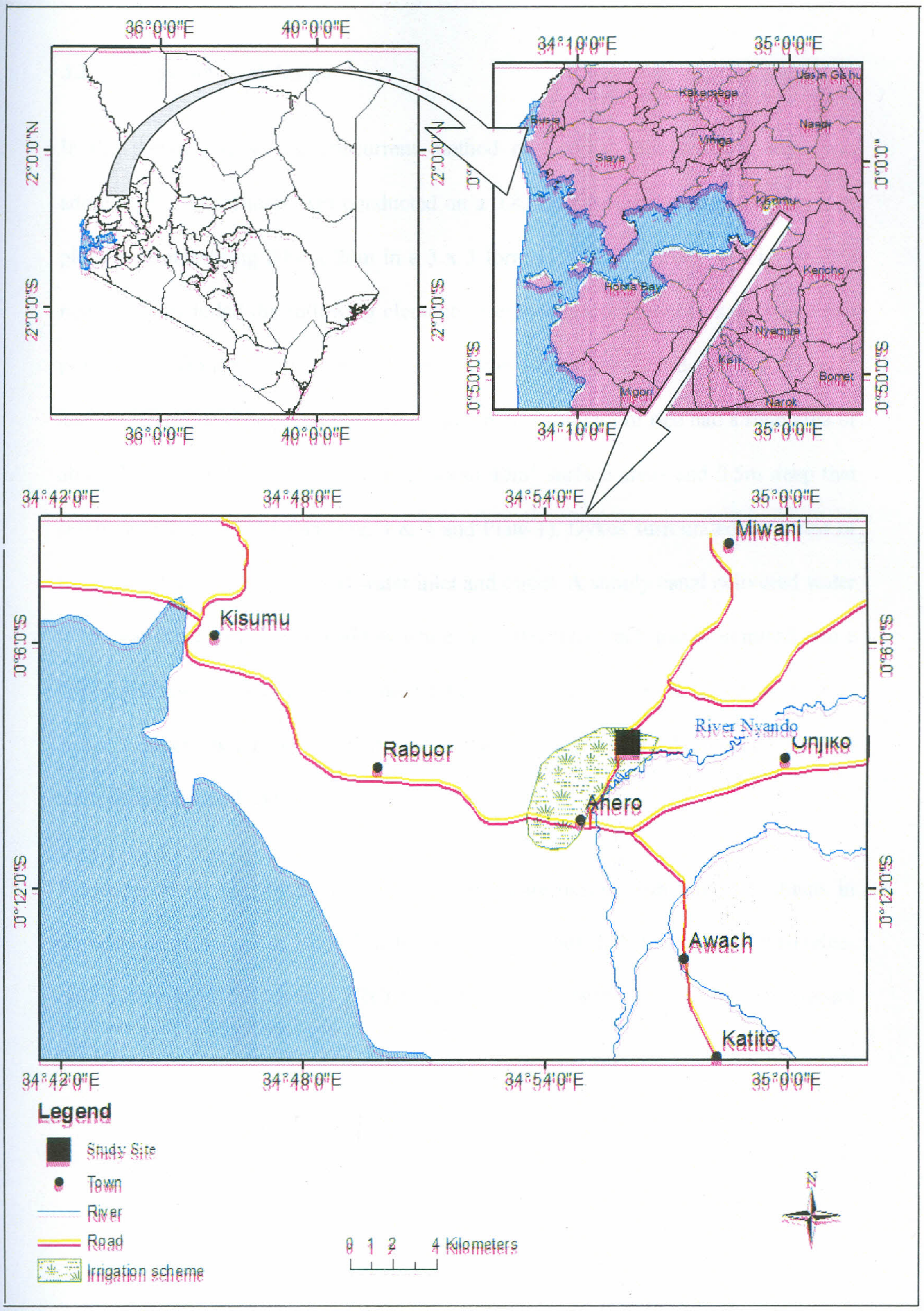

Figure 1: Map of the Study Area showing the East Kano Rice Irrigation Scheme (Developed by J. Bolo)

3.2 Experimental design

In the present study, the concurrent method of rice-fish production system was adopted. The experiment was conducted on a 0.81-hectare farm subdivided into nine plots each measuring 20m x 20m in a 3 x 3 formation (as illustrated in Fig. 2). The rice paddy included the following elements: elevated embankment to keep water and prevent fish from escaping; and refuges to provide shelters. There was a 1.5m wide and 1m deep side channel all round the entire plot. Each plot of rice had a field area of about 320m^2 and two trenches each of about 40m^2 surface areas and 0.5m deep that served as refuge for the fish (Fig. 3 & 4 and Plate 1). Dykes surrounded each plot of rice where there was a screened water inlet and outlet. A supply canal delivered water to the various experimental paddies while an outlet from each paddy emptied into a larger drainage canal. The experimental field was fenced using a 1-inch wire mesh and a 3-meter border kept free of bushes and weeds to ward-off predators such as otter, monitor lizard and humans.

The experiment was conducted using a latin square design with three treatments in triplicate as explained in Table 2 as follows: (i) rice-catfish & tilapia (RCT); (ii) rice-catfish culture in low density (RCL); and (iii). rice-catfish culture in high density (RCH).

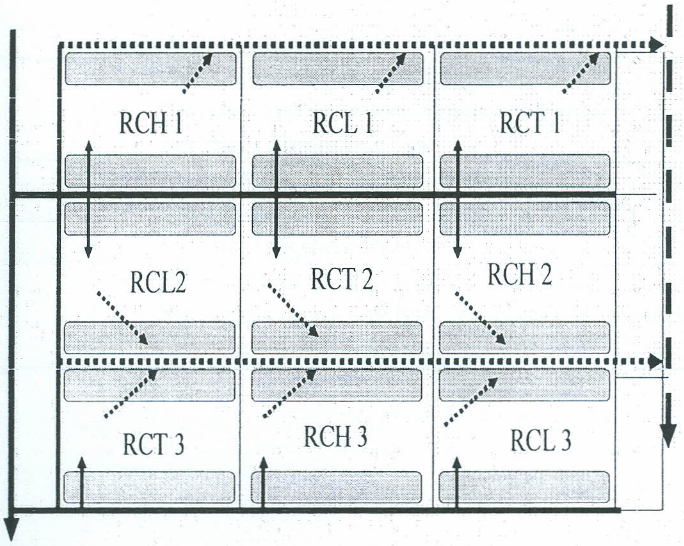

Figure 2: Experimental layout for the Ahero integrated rice-fish farm.

Where: RCL - Rice- catfish culture in low density; RCH - rice-catfish culture in high density; and RCT - rice-catfish & tilapia polyculture.

The arrows show the drainage system, viz. water intake (solid arrows) and exit (broken arrows).

Table 2: Stocking rates and treatments applied to different plots during the present study

Treatment	Details of treatment
RCL	- Rice-catfish culture replicates - Catfish stocked in low density (4 fish/m^2) - Fertilizer applied on rice
RCH	- Rice-catfish culture replicates - Catfish stocked in high density (8 fish/m^2) - Fertilizer applied on rice
RCT	- Rice- catfish & tilapia culture replicates - Stocking rate of 4 fish/m^2 for each fish species - Fertilizer applied on rice

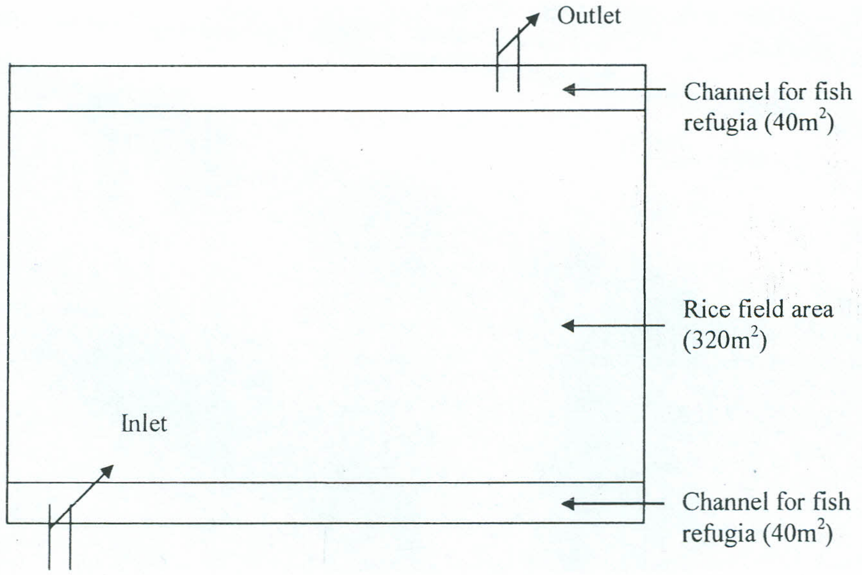

Figure 3: Plan drawing depicting a rice paddy at the experimental site

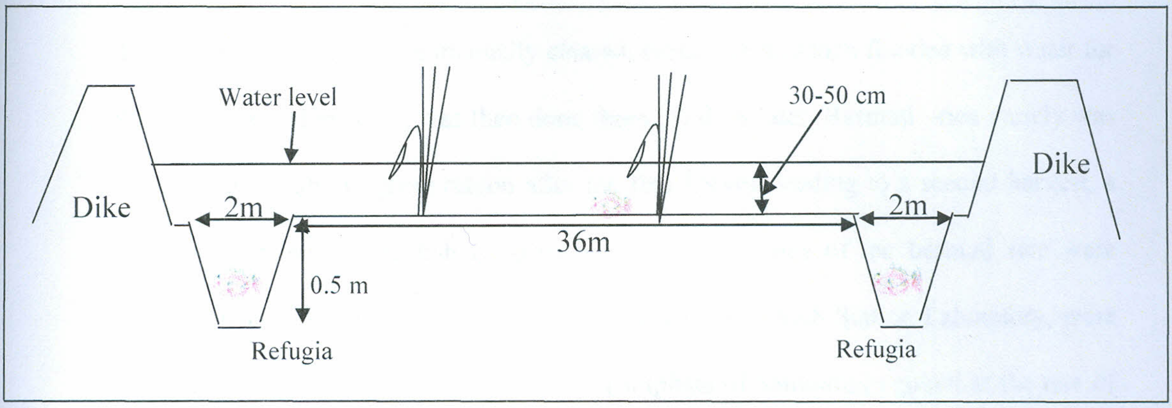

Figure 3: Cross-sectional layout of a rice field showing the refuge trenches at the experimental station in Ahero.

Plate 1: Photograph of the research plot showing the rice paddy and the refugia (water medium in the fore ground). The rice (middle ground) is only a few weeks from harvesting. (Photo by J. Bolo).

3.3 Farm Preparation and Management

The experimental farm was manually cleared, ploughed, and then flooded with water for three (3) days. Harrowing was then done three (3) days later. Basmati –rice variety was used due to its ability grow ratoon after the first harvest leading to a second harvest, a situation that enable the fish to grow to table size. Seeds of the basmati rice were obtained from National Irrigation Board Ahero Rice Research Station Laboratory, were then planted in nursery beds and fertilizer (Sulphate of ammonia) applied at the rate of 18 Kgs/acre. Seedlings raised in the nursery were transplanted, on the 22nd day after planting, at 20cm x 20cm spacing between rows following the methods and recommendations by Yaro *et al.* (2005). On planting, fertilizer was applied at the same rate as had been done in the nursery. Prior to transplanting, the field was flooded with water and kept flooded all the times until the first rice harvest. Before rice tillering, water level in the paddies was kept at a minimum depth of 5 cm and then on to 30 - 50 cm until harvesting. The rice was harvested 82 days after transplantation, and the ratoon led to a second harvest after another 52 days

3.4 Sampling and Data Collection

3.4.1 Fish Growth Parameters

On the 14th day after transplanting rice, catfish fingerlings weighing 16 ± 0.4 g and of 9.5 ± 1.7 cm length and tilapia fingerlings weighing 10.0±0.1g and of 6.5 cm length that were sourced from Lake Basin Development Authority (LBDA) Fish Farm at Kibos near Kisumu, were stocked into the refugia (Fig 3 & 4) after a six- hour acclimatization. Three treatments consisting of different stocking densities and species combinations (Table 2) were tested. There were three replicates per treatment and the replicates were allocated randomly among the nine plots in the experimental field. To monitor fish condition and growth, sampling was done in the pond refugia by netting A day prior to sampling, water in the paddy was drained, save for the fish refuge, to ensure that the fish were confined within the refuge area. The fish sampling process was done through seining that covered the bottom of the refugia. Measurements of length and weight were taken monthly, using a graduated measuring board and weighing scale respectively, where 32 catfish each in RCL and RCH , and 16 catfish and 16 tilapia in the RCT were measured per plot per sampling and used to determine the specific growth rate, survival and the condition factor of the fish. The Specific Growth Rate (SGR%) was calculated using Brett and Groves (1967) formula:

$$\mathrm{SGR} = \frac{(\mathrm{InW}_2 - \mathrm{InW}_1) \text{ X } 100}{(t_2 - t_1)}$$

Where:- t_1 and t_2 are the start and end period of culture respectively in days,

-W_1 and W_2 are the mean initial and final weight for the same period, and

- InW_1 and InW_2 are natural logarithms of weights at stocking and harvesting respectively.

Weight gains (%) were calculated according to the formula:

$$\text{Weight gain} = \frac{(\text{final weight} - \text{stocking weight}) \text{ X } 100}{\text{Stocking weight (g)}}$$

Survival rate was calculated as the percentage of the number of fish at complete harvest to the number stocked (Rothius, 1998):

$$\text{Survival} = \frac{\text{Nt X } 100}{\text{No}}$$

Where,

Nt = total number of fish harvested

No = total number of fish stocked.

The condition factor, on the other hand, was calculated according to the Fulton's condition factor formula that was first used by F. Heincke as a measure of the condition of fish (Nash, Valencia, and Geffen, 2006):

$$K = \frac{W \times 10^5}{L^3}$$

Where,

W = weight in grams

L = length in millimeters

10^5 is the correction factor that brings K to near unity

All the fish were harvested and measured 122 days after stocking. The harvests from replicates of same treatment were pooled together to obtain the total treatment production. Net Fish Yield (NFY) was calculated by dividing the weight of fish harvested in a pond by the surface area of the pond.

3.4.2 Rice Production

At the end of the cropping season, rice was harvested, processed and weighed. Harvests from different replicates of the same treatment were pooled to obtain the total treatment production. The data obtained was used to calculate the net rice yield and determine the production potential for the different treatments.

3.4.3 Water Quality Assessment

Water quality parameters [temperature, dissolved oxygen (DO), pH, turbidity, alkalinity, conductivity, soluble reactive phosphates (SRP), nitrate (NO_3-N) and ammonia (NH_4-N)] were monitored monthly in the paddies. Mid-morning sampling of water, temperature, DO, pH, turbidity, and conductivity were taken in the field, while water samples were also collected separately for laboratory analysis for hardness, alkalinity, and the levels of nitrate, ammonia and SRP. The laboratory analyses were done at the Kenya Marine and Fisheries Research Institute Laboratories in Kisumu following the methodologies outlined in APHA/AWWA/WEF (1999) and Makcereth, Heron and Talling, (1989).

In situ measurements of temperature, DO, conductivity and pH were taken using a hand held YSI sample analyzer model TSI 3500i that was lowered to uniform depth of 20 cm below the water surface in the refugia. For refugia turbidity determination, model HACH 2100P-470 turbidimeter from Jenway was used to take measurements *in situ*. The turbidity measurements were taken in Nephelometric Turbidity Units (NTU).

Alkalinity was determined on 100 ml-volumes of samples. The water sample was titrated against a 0.02 N Sulphuric acid solution to get an estimate of the acid-neutralizing capacity of the refugia waters, using methyl orange as an indicator. Determination of ammonia nitrogen was done on 20 ml of pre-filtered water sample in a 50-ml Erlenmeyer flask where 1 ml of phenol was added followed by 1 ml of 0.5% Nanitroprusside which was in turn followed by 2.5 ml of oxidizing solution. Standard solution of 0.00, 0.50, 1.00, 1.50 and 2.00 mg/l as ammonia nitrogen was prepared with NH4Cl salt and de-ionized water from a stock solution of 100mg/l ammonia nitrogen concentration. All the standards and sample were then covered with Para film and placed in the dark for one hour for colour to develop. Absorbance was then measured at 640 nm on a spectrophotometer.

For nitrite determination, as per the methods described by APHA/AWWA/WEF (1999) and Mackereth *et al.* (1989), 0.5 ml of diazotizing reagent was added to 25ml of filtered water sample in a 100-ml beaker, stirred and allowed to stand for two minutes for complete reaction. Thereafter, 0.5 ml of coupling reagent was added, stirred and left to stand for 10 minutes to form azo-compound. Absorbance was then measured at 543 nm after calibrating the spectrophotometer.

For determination of soluble reactive phosphate, one drop of Phenolphthalein indicator was added to 25 ml water samples in 125-ml Erlenmeyer flasks. Drops of 5 N H_2SO4 were added to samples where red colour developed until the red colour disappeared. 4 ml of combined reagent was added and stirred. The set up left to stand for 30 minutes to allow for colour development. Absorbance was then measured at 880 nm using distilled water reagent blank to zero spectrophotometer according to the method described by APHA/AWWA/WEF (1999).

In the case of each parameter, three replicate measurements were used to compute the mean values. Monthly mean averages were subsequently pooled to obtain the treatment averages.

3.5 Statistical analysis

To establish the variations in the culture systems, stocking density, fish growth and production responses, Analysis of Variance (ANOVA) was conducted and multiple range testing of the mean carried out using Turkeys LSD whenever there was a statistically significant difference.

CHAPTER FOUR

4.0 RESULTS

4.1. Effects of culture type on productivity

1.1.1. Fish Growth

The growth performance and production data on catfish (*C gariepinus*) and nile tilapia (*O. niloticus*) are shown on Table 3. The catfish grown under high-density conditions (RCH) had mean weights of 136±11.2 g, those in low density (RCL) had 150.3±6.4 g and the polyculture (RCT) had fish weights of 156.9±9.09 g. The tilapia mean weight was 105.4 ± 7.05g. There was a significant difference in growth (weight) of catfish in the three systems used (ANOVA; $P < 0.05$) where fish grown under high-density conditions had lower growth rates than those in low density or polyculture conditions.

1.1.2. Fish survival

Recorded survival rates of catfish (Table 3) were 61.3% in the low culture system (RCL), 46.53% in the polyculture system (RCT) and 42.17% in the high- density (RCH) condition. For tilapia, the survival rate was 47.4%. The low culture system recorded significantly better survival rates (ANOVA; $p<0.05$) than in the polyculture and high-density conditions.

1.1.3. Fish condition factor

As shown in Table 3, the relative condition factor of catfishes was 0.79 in the polyculture system (RCT), 0.77 in the high-density (RCH) condition and 0.61in the low culture system (RCL). As for tilapia, the condition factor was 0.63. The relative condition factor was below average for all the three treatments.

1.1.4. Specific Growth Rate

The catfish Specific Growth Rate was 1.8 in the polyculture system, 1.8 in the low-density culture, and 1.7 in the high-density condition while that for tilapia was 1.7 (Table 3). The specific Growth Rate therefore remained the same in all the three systems.

Table 3: Mean stocking size, stocking rates, growth performance and production of fish and rice at different stocking densities and species combinations.

		TREATMENT			
		RCT		RCL	RCH
		Catfish	Tilapia		
Stocking	Density (fish/m^2)	4	4	4	8
	Total No. stocked	1440	1440	1440	2880
	Weight (g)	16.6±0.2	10.0±0.1	16.0±0.1	16.2±0.4
Harvest	No. fish recovered	671	682	883	1215
	Weight (g)	156.9±9.09^{a}	105.4±7.05	150.3±6.4^{a}	136.1±11.2^{b}
	Survival (%)	46.5^{a}	45.4	61.3^{b}	42.2^{a}
	Condition Factor	0.79	0.63	0.61	0.77
	SGR	1.8	1.7	1.8	1.7
Plot Production (Kg/ha)	Fish Yield	373.16^{a}	156.3	236.26^{b}	288.88^{b}
	Mean Rice Yield per harvest (Integration) *	1650^{a}		1448^{ab}	1348^{b}

Values for the same parameter with same superscript are not significantly different.

* There were two rice harvests during the study period.

1.1.5. Fish Yield

The recorded yields for catfish were 373.16 kg/ha in the polyculture system, 288.88 kg/ha in the catfish high-density system and 236.26 kg/ha in the low-density culture. The yield for tilapia was 156.3. The polyculture system yielded significantly more

(ANOVA; $p<0.05$, Table 3) fish compared to the catfish high-density condition and low-density culture. The yields in the polyculture condition were 23 per cent higher than that of high-density and 37 percent higher than low-density systems.

1.1.6. Rice yield

As indicated in table 3, the mean recorded rice yield was 1650 kg/ha, 1449 kg/Ha, and 1348 kg/Ha for RCT, RCL and RCH respectively. This translates to a total of 3350 kg/Ha, 2898 Kg/Ha and 2696 Kg/Ha for RCT, RCL, and RCH respectively for the whole production period of 134 days. Rice yield was significantly higher (ANOVA; $p<0.05$) in the polyculture system than in and high-density culture system.

4.2. Effect of culture system on water quality

4.2.1. Water turbidity

The recorded mean turbidity values (Table 4) in the treatments ranged from 56.0±92.7 NTU in the polyculture system (RCT) to 65.0±86.4 NTU in the low-density condition (RCL) with 63.9±76.6 NTU in the high-density condition (RCH) falling in between. The measurements in the three experimental treatments showed no significant variations (ANOVA; $p>0.05$).

4.2.2. Water Conductivity

Mean water conductivity measurements in the culture systems (Table 4) were 312.67±16.15 Ohm in the polyculture (RCT), 304.93±21.94 Ohm in the lo-density (RCL) and 302.67±17.57 Ohm in the high-density. The mean conductivity in the culture systems did not elicit any significant difference (ANOVA: $p>0.05$).

4.2.3. Water temperatures

The recorded mean water temperatures (Table 4) in the three rice-fish systems were 24.5±1.0 ^{0}C in the polyculture (RCT), 24.4±1.0 in the low-density (RCL) and 24.4±1.3in the high-density. There was no significant difference (ANOVA; $p>0.05$) in mean water temperatures in the three rice-fish systems under investigation.

Table 4: Pooled Mean monthly (mean ± SD) water quality measurements for the Ahero rice-fish culture system during the experiment study.

PARAMETER	TREATMENT			ACCEPTABLE LEVELS*
	RCT	RCL	RCH	
Turbidity (NTU)	56.0±92.7	65.0±86.4	63.9±76.6	<30 NTU
Conductivity Ohm/s	312.67±16.15	304.93±21.94	302.67±17.57	--
Temperature ^{0}C	24.5±1.0	24.4±1.0	24.4±1.3	>22 ^{0}C
DO (mg/l)	3.9±1.2	4.1±1.7	3.8±2.0	>3.0 mg/l
pH	7.9±0.5	8.0±0.4	8.0±0.3	6.5 – 9.0
Alkalinity	161.3±4.7	164±25.2	157.5±26.8	>30 mg $CaCO_3$
NO_4-N (µg/l)	52.9±21.5	49.0±27.6	57±24.4	<20 µg/l
NO_2-N (µg/l)	19.8±1.6	19.8±4.3	21.6±3.7	<50 µg/l
SRP (µg/l)	29.1±17.9	32.3±21.0	29.5±15.5	<200 µg/l

*The acceptable levels are based on APHA/AWWA/WEF (1999) water quality criteria

4.2.4. Dissolved Oxygen

The mean dissolved oxygen was 3.9±1.2 mg/l in the polyculture system (RCT), 4.1±1.7 mg/l in the low-density condition (RCL) and 3.8±2.0 mg/l in the high-density condition (RCH) as illustrated in Table 4. Even though the amount of dissolved oxygen was higher in low-fish density system as compared to that in fish-polyculture system and fish-monoculture high-density system, the observed differences were not significant (ANOVA; $p>0.05$).

4.2.5. Water pH

The recorded mean water pH within the refugia (Table 4) was 7.9±0.5 in the polyculture system (RCT), 8.0±0.4 in the low-density system (RCL) and 8.0±0.3 in the high-density system (RCH). The mean water pH in the three treatments of the experiment exhibited no significant variations (ANOVA; $p>0.05$).

4.2.6. Alkalinity

Mean alkalinity measurements in the culture systems (Table 4) were 161.3±4.7 in the polyculture (RCT), 164±25.2 in the low-density (RCL) and 157.5±26.8 in the high-density. There was no significant variation (ANOVA; $p>0.05$) in the recorded water alkalinity value in the three treatments.

4.2.7. Ammonium (NH_4-N) levels in water

Ammonium levels (Table 4) in the water in the three systems ranged from 49.0±27.6 µg/l in the low density system (RCL) to 57±24.4 µg/l in the high density system (RCH) with no significant differences (ANOVA; $p>0.05$) between the values.

4.2.8. Nitrate ($NO_2 - N$) levels

The recorded mean values for the levels of Nitrate ($NO_2 - N$) were 19.8±1.6 μg/l in the polyculture system (RCT), 19.8±4.3 μg/l in the low-density system (RCL) and 21.6±3.7 μg/l in the high-density condition. No significant differences (ANOVA; $p>0.05$) were noted in the recorded levels of Nitrate ($NO_2 - N$) between the different treatments.

4.2.9. Soluble Reactive Phosphates (SRP) levels in water

Mean recorded levels of Soluble Reactive Phosphates (Table 4) were 29.1±17.9 in the polyculture system (RCT), 32.3±21.0 in the low-density system (RCL) and 29.5±15.5in the high density system. The mean levels 32.3±21.0 did not vary significantly (ANOVA; $p>0.05$) between the three different systems used in the experiment.

CHAPTER FIVE

5.0 DISCUSSION

In agricultural production, integration of production systems has been identified as an avenue of improving productivity. Rice–fish integration worldwide is practiced at various levels with varying results. The current study brings together a rice production system integrated with fish (catfish and tilapia). In the rice-catfish-tilapia integration system, yields were 3.30 tonnes per hectare for rice, 0.375 tonnes per hectare for catfish and 0.156 tonnes per hectare for tilapia for the period of the study of 122 days for fish and 134 days for rice. Trials under the rice-catfish low-density system and rice-catfish high-density system, of this same study, presented lower yields for both fish and rice. These results were significantly lower for fish yields when compared to the yields under the rice and fish-polyculture integration.

In this present study, comparing treatments with same fish stocking densities (rice-catfish-tilapia and rice-catfish high-density), higher yields were attained where different fish species were cultured together. This observation could be attributed to a number of factors. In the situation of fish polyculture, competition amongst the fishes is limited given that the two fishes occupy different niches in line with what (Rothuis, Duong, Richter and Ollevier, 1998c) noted that competition for natural food among fishes is unlikely in situations where trophic niches are distinguished. The predatory habits and high growth rates of catfish (De Graaf and Janssen 1996) befits the rice-fish polyculture system further by the fish, being an omnivorous predator, feeding on tilapia juveniles thereby keeping check on the density. In this process, part of the biomass in the tilapia is transferred to catfish, and in combination with its high food conversion ratio, the growth of the fish escalates. The catfish, being a bottom dweller, also improves nutrient cycling through bottom soil perturbation and aeration (Rothuis *et al*, 1998c) within the system. This acts as a feedback mechanism on productive capacity in the tilapia through increased phytoplankton productivity and increased food availability as was reported by Vromant *et al* (2000). The churning effect of catfish in the paddy could probably benefit the tilapia filter feeder by readily availing detritus from the bottom. Low production in situation where rice was integrated with catfish in low-fish density (4 fish m^{-2}) could be attributed to the absence of this synergy.

The presently observed high yields for both rice and fish in rice-catfish-tilapia integrations could be a result of the interaction between the two fish species and the nutrient supply to the rice. The two fish species are probably greatly responsible for nutrient supply in this system through excretory processes in line with Sule et al (2007) who were of the opinion that fish feaces in the paddy serves as organic manure that is important in the addition of nutrients to the soil apart from the improvement of soil texture. The churning behavior of catfish possibly unlocks the nutrients in the fish droppings thereby readily availing the same for use by the rice. Also important for the rice is the timely control of weeds and pests, by the fish, that could otherwise reduce rice crop production. As the rice utilizes the nitrogen from the fish feaces it therefore makes the water cleaner for the fish. In the situation where rice and catfish were integrated under high-fish density, low rice production was observed which may be a case of negative synergy. Churning by a relatively higher number of catfish may result in counter-productive results given that the churning may be overdone thereby interfering with roots and subsequent nutrients uptake by rice plants. The same reasoning could be alluded to in the situation where rice and catfish were integrated in low-fish density.

For same fish stocking densities, fish survival was low in both the rice-catfish-tilapia integration (46.5% - catfish and 45.4% - tilapia) and the integration of rice-catfish in high density (42.2%). This relatively low survival rate of the fish may be attributed to a number of factors one being the cannibalistic habit of catfish where it preys on the small tilapines while the more aggressive amongst the catfish (shotters) preying on the less aggressive ones. The possibility of the shooters preying on their own may had been aggravated by nutritional inadequacies in the system arising from no supplementary feeding to the fish. Environmental conditions may also have contributed to the low fish survival rates with the higher than the acceptable levels (between 49 μg/l - 57 μg/l while acceptable level is less than 20 μg/l) of ammonia-nitrogen for fish that prevailed within the various treatments. These high levels that may have been brought about by excessive fish dropping, among other nitrogenous organic wastes, can present significant obstacles to fish growth and survival.

Work undertaken by various authors in different regions of the tropics, which integrated different fish species with various rice varieties, observed varying results as illustrated in Table 5. The yields under these previous studies on fish-rice integration vary from 1.4 to 7.3 tonnes per hectare of rice and 0.1 to 2.2 tonnes per hectare of fish. These wide variations observed could be attributed to the treatment systems and ecological conditions. Highest rice yield under field experiment was reported in Mekong delta, Vietnam by Rothius (1998) and Vromant *et al* (2002) while that for fish is that reported by Kingmin (1988) working in China. Rasowo and Auma, (2006) working in West Kano Irrigation Scheme in Kenya recorded yields of 4.72 tonnes of rice per hectare and 0.13 tonnes of fish per hectare. In the present study, the recorded yields in the rice-fish polyculture system were 3.3 tonnes of rice per hectare and 0.53 tonnes per hectare for fish in total. In a stand-alone rice production, GOK (2010) has recorded an average rice yield of 2.63 and 2.73 tonnes per hectare in East Kano and West Kano irrigations schemes respectively.

Table 5 Rice and fish productivity in integrated systems as reported for various countries

Country	Type of study	Rice yield (tonne/ha)	Fish yield (tonne/ha)	Fish species	Reference
Vietnam	Field experiment	1.8-7.3	0.3 – 0.5	*C. carpio* *Barbonymus gionootus* *O. niloticus*	Rothius., 1998; Vromant *et al.*, 2002
	Socio-economics	4.2-4.5	0.3 – 0.5	*C. carpio* *B. gionootus* *O. niloticus*	Berg, 2002
Bangladesh	Field experiment	--	0.2 – 0.3	*B. gionootus* *O. niloticus*	Haroon and Pitman, (1997)
	Field experiment	1.5-3.7	0.3 – 0.6	*C. carpio* *O. niloticus*	Frei *et al*, (2007)
India	Field experiment	3.0-3.6	0.9 – 1.3	*Clarias catla* *C. mrigala* *Labeo rohita* *C. carpio*	Mohanty *et al.*, (2004)
Various	Review	--	0.1 – 1.8	*Various*	Halwart and Gupta, (2004)
China	Review	--	0.2 – 2.2	*C. carpio* *B. gionootus* *O. niloticus*	Kangmin (1988)
Kenya	Field experiment	4.72	0.13	*O. niloticus*	Rasowo and Auma, (2006)
	Field experiment	2.7-3.3	0.2 – 0.4	*C. gariepinus* *O. niloticus*	Present study

From the foregoing, it is clear that the yields could extremely be varying. Whereas the prediction in a model by FAO/UNDP/LBDA (1999) gives a fish yield of 9 tonnes per hectare in fish polyculture system in the region where this study was undertaken, this has not been attained in stand-alone systems. The total fish yield under the rice-catfish-tilapia integration of 0.53 tonnes per hectare depicted in this study falls within the range of observed value of the various authors. Rasowo and Auma (2006) integrating rice with tilapia and working in the same area as of the present study recorded a fish yield of 0.13 tonnes per hectare. Comparing the results of this current study with that of Rasowo and Auma (2006), the synergy of integration is clearly exhibited.

This present study observed a total rice yield of 3.3 tonnes per hectare under the rice-catfish-tilapia integration, a figure that is 670 Kg above those reported in stand-alone rice systems for the same area (GOK, 2010). Leaving alone the benefits accruing from fish as a crop, this higher rice yield alone presents a positive net benefit. Working in this area, Rasowo and Auma (2006) recorded a rice yield of 4.72 tonnes per hectare after 77 days in rice-tilapia integrated system. This is about 1.4 tonnes per hectare higher than the values observed in the 122 days of in the current study. However, comparing the two production systems in totality, the work by Rasowo and Auma (2006) records 4.72 tonnes of rice and 0.13 tonnes of fish per hectare of production system while this present study yields 3.3 tonnes of rice and 0.53 tonnes of fish per hectare of production. The system used by Rasowo may therefore not out-compete the rice-fish-polyculture system of the current study in the long run given the difference in the economic value of the produce (fish and rice).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The findings of this study support the idea of integrating fish culture with rice farming in East Kano Irrigation Scheme with positive effect on the overall farm productivity and have the potential to impact positively on farm economy in that:

i. Higher fish production rates are obtained in the rice and fish-polyculture system suggesting that it is not only possible, but actually desirable to culture more than one fish species in an integrated rice-fish culture in East Kano Irrigation Scheme.

ii. Integration of rice and fish, and more so in the rice and fish-polyculture, increases rice production in East Kano Irrigation Scheme.

6.2. Recommendation

The fish involved in the current study did not get any supplementary feeds but still posted finding that compare well with studies that had been undertaken in other locations where some had supplementary feed while others did not. Investigation on the effect of giving supplementary feeds to fish in rice-fish polyculture integration is therefore recommended.

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