INTEGRATED

WATER AND NUTRIENT MANAGEMENT IN IRRIGATED KANO PLAIN'S PADDY FIELDS, KENYA

BY

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DECLARATION

Declaration by the Student

I declare that this thesis is my original work and has not been presented for examination in any other University. No part of it may be reproduced without prior written permission from the author and/ or Chepkoilel University College, and all works referred to from this thesis must be acknowledged.

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DEDICATION

To my parents Mr. Noah K. Kipkabuch and Mrs. Evelyne K. Kaboch who were patient with me during this study and gave me encouragement, moral support and unrelentingly prayed for me.

ABSTRACT

Water shortage and paddy field nutrient (nitrogen) depletion are major constrains to sustaining and increasing rice (*Oryza sativa* L.) production in Kano plains, Kenya. Scarcity of water resources and increasing cost of conveying to paddy field calls for proper *in situ* water management towards reducing volume used per unit rice field. On the other hand high cost of commercial fertilizer makes rice farming expensive to many peasant rice farmers. As a response, an experiment was initiated with an objective to study effect of local inputs (rice straw, Azolla and fish culture- droppings) on some soil physico-chemical properties, nitrogen uptake, rice growth, yields and paddy field water requirement, when the inputs were used as nitrogen supplement to farmers’ practice (58kgN-Urea/ha).The experiment was conducted in West Kano Irrigation Scheme Kisumu County, consisting of three treatments and a control (farmer’s practice), laid out in a Randomized Complete Block Design (RCBD), replicated three times. Sample collection and characterization were done using standard procedures. Data was managed using Microsoft Excel software. Analysis of variance between treatments on the mentioned soil and rice attributes was carried out using General Statistical (GENSTAT) computer software and means separated with LSD ($p \leq 0.05$). Significant difference in nitrogen uptake ($p \leq 0.05$) were obtained in treatments; Azolla>fish-culture>farmers’ practice> rice straw. This was reflected in rice biomass accumulation and yield of 4.3, 3.8, 3.6 and 3.0 ton /ha respectively. Effective hydraulic conductivity induced by change in soil bulk densities was significantly different ($p \leq 0.05$) in the treatments; rice straw>Azolla>fish-culture>farmers’ practice, that of straw being exceptionally higher translating to treatment with the highest paddy-field water requirement (20.3 Megalitres/ha). The paddy field water requirements of Azolla and Fish-culture were significantly lower due to other factors that affected paddy- field water balance. Azolla and fish-culture treatments were considered to have potential to increase paddy rice production in Kano plains.

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CHAPTER ONE

INTRODUCTION

Rice is the seed of the monocot plants *Oryza sativa* (Asian rice) or *Oryza Glaberrina* (African rice). As a cereal grain, it is the most important staple food for a large part of the world's human population, especially in Asia and the West Indies. It is the grain with the second-highest worldwide production, after maize, (FAO, 2006).

World production of rice has risen steadily from about 200 million tonnes of paddy rice in 1960 to over 678 million tonnes in 2009. The three largest producers of rice in 2009 were China (197 million tonnes), India (131 million tonnes), and Indonesia (64 million tonnes). Among the six largest rice producers, the most productive farms for rice, in 2009, were in China producing 6.59 tonnes per hectare (FAOSTAT, 2012). India on the other hand had the largest rice farm, 44 million hectares, with 45% productivity compared to China. The average world yield for rice stands at 4.3 tonnes per hectare (FAO, 2012).

As of 2010 world food consumption of rice was 354,603 thousand metric tonnes, China and India consuming 29.4 and 23.3% respectively (FAO, 2012). Between 1961 and 2002 the world per capita rice consumption increased by 40%. Rice is the staple food of over half world's population. It is the predominant dietary energy source for 17 countries in Asia and the pacific, 9 countries in North and South America and 8 countries in Africa. Rice provides 20% of the world's dietary energy supply, while wheat supplies 19% and maize 5% (FAO, 2004)

Rice is the third consumed cereal in Kenya after maize and wheat (CBS, 2010). The annual consumption of rice is between 180,000-250,000Metrictonnes against a local production of 35,000-50,000 Metrictonnes and the deficit is made by importation from Asian countries (NCPB, 2011). 80% of local production is produced under paddy system while the remaining is grown as upland crop (Government of Kenya (GoK, 2010)). Unlike maize, rice was not a staple food for most Kenyans except for communities along the Indian Ocean and North eastern parts (CBS, 2001). Until recently, rice was eaten mainly on special occasions by the average Kenyan family. However, the trend has changed and rice is now a regular dish, especially among urban communities. Consequently, the very rapid growth of urban population has placed a strain on rice availability.

The total rice cropped area and grain rice production in the world were 147 million hectares and 587.28 million tonnes respectively, in 2009 (International Rice Research Institute (IRRI, 2010)). Rice farming is practiced in several Agro-Ecological Zones (AEZs), although confined in; warm-cool humid subtropics (AEZ 7), warm humid tropics (AEZ 3) and in warm sub-humid tropics (AEZ 2). IRRI (1993) has further categorized rice land ecosystem into four types; irrigated rice ecosystem, rain-fed lowland rice ecosystem, upland rice ecosystem and flood-prone rice ecosystem. Apart from the upland ecosystem the others are under wet cultivation. Irrigated lands cover over half of the world's rice land and produce about 75% of the world's rice supply (IRRI, 2004). In Kenya rice is grown in irrigation schemes managed by the National Irrigation Board

(NIB), a statutory board of the Government of Kenya (GoK, 2010). At present there are four such schemes. The largest and oldest Mwea with 5700 ha is located in the Mwea plains to the south of Mt. Kenya The other three, Ahero with 500 ha, West Kano with 500 ha and Bunyala with 300 ha, are located within the Lake Victoria basin (NIB, 2009). These four cover about 8000ha (GoK, 2010). Mwea the largest single scheme of 5700ha is irrigated by gravity, but in the other schemes, water is pumped from rivers or the lake (Njokah, 1985). Land is mechanized and crop management standardized by NIB (Manager NIB; personal communication). The schemes are located at about 1100-1200 m above sea level on soils generally high in clay content and with a pH range of 6.0- 7.9 (NIB, 2009).

1.1 Soil fertility management practices

The most common deficiencies in rice production systems are nitrogen and phosphorus, with potassium and sulphur in limited areas and sometimes silica on peaty soils (IRRI, 1993). There is always need to replenish the land after each cropping season in order to sustain or increase its productivity. The average yield of variety IR2793-90-1 grown in Kenya is 3 tons/ha, much less than potential yield 5 tons/ha (KARI, 1995). This was attributed to insufficient use of fertilizer especially nitrogen (N), and phosphorus (P). Nitrogen is deficient in Kano plains (NIB 2009).A rice crop producing about 3,360 Kg of grain and equal amount of straw, per hectare, removes approximately 54Kg N, 26Kg P and 46 Kg K (NIB, 2009). Apart from nitrogen, potassium and phosphorus have been considered to be sufficiently supplied by Kano’s soils inherent sources (NIB, 2009). Several techniques are used to replenish soil nitrogen pools of Kano paddy-fields in Kenya. They include: Farmers’ practice recommended by NIB (53-58KgN/ha), farmers’ practice + Azolla incorporation, farmers’ practice+ straw incorporation and farmers’ practice+ fish-culture.

1.1.1 Farmers’ practice

West Kano Irrigation Scheme is managed by National Irrigation Board (NIB) western region. The main task of the board is to provide farm inputs to the farmers at debit –basis to be paid at the end of each season. Fertilizer application is always recommended by the board at the rate of 53-58 kg N per hectare (21-23 kg N/ acre) mainly as ammonium sulphate or Urea. Nitrogen fertilizer is always applied manually, placed within 5 cm below soil surface in three splits to give the total application rate 53-58 Kg N/ha depending on fertilizer type. This was according to Rao *et al*. (1971), who concluded that a transplanted rice crop needs half of the total quantities of N fertilizer at transplanting time then 25% about 3weeks later and the balance at panicles initiation.

1.1.2 Farmer’s practice with Azolla incorporation

Apart from NIB’s Nitrogen specification, Azolla can be integrated with inorganic nitrogen fertilizer to increase soil nitrogen availability. Azolla is a genus of small water ferns of the *salviniaceae* family commonly growing in paddy-fields. The plant is of particular interest to agriculture because blue-green algae *Anabaena azollae* present in cavities within azolla leaves; are capable of assimilating atmospheric nitrogen. Symbiosis is based on Biological Nitrogen Fixation (BNF), the fern utilizing nitrogen from the algae, the algae benefiting by mineral nutrition and physical protection from the fern. Farmers in Asia have long benefited from the technology and have considered it viable and sustainable (Lejeune *et al.*, 1999). Azolla in grow naturally in some of the Kano paddy-fields and farmers have been incorporating it not knowing their soil replenishing values or just as part of land preparation. On a personal communication to several farmers the acknowledged higher yield in azolla colonized paddy-fields.

1.1.3 Farmer's practice with rice straw incorporation

The manurial value of straw is usually overlooked; indeed, burning straw, stubble and hay making is a common practice in many countries Kenya included, chiefly because of the difficulty of incorporating a large quantity of straw into the soil. Since the rice straw contains about 0.6% nitrogen, 0.1% phosphorus, 3% potash and other nutrients the removal of straw depletes the land of considerable quantities of plant food. Ploughing back of rice straw is considered as one way of nutrient cycling in paddy-field especially when basal nitrogen is added. Tanaka (2001) reported higher rice yield with rice straw incorporation in a paddy-field. The normal basal application (that of normal farmers' practice) is expected to support mineralization by decreasing the soil carbon:nitrogen ratio.

1.1.4 Integrated farmer's practice with fish - culture

Kenya has an estimated 11000 ha of irrigated rice field (Kouku, 2000) that can play an important role in fish production. The rice fields are potential fish ponds since in its aquatic phase the rice field is a rich and productive biological system that can produce a crop of fish. Farmers in Kenya could adopt this poly-culture technology where fish and rice culture are run concurrently. Rice receives NIB recommended fertility management in addition of fish droppings. Fish culture is also attributed to pest control as they feed on insects.

1.2 Rice water requirement

In designing any rice irrigation project, it is important to understand water requirement for rice cultivation under varying field conditions and factors affecting these situations respectively. Rice water requirement is referred to as the sum total of evaporation from the field, crop transpiration, seepage and percolation loss during the growth period. Evapo-transpiration (ET) describes the combined values of evaporation (E) and transpiration (T) from a specific planted area. Water requirement of a crop can be defined; as the quantity of water regardless of source, needed for optimum growth and yield in a period of time at a place and may be supplied by precipitation, irrigation, soil profile contribution or any of the combinations. Kano plains' irrigated rice schemes are considered water scarce, limiting intensification and expansion of rice production (NIB, 2009). The scarcities include; source decline, inefficient water pumping systems and poor paddy-field management by farmers (NIB, 2009). In the case of the latter (that can be managed by farmers) caution should therefore be taken when different soil replenishing techniques are used to ensure that they do not aggravate water shortage.

1.2.1 The paddy field and its water balance

Irrigated lowland rice is grown under continuously flooded conditions. Rice seedling is usually transplanted onto wet soil paddy field. After crop establishment, the paddy field is usually kept continuously flooded as this helps control weeds and pests. Before crop establishment, the paddy field is prepared under wet conditions. This wet land preparation consists of soaking, ploughing, and puddling (i.e. rotavating under shallow submerged conditions). Puddling is done to control weeds, and also to reduce soil permeability. Puddling leads to a complete or partial destruction of soil aggregates and macropore volume, and to increase in micropores volume (Moorman and van Breemen 1978). A typical puddled rice field has a layer of 0-5 cm of ponded water, a puddled, muddy topsoil of about 20 cm, a plough pan, and an undisturbed soil. Rice roots are usually contained within the puddled layer and are therefore quite shallow. The plow pan reduces the hydraulic conductivity and percolation rate of rice field dramatically. Because of its flooded nature, the rice field has a water balance that is different from that of upland crops. The water balance of rice field consists of the inflows by irrigation, and rainfall, and the out flow by transpiration, evaporation, overbund flow, seepage, and percolation. In flooded rice fields, there is a continuous downward flow of water from the puddled layer to below the plough pan called “percolation” (Sanchez, 1973).

During the crop growth period, water outflows are by overbund runoff, evaporation, seepage, percolation and water also leaves the rice field by transpiration. Of all water outflows, runoff, evaporation, seepage, and percolation are nonproductive water flows and are considered losses from the field. Only transpiration is a productive flow as it contributes to crop growth and development. When rainfall raises the level of ponded water above the height of bunds or drainage outlet control box, excess rain leaves the rice field as surface runoff or overbund flow. This surface runoff can flow into neighbouring field, or lost in a drain, or ditch.

Evaporation leaves the rice field directly from the ponded water layer. Transpiration by paddy plant withdraws water from the puddle layer. During the crop growth period, about 30-40% of evapotranspiration is evaporation (bouman *et al* 2005, Simpson *et al* 1992). Seepage is the subsurface flow of water underneath the bunds of a rice field. With well maintained bunds, seepage is generally small. In fertilizer trail poly-ethene material is sand -wiched between the bund to stop seepage (NIB, 2009).

Percolation is the vertical flow of water to below the root zone. The percolation rate of rice fields is affected by a variety of soil factors (Wickham and Singh 1978): structure, texture, bulk density, mineralogy, organic matter content, and salt type and concentration. Soil structure is changed by the physical action of puddling. In heavy –textured, montmorillonitic clay, sodium cations and a high bulk density are favorable for effective puddling to reduce percolation rates. Large depths of ponded water favour high percolation rates (Sanchez 1973, Wickham and Singh 1978). Water losses by seepage and percolation account for about 25 -50% of all water inputs in heavy soils with shallow ground water tables of 20- 50 cm depth (Cabangon *et al* 2004, Dong *et al* 2004), and 50-85% in coarse textured soils with deep groundwater tables of 1.5 m depth or more (Sharma *et al* 2002, Singh *et al* 2002).

1.3 Background information to the study

West Kano Irrigation Scheme (WKIS) is one of scheme managed by National Irrigation Board (NIB), western region office based in Ahero. An energy requiring process (pumping) is used to convey water from Lake Victoria to the paddy field. The soils are moderate in phosphorus >50 mg/Kg but low in nitrogen (Serrem *et al.,* 2010). The inherent moderate soil phosphorus has promoted growth and propagation of Azolla in water canals and some rice fields. Some farmers do admit better rice yield in Azolla colonized paddy fields compare to those without (Farmers; Personal communication).Rice straw is burned or fed to ruminants since farmers associate them with difficulty in mechanized tillage. The research officers at NIB – western region have been advising farmers to apply between 53-58 Kg N/ha based on economical analysis (NIB; Personal communication).In the study carried out by Moi University between 2008-2010 on nitrogen dynamics, it was found that organic inputs Azolla and fish droppings increased yield of rice while rice straw reduced the yield (Serrem *at al.,* 2010).

1.4 Problem statement and justification

1.4.1 Problem statement

Suitability and capability of land for paddy-field do not only depend on climate and soils but also availability of large reservoir of water resource. Depletion of water and nutrients resources within the paddy rice systems is a major challenge to sustainability, intensification and expansion of rice production in Kano plains (NIB, 2009). Scarcity of water has been mainly attributed to frequent droughts/ climate change and scheme management , as result farmers are forced to do less cultivation than before to match the capacity of water provided by National Irrigation Board (NIB) (GoK,2010).On the other hand uneconomical prices in fertilizer due to high global cost of fossil fuel as raw material, in freight, and application has forced farmers to resort to Low External Input Sustainable Agriculture (LEISA) technologies to cushion themselves against income losses. The technologies are based on hybrid (local –external) nutrient sources, the local sources are mainly of organic forms. Organic inputs are known to affect soil physico - chemical properties (Yang *et al.,* 2010). Despite disparity among the researchers' findings on effects of organic inputs on paddy field nutrient availability (Serrem *et al,* 2010), there are clear gaps on their effects on soil physical properties, rice growth and paddy-field water requirement in Kano plains. To explain their effects on rice growth, growth curves had to be developed from the experiment. On the other hand to explain effects on water requirement, deep percolation determining factor i.e. soil hydraulic conductivity had to be determined since other factors like evapo-transpiration and crop growth duration were assumed to be almost constant (Chan and Chong,2007). Farmer have been reducing deep percolation by puddling (compaction technique), but with presence of organic inputs and related biotic activity, soil permeability may differ even with puddling resulting into variation in water requirement with the type of organic input. It is important to ascertain organic inputs that can benefit the farmer by reducing the cost of production (fertilizer and water to be used) and foster sustainability of rice farming.

1.4.2 Justification

Considering that organic inputs have effect on physico-chemical properties (Sharma *et al.* 1986., Yang *et al.* 2010), the two constraints to rice production in Kano plains paddy-field; water shortage and nutrient-nitrogen depletion (NIB, 2009., Serrem *et al* 2010) could be solved simultaneously. Solution in nutrient depletion should not aggravate water shortage and vice versa. Sustainable solution should be able to have the two constraints solved. The experiment had three organic inputs (Azolla, rice straw and fish-culture) studied to understand their potential to manage the two constraints in rice production. Nitrogen uptake, rice growth and yield were used to monitor and evaluate the ability of the organic nutrient sources to supply nitrogen to rice crop. Soil bulk density and saturated hydraulic conductivity were used to monitor and evaluate the potential of organic inputs to reduce water used in paddy-field.

1.5 Overall Objective

To study the effects of organic inputs on water and nutrient management of irrigated paddy-field in West Kano plains, Kenya.

Specific Objectives

The specific objectives were;

1.5.1 To determine effects of local organic inputs on soil bulk density and hydraulic conductivity of the paddy-field.

1.5.2 To determine effects of organic input treatments on rice growth and yield.

1.5.3 To determine the effect of organic input treatments on paddy-field water requirement.

1.6 Hypotheses

- **H-1o**: The organic inputs will have no effect on soil bulk density and hydraulic conductivity hence equal paddy-field water requirement for all the treatments.
- **H-1$_A$**: The organic inputs will have effect on soil bulk density, hydraulic conductivity and related deep percolation hence significant difference in

paddy-field water requirement of treated plots compared to Farmers' practice.

- **H-2_0**: The rice crop will have the same growth curves and yield irrespective of the treatment.
- **H-2_A**: The rice crop in each treatment will have a different growth curve and yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Rice

Rice has been cultivated for such countless ages that its origin must always be a matter for conjecture. Botanists base their evidence of the origin of rice largely on the habitats of the wild species. It is presumed that the cultivated species have developed from certain of the wild rices; it is possible, but considered unlikely that any of the wild rices descended from cultivated rice. There seems to be no agreement among experts as to whether rice was first upland crop which was then adapted to wet conditions or vice versa. There are only two cultivated species, *O. glaberrina* and *O.sativa* . *Oryza glaberrina* is confined to West Africa where it is an upland crop but is being replaced by *O.sativa*. Chang (1975) concluded that rice was first domesticated in the area between northern India and the Pacific coast adjoining Vietnam and China. In 2011, a combined effort by the Stanford University, New York University, Washington University in St. Louis, and Purdue University provided the strongest evidence that there is only one single origin of domesticated rice, in the Yangtze valley of China (Science Newsline,2011, Molina *et al* 2011).

Lowland rice (*Oryza sativa L.)* tolerates a very wide range of climatic conditions and can be grown in temperate or hot tropical climates from sea level to 1500m altitude. The average temperature should lie between 20- 38^{o}C during the growing season.

Rice will grow on a wide range of soils, there being no optimum soil type. The optimum pH is 5.5 to 6.5 when dry, though this may rise to 7.0 to 7.2 when flooded due reduction reactions. Cultivation is possible in alkaline soils, on contrary low pH 2.0-3.4, as is possible in reclaimed mangrove swamp, rice cannot be grown. Rice is of medium tolerance to soluble salt (50% yield reduction with ECe =10 $mScm^{-1}$). ECe at initial yield decline threshold is 3.0 $mScm^{-1}$ (Landon, 1991). In Kenya, three varieties are commonly grown in flood irrigated rice schemes; ITA, Basmati and IR8 (2009).

Upland rice also known as aerobic rice are bred varieties that provide considerable yields with lower water input than required for lowland rice. Compared with traditional lowland rice production, aerobic systems using aerobic cultivars in China currently yield about 30% less, but with input water savings of about 60% (Tang *et al*. 2002). In Africa, varieties New Rices for Africa (NERICA) were developed to meet the raising demand of rice. Several trails have been implemented in Kenya by Japanese International Co-operation Agency (JICA) in dry-land parts of Keiyo, Kibos and in Mwea Irrigation scheme (Bunyatta, 2010). Results from the trails registered lower average yield (2 ton/ha) when compared with those of lowland rice (3.5 ton/ha) but with advantage of low water requirement (rain-fed). This therefore does not restrict rice cultivation to areas with vertisols with availability of flood irrigation facility.

2.2 Nitrogen uptake, and physiological function in rice

Total nitrogen levels in soils range between 0.02% in sub soils to 2.5% in peat, but the ploughed layer of the majority of cultivated soils contains 0.02-0.04% N by weight.

Nitrogen is the key element to increased yield of rice. It is a constituent of proteins, nucleic acids, chlorophyll and growth hormones. Nucleoproteins (DNA and RNA) are involved in the control of development and hereditary processes. Nitrogen is an integral part of chlorophyll (porphyrin ring system), which is the primary absorber of light energy needed for photosynthesis during conversion of inorganic forms of carbon into organic forms (Brady and Weil, 2002).

Inorganic nitrogen is taken up by plants from the soils as nitrate (NO_3^-) and or ammonium (NH_4^+) ions (Tisdale *et al*., 1990). The rice plant is known to preferentially take up ammonium (NH_4^+-N) compared to the nitrate (NO_3^--N).

Adequate supply of nitrogen increases both the soluble amino acids and proteins in leaf; the additional protein allows the leaves to grow larger and hence to have a larger area for photosynthesis. In addition, an adequate supply of nitrogen promotes a dark green colouration by promoting chlorophyll formation through increase in nitrogen concentration in the crop (Bieleski and Ferguson, 1983). This is because nitrogen is an integral part of the chlorophyll molecule that has four pyrole (cyclic hydrocarbon) rings each with one nitrogen, four carbon atoms and magnesium as a central atom.

Excess nitrogen application weakens the plant, exposes it to various cryptogamic diseases, causes lodging and has an unfavourable effect on rice milling quantity and quality. It results in an increase in the number of unproductive tillers and these, by causing mutual shading, may depress yield of rice grain. Excess supply of nitrogen increases demand for carbon compounds thus reducing the proportion of carbohydrate left available for cell wall material and that to be translocated to grain sink. Thus, leaves with large, thin-walled cells that are susceptible to attack by insects and fungi and are harmed by unfavourable weather conditions such as droughts and frosts (Nye and Tinker, 1977). Varieties of rice suitable for heavy fertilization usually have short culms and numerous tillers.

Low supply of N results to carbohydrates being deposited in the vegetative cells (less carbohydrate demand) causing thickening (reduced photosynthesis) and the leaves are harsh and fibrous (Ali, 2002). When the roots are unable to absorb sufficient N due to low concentration in the soil solution, N in older leaves become lysed, converted into soluble form, translocated to meristematic regions of the roots and leaves and are reused in synthesis of new protoplasm (Nye and Tinker, 1977) translating to low grain yield.

2.3 Phosphate uptake and physiological function in rice

Apart from inherent phosphate pool, from fertilizer application, and that brought in solution or suspension in irrigation water, there is no natural means of increasing the quantity of this element in the soil. Since the phosphoric acid content of the soil is small, ranging from 0.02 to 0.04 per cent, and the rice crop removes a considerable quantity of this element, it might be anticipated that paddy will respond to application of phosphate fertilizers. In a point of fact, a crop grown in flooded fields it shows less response than do upland crops, indicating that it has access to sources of soil phosphate when grown in water. Increased availability of phosphate under flooded conditions is attributed to reduction of ferric phosphate to the more soluble ferrous form and to hydrolysis of phosphates compounds.

Paddy soils fix phosphates in varying degrees and this fixation may be very great in acid soils containing large amounts of free iron and aluminium, phosphate fixation may be so great as to prevent response of the paddy to phosphate dressings unless accompanied by calcium. Phosphate availability is optimum at pH 6.5, becoming very low below pH 6.0 and, because of fixation, small dressings are sometimes quite ineffective, there being little or no response until a sufficient quantity has been applied to overcome the fixation inherent in the soil.

There are often long-sustained residual effects from phosphate dressings on paddy soils, particularly those with a montmorillonite type of clay. Rhind and Tin (1952) demonstrated residual effects in Lower Burma giving measurable increases in yield over ten years and, by extrapolation, probably much longer. This long persistence of phosphorus in the soil indicates the need for caution in laying down fertilizer trials involving phosphorus, since results may be vitiated by previous applications.

Decomposition of rocks containing the mineral apatite and also organic matter are the primary derivatives of soil phosphorus (Bonheure and Willson, 1992). Phosphorus is present in soil solution as PO_4^{3-}, $H_2PO_4^-$ and HPO_4^{2-} ions mainly; $H_2PO_4^-$ being the principle form absorbed in soil by plant roots (Tisdale *et al*., 1990). After absorption, much of the phosphate reacts very quickly to form organic compounds (Bieleski and Ferguson, 1983).

The organic compounds formed play an important role in enzymatic reactions that depend on phosphorylation such as incorporation of phosphate in to nucleotides (ADP and ATP). ADP and ATP are the most common phosphorus energy currency that occurs in the form of high-energy pyrophosphate bonds in the mitochondria of the cells. Energy obtained from photosynthesis metabolism of carbohydrates is stored in phosphate compounds for subsequent use in growth and reproductive processes (Sanchez *et al*; 1997). Phosphate and the other nutrient ions are important for cell division, formation of fibrous roots and for development of meristematic tissue (Nye and Tinker, 1977). According to Benton, (1998), phosphorus is a constituent of chromosome and is important for protein formation and enzymes.

2.4 Potassium uptake and physiological function in rice

The response of paddy to potassium fertilizers is less than to nitrogen and phosphorus, probably because flooded soils are usually of a heavy nature and contain quantities of this element that are easily absorbed by the plant. Potassium is less fixed in soils than is phosphorus but nevertheless is retained to a large extent. The availability is not markedly influenced by soil reaction but there is some reduction in availability under very acid soil conditions (below pH 5).

Potassium exerts a favourable influence on tillering, size and weight of grain, stimulates build-up and translocation of carbohydrates to grain and, by strengthening the plant cell walls, renders the crop more resistant to disease and adverse weather (Roy 1981). Some evidence exists that where no lack of potassium, further additions is may have small negative effect on yield and too much potassium in the nursery may reduce tillering. High concentration of potassium in the soil solution during the early growth stage appears to delay or reduce nitrogen uptake by the plant, especially if the available phosphorus is low. Drainage after maximum tillering increases the oxygen content of the soil, decreases available nitrogen and increases potassium uptake.

2.5 Silicon uptake and physiological function in rice

Paddy is unique in that the plant absorbs large quantities of silicon and this element is present in all parts of the plant. It has been suggested that the benefits of silicon to the plant are mechanical, such as giving resistance to diseases and insect attacks, increased resistance to lodging, promotion of an erect growth and reduction of transpiration losses. Whereas absence of silicon only slightly affects yield of other *Graminaceous* crops, it materially decreases growth and yield of paddy. It favourably influences growth and nutrient uptake and decreases iron and manganese uptake, influences growth and ripening especially when the phosphorus supply is low (Okuda and Takahashi, 1964)

In Japan, silicates slags are applied to ameliorate degraded paddy soils and peaty soils. It is estimated that over 1 million tons of silicate materials – mainly silicates slags and calcium silicates –are applied annually to soils in Japan.

2.6 Paddy field physical properties and water requirement

Tuong *et al (*1994) in the Philippines and Chen and Liu (2002) in Taiwan found that the puddled soil in their respective fields had an order of magnitude lower hydraulic conductivity than the non-puddled soil even though the bulk density (Tuong *et al.*, 1994; Chen and Liu, 2002) and porosity (Chen and Liu, 2002) of the soils varied by less than a factor of 2. Soil bulk density of paddy-field plough layer is expected to have almost constant bulk density (Dittmar *et al.*, 2007). They further showed that Radiographs of the soil cores of paddy-field ploughed layer were uniform with even root distribution restricted within the layer. They found no roots in plough pan and only present in cracks cavities. Sharma and De Datta (1986) stated that ploughing rice fields in water –saturated conditions can increase, decrease, or leave unchanged the soil's bulk density, porosity and conductivity values. The impact depends on the soil types, their aggregation status, and orientation of the soil particles. The saturated hydraulic conductivity of soil beneath the surface muck was found to be uniform at 0.25 cm/d in the Philippines (Datta, 1984).

Total seasonal water input to rice fields (rainfall plus irrigation) can be up to 2-3 times more than for other cereals such as wheat or maize (Tuong *et al* 2005).It varies from as little as 400 mm in heavy clay soils with shallow groundwater tables (that directly supply water for crop transpiration) to more than 2000 mm in coarse –textured soils with deep groundwater tables (Bouman and Tuong 2001, Cabangon *et al* 2004).Fuji and Cho (1996) revealed that the direct seed rice consumed less water than transplanted crop based on irrigated block studies. They reported that the supply had amounted to 1836mm on the average for transplanted rice crop and decreased to 1333 mm for direct seeded rice. Upland rice that is rain-fed was considered to be rainfall sufficient when >400 mm is received during the growth period (Bunyatta, 2010). Rachel (2006) working with the Department of Primary Industries (DPI) reported that the paddy water requirement ranged between 10.35 and 15.58 Megalitres/ha in 1980-98 in Murrumbidgee irrigation area. Meteorological conditions and soil characteristics were considered to vary with paddy rice requirement between 15.28-20.48 Megalitres/ha.

2.7 Low cost fertility amendments

2.7.1 Straw

Dei (1970) found that rice straw, incorporated into the soil, fixes nitrogen during the early stage of decomposition of soluble carbohydrates but releases it thereafter. Trials in Portugal (De Miranda, 1967) showed that ploughed –in straw at the rate of 10 ton/ha gave highly significant increases in grain yield and no significant increase in straw yield. Yung *et al* (2010) showed that rice straw retention in paddy field decreased bulk density and soil hardness and increased porosity. Watanabe (1988) reported delayed rice growth in soil rich in nitrogen when wheat straw was added. Tanaka (2001) using ^{15}N tracer confirmed immobilization of N by microbes.

2.7.2 Azolla green manure

A great potential of Azolla as a source of nitrogen has been demonstrated. This incorporation of two crops of Azolla has led to rice yield increase by 0.6-1.0 ton/ha accompanied by improvement of soil structure (Watanabe *et al,* 1981). Bohlool *et al.,* (1992) further showed that azolla fixes atmospheric N which is made available to rice upon death and decay. Azolla can fix 22-40 Kg N in 30 days (Peoples *et al.,* 1995). The N accumulated by azolla is derived mostly from the air established by using the ^{15}N tracer technique, by which rice plants can accumulate around 33% of the N fixed by azolla within 60 days (Mian, 2002). However this recovery of N by rice varies with soil conditions (Galal, 1997). Azolla decomposes and supplies N most readily if C/N ratio is about 10 (Liu, 1995). It is important to note that the potential of using azolla is mostly restricted by climatic factors, water, inoculum's availability, incidence of pest, phosphorus requirement and the need for labour intensive management (Roger and Watanabe 1986). Kamalasanan *et al* (2004) reported ability of azolla to reduce evaporation in paddy system.

2.7.3 Integrated rice- fish culture

Integrated rice-fish farming is not a new technology. It has been practiced in tropical Asia for centuries. In Africa, it is practiced in several countries, including Senegal, Madagascar, Malawi and, most prominently, in Egypt (Halwart 1998). In China, fish farming in rice fields is promoted through the National Development Plan and fish yields ranging from 180-750 kg/ha have been achieved in concurrent rice-fish, with production being twice as high in rotational rice-fish farming systems (FAO and NACA 1997). Rasowo *et al.* (2003) on On –farm trails in West Kano Irrigation Scheme found viability of rice- fish culture in Kenya.

CHAPTER TREE

MATERIALS AND METHODS

3.1 Study sites

An on -farm experiment was carried out at West Kano Irrigation Scheme (WKIS) farms Kisumu County, Kenya. The farms are owned by small scale farmers who usually grow a crop of maize and legumes, besides having rice-fields within the irrigation scheme. The site lies between 00 6'S and 00 12'S latitude and 34 48' E and 34 57'E longitude and at altitude of 1400 m a.s.l. It receives average annual rainfall of about 1100mm which is distributed as long rains from March to early June and short rains from September to December. The soils chosen for the study were those of unit 9 whose soil type phase name is Kano clay and sub- group class is typic Pellic vertisols (D'Costa and Ominde, 1973).These soils are predominant in the kano plains. They are very dark and almost black, and become waterlogged during the rainy season. They have high amounts of montmorillonite and a high base saturation (FitzPatrick, 1988).

3.2 Crop history of the experimental fields

The experimental plots were located outside the irrigation scheme but adjacent to it bordered by irrigation canal. The main scheme plots were avoided to ensure that there was no residual effect from long term fertilizer use. The field was mainly used for upland crops mainly maize and beans. High inherent phosphorus was evident from initial soil characterization (Table 3) and was attributed to deposition on Lake Victoria bed before receding leaving the plain for cultivation (Farmers: personal communication). The phosphates mineral are mainly of organic form sedimented within the clay network of vertisols. Fertilizer application is not practiced and most upland crop especially maize show no phosphorus deficiency however nitrogen deficiency is observed especially during high rainfall due to waterlogging and resultant leaching (Agricultural Extension Officer: personal communication). To ascertain fertility status of three blocks used in experiment, a composite sample for each block was obtained and taken to University of Eldoret –Soil Science Department laboratory for analysis. Soil amendments (Azolla, rice straw and fish droppings) were also characterized in relation to their nutrient contents.

3.3 Crop management of the experiment

Each plot measured 5 m by 5 m and had elevated dikes with base of 0.6 m, top width 0.4 m and height of 0.4 m having separate screened water inlets and outlets (appendix IV). The plots were physically modified to provide refuge for the fish by constructing peripheral trenches each with an area of 5 m^2 and a depth of 0.5 m (Plate 3 and appendix IV).The plots were ploughed, flooded and puddling followed prior transplanting of rice. Rice straw and azolla green manure were incorporated to the soil 2 weeks to rice transplanting in each specific treatment plot.

Rice seeds IR 2793 -80-1 were germinated and seedling managed for 30 days. Rice seedlings were transplanted from the nursery to experimental plots at 31 days after seeding (DAS) and at spacing of 25 cm between the rows and 10 cm within the rows, with 1 seedling per hill. The seedlings were allowed to establish at a shallow water level of less than 5 cm to allow anchoring and then raised in all treatments to 25 cm on the day of fish stocking 14 days after transplanting (DAT) at a rate of 6000 catfish (*Clarias gariepinus*) fingerlings per hectare. The average weight of the fingerlings at stocking was

15.4 ±0.6 g. During the experiment the fish in the rice-fish culture received supplementary feeding of rice bran at 3% of body weight. The feeding was started 1day after stocking and was provided manually into two equal daily portions at 9.00 hrs and 15.00 hrs until 98 days after fish stocking. Nitrogen fertilizer Urea-46%N was blanket applied manually at the rate of 58 Kg N/ha, placed at 5 cm below soil surface in three parts. This was done according to Rao et al. (1971), who concluded that a transplanted rice crop needs half of the total quantities of N fertilizer at transplanting time then 25% about 3weeks later and the balance at panicle initiation. During fertilization flooded field were drained and fish made refuge in trenches. The plots were manually kept weed free for the entire culture period.

Water physical and chemical properties were monitored during the culture period to ensure fish growth was not inhibited by poor quality water.

3.4 Experimental design and treatment allocation

The experiment consisted of three treatments and a control (Farmer's practice) laid out in a Randomized Complete Block Design (RCBD). The treatments were 2 ton/ha Azolla, 2 ton/ha rice straw and fish –culture as an addition to farmer's practice. All the treatments and control were repeated three times within each of the three blocks to minimize experimental error.

General model to describe the experiment:

$$\mathbf{Y_{ijk}=\mu+ b_i+ t_j+ r_k + e_{ijk}}$$

Where: $\mathbf{Y_{ijk}}$ = Observed value of either test plant or soil parameter,

$\boldsymbol{\mu}$ = general mean of all observations,

b_i = Block effect on parameter in block **i,**

tj = treatment effect on parameter in treatment **j**,

rk = repetition effect on parameter in repetition **k**,

eijk = represent random variation within observation plot **ijk**.

Plot No.	Treatment	Plot No.	Treatment	Plot No.	Treatment
Block 1		Block 2		Block 3	
1	T_{1r1}	13	T_{3r1}	25	T_{2r1}
2	T_{4r1}	14	T_{2r1}	26	T_{4r1}
3	T_{3r1}	15	T_{4r1}	27	T_{3r1}
4	T_{1r2}	16	T_{4r2}	28	T_{4r2}
5	T_{1r3}	17	T_{3r2}	29	T_{1r1}
6	T_{2r1}	18	T_{1r1}	30	T_{3r2}
7	T_{4r2}	19	T_{2r2}	31	T_{1r2}
8	T_{3r2}	20	T_{4r3}	32	T_{2r2}
9	T_{2r2}	21	T_{3r3}	33	T_{1r3}
10	T_{3r3}	22	T_{1r2}	34	T_{4r3}
11	T_{4r3}	23	T_{2r3}	35	T_{2r3}
12	T_{2r3}	24	T_{1r3}	36	T_{3r3}

Figure1: Simplified experimental layout outlining the experiment.

Legend;

T_1 = Farmers' practice,

T_2, = Farmers' practice +2ton/ha Azolla,

T_3 = Farmers' practice +2ton/ha rice straw,

T_4 = Farmers' practice +fish –culture respectively.

Subscript **'r'** indicates repetition within a block to increase precision.

3.5 Treatments application

3.5.1 Farmer's practice (T_1)

In each plot 0.25 Kg of granular Urea was applied 7 DAT, 0.125 Kg at tillering and another at 0.125 Kg at panicle initiation.

3.5.2 Farmer's practice with 2 ton/ha Azolla incorporation (T_2)

Azolla green manure was harvested from irrigation canals using 0.5 mm mesh fishing net and washed well to remove impurities. It was then left to wilt to 30% moisture where the sample was taken for nutrient analysis, and then 4Kg was incorporated in each allocated plots in the top 15 cm plough layer 2 weeks before transplanting. It was then followed by farmers' practice and observation made during the culture period (Plate1).

Plate 1: Experimental plot treated with Azolla. (Source: Author, 2010)

3.5.3 Farmer's practice with 2 ton/ha straw incorporation (T_3)

Newly harvested rice straw from previous season was collected and allowed to sun dry to 30% moisture, they were then manually chopped to 5 cm pieces and sample taken for characterization. 4 Kg of chopped straw was incorporated in each allocated plots in the top 15 cm ploughed layer 2 weeks before transplanting. It is then followed by farmers' practice. During the culture period observation were made (Plate 2).

Plate 2: Poorly established rice in straw treated plots. . (Source: Author, 2010)

3.5.4 Farmer's practice with fish – culture (T_4)

After transplanting and basal application of 0.25 Kg urea/plot, Catfish fish (*Clarias gariepinus*) fingerlings were obtained from Lake Victoria Development Authority (LBDA) and stocked at rate of 12 fingerlings per allocated plots 2 weeks after transplanting. This was then followed with the two fertilizer applications as in farmers' practice. The fish were continuously sampled from their refuge (Plate 3) to ascertain the body size to ensure 3% body weight feed supplementation.

Plate 3: Experimental plot with a trench (fish refuge) in integrated rice-fish culture. (Source: Author, 2010)

3.6 Data collection

3.6.1 Soils

3.6.1.1 Chemical properties

All the plots were drained to allow collection of soil samples. The samples were sampled at saturated state to ensure that the soil remain reduced (*in situ* state) for especially for pH measurement to depict that at root zone conditions. In each plot, three auguring were done to the required depths (0 – 15 cm). Soil samples were respectively put in clean labeled plastic bags and thoroughly mixed (Plate 4). A sub-sample of about 1 kg was taken and the remaining soil discarded within the plot. After auguring, the auger holes were covered with soil.

Plate 4: Soil samples for chemical analysis in the laboratory. . (Source: Author, 2010)

3.6.2 Physical properties and biomass sampling

3.6.2.1 Hydraulic conductivity its in situ sampling

Soil samples for hydraulic conductivity were obtained using PVC pipe coring, 3 Inch class "A"(Kebs –Kenya, 2010). The cores were slowly driven into saturated soil of the ploughed layer to 2/3 (10 cm) the 15 cm plastic coring. A repeat was made for sublayer (15-30 cm) after removal of the first core. The cores were slowly removed and bottom covered with micro- mesh. The samples in corings were placed in poly-ethene bags then transported to the hydrology laboratory in Kisumu for analysis.

3.6.2.2 Bulk density

Soil bulk density was measured on cores obtained by manually driven 2 inchx10 cm length PVC pipes of standard class "A" (Kebs –Kenya, 2010). These cores were 5cm in diameter, 10 cm deep and about 200 cm^3 in volume (Blake and Hartge, 1986). The collection of soil samples was made at three locations in each plot

3.6.2.3 Plant Biomass

Above soil surface rice biomass was collected in each plot, three representative plants per plot at transplanting (**TP=**30 days after seeding), at tillering (**T=** 60 days after seeding**)**, at panicle initiation (**PI=** 90 days after seeding), and at harvest (**H=** 120 days after seeding). The samples were placed in labeled paper bags.

3.6.3 Laboratory analysis

3.6.3.1 Soil Pre-laboratory analysis

The soil samples were arranged according to plot numbers in ascending order. The samples were then registered in an inward register and given a laboratory code number. Sampling date and plot numbers were also recorded. Soil samples were scooped in order (about 25 g) into 50 ml beakers for pH analysis. The soil samples were then air-dried in the green house, after which they were ground, passed through 2-mm brass sieve and stored for texture and chemical analysis.

3.6.3.2 Rice biomass samples pre-treatment

Biomass samples were received and registered in a sample register and given a laboratory code number. This number was maintained up to when the results were generated.

The biomass samples were then oven-dried at 70^{o}C in a well-ventilated oven for about 24 hours. The samples were then transferred to weighing table for weight taking.

3.6.4 Physical and chemical analysis

3.6.4.1 Texture

The air-dried soil samples were subjected to laboratory physical and chemical analysis. Soil particle size analysis was by Hydrometer method (Okalebo *et al*., 2002). Hydrometer method estimates amount of silt and sand taking consideration of their differential settling velocities within a water column. The settling velocity is governed by the liquid temperature, viscosity and specific gravity. Hydrometer method puts into consideration the Stoke's Law with assumption that the particles are spherical, have a specific gravity of 2.65, are not affected by Brownian movement and that the settling velocity is proportional to the square of the radius of the particle.

3.6.4.2 Soil reaction (pH) and available phosphorus

Soil pH was determined in 1:1.5 soil/H_2O method (ITTA, 1979a) and available phosphorus was by Olsen's method (1954) both methods as described in Okalebo *et al*., (2002).

3.6.4.3 Percentage total nitrogen and soil carbon

Total nitrogen determination was carried out using Kjeldahl digestion method (Anderson and Ingram, 1996). Total nitrogen was analyzed by colorimetric method following the procedure outlined in Okalebo *et al*., (2002). Organic carbon in the soil was determination by the Walkley-Black Method (IITA, 1979a),

3.6.4.4 Bulk density

Soil bulk density was obtained gravimetrically, the soil sample in each of 200 cm^3 plastic core was removed and placed on an oven at $105^{O}C$ for 48 hours to a constant weight. Each sample was allowed to cool then weighed. Bulk density was then obtained by dividing the mass with the core-volume using an empirical formula (appendix I) procedure outlined in FAO (2008).

3.6.4.5 Hydraulic conductivity

Hydraulic conductivity was measured according to the protocol outlined in FAO (2008). Falling- head method was adopted considering the low permeability of vertisols. The soil sample was first saturated under a specific head condition. The water was then allowed to flow through the soil without maintaining a constant pressure head. Measurements discharge (Q) and time (t) was made for each sample and hydraulic conductivity obtained using the formula in appendix I (b).

3.7 Rice yield records

Rice crop in each plot was harvested threshed to obtain un-husked grains which was put into labeled gunny bags, then transported to open solar drying field for drying to recommended moisture (20-30%) for dehusking. The dried harvest was milled using electric rice miller for all obtained plot samples. The samples were further dried to storage moisture of 13%. Each sample was then weighed to give the plot yield. Reporting yield in ton /Ha was obtained using the empirical formula below;

Yield in ton /Ha = 10/ plot area in M^2 x plot yield in Kg

3.8 Paddy -plot water requirement

3.8.1 Rainfall measurement

Rainfall data in mm was obtained from a metrological station at West Kano Irrigation Scheme NIB Station. Rainfall amount in mm for the rice culture period was extracted from the rainfall chart and summed to give total amount of rainfall in the culture period (appendix III).

3.8.2 Irrigation measurement

Irrigation water was obtained using a petrol powered centrifugal pump model G-200 Kyoto- Japan make. Prior to irrigation the pump was calibrated to known delivery volume $1M^3$/minute. Considering the time taken to attain recommended 25cm water depth, irrigation requirement in mm was obtained and record in chart (appendix III).

3.8.3 Total water requirement

Total water requirement was obtained from summation of rainfall and irrigation over the rice culture period ($\sum$ (IR+R)). The total water requirement is then translated to mega-litres /ha using an empirical formula. (Rachel 2006 in appendix III)

3.9 Statistical analysis

Data for soil properties, biomass at each growth stage, N-uptake, paddy-field water requirement and rice grain yields obtained were managed using Microsoft excel software (2000), then subjected to a two-way analysis of variance (ANOVA), using randomized complete block design to ascertain any significant effects of treatments (F-test at 5% confidence levels on all variables) using General Statistical Software GENSTAT version

3.0 (2007) computer package. Separation of means was computed with protected least significant difference ($LSD_{0.05}$) test.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Initial characterization

4.1.1 Soil amendments

Characterization of organic soil inputs was necessary to ascertain their replenishing attributes before addition to the soil as amendment. Characterization results (Table 1) of azolla, Rice straw, and fish droppings showed that the percentage nitrogen content in azolla and fish droppings were high and relatively equal attributed to *anabaena azollae* bacteria biological nitrogen fixation of azolla and fish urea-rich excrement, for azolla fish droppings respectively, while that of rice straw was very low, a normal rice straw nitrogen content also reported by Tanaka (2001). Phosphorus content in catfish droppings was relatively higher compared to that of Azolla and rice straw. This was attributed to feeding habits of catfish that mainly feed on insects; rich in calcium and phosphate the constituent of their exoskeleton. A related finding was reported by Fernando (1993). The carbon: Nitrogen (C/N) ratio of rice straw was higher than that of the other two soil amendments. Rice straw has high structural carbon content responsible for upright stand, the tetravalent- bond of carbon atoms hold the rice straw and always reinforced by silicon, element of the same group in the periodic table (Grist, 1990).

Table 1: **Elemental composition of Azolla, Rice straw, and Fish droppings in percentage dry weight basis (% dwb).**

Element	Azolla	Rice straw	Catfish droppings
Carbon	46.8 ±4.5	52.3±4.75	40.25±0.67
Nitrogen	5.0±0.52	0.75±0.13	4.75±0.56
Phosphorus	0.5±0.14	0.22±0.08	3.24±0.78
Potassium	3.2±1.23	1.74±0.54	0.30±0.11
C/N ratio	9	70	10

NB; Confidence level at ($p \leq 0.05$)

4.1.2 Soils in the study sites

Soil particle size analysis confirmed that the three blocks chosen for the experiment were texture (Table 2), with clay content of above 60%. There was no significant difference in clay, sand and silt particles ($p \leq 0.05$) between the three blocks confirming homogeneity of the soil. Soils with fine texture are suitable for lowland rice growing (Lal, 1985), the 2:1 montmorillonitic clay with high coefficient of linear expansivity (COLE) has high water retention capacity the suitable characteristic for ponding. Puddling processes further destroy the soil structure reducing the pores sizes to micropores associated with high matric potential (ψ_m) that immobilize water within the soil matrix leading to very low saturated hydraulic conductivity through the puddled layer. This makes soils of Kano plains suitable for ponding characteristics of pellic vertisol as also described by FitzPatrick (1988).

Clay particles have small particle sizes with reactive surfaces important in cation exchange and chemical stability of organic matter in the soil as reported by Othieno, (1992). As reported by Brady and Weil, (2002), high percentages of soil clay particles play a role in the adsorption of nutrients reducing the effect of leaching especially for cations. This characteristic is suitable for holding nutrients in flooded rice system.

Table 2: Soil particle size analysis in three experimental blocks

Experiment Unit	%Sand	%Clay	%Silt	Textural class
Block1	23.53	64.32	12.16	Clay
Block2	23.84	63.66	12.50	Clay
Block3	21.84	67.34	10.82	Clay

Summarized results on initial soil chemical characterization of study site prior to onset of the experiment in the year 2009 (Table 3), shows that soils were generally slightly acidic, the pH levels were within the recommended pH range of 5.5 – 6.5 for rice crop. The percentage total N and percentage organic carbon were high with average C : N ratio of 22 and this was attributed to the high clay content that stabilized the organic matter content. The C : N ratio of 22 is within the limit of 18 – 25 for quick decomposition and nutrient release as reported by Dogo, (2001) working on tea and Watanabe (1988) working on rice straw . Hence addition of organic matter with lower C:N will be of complementary value while that value beyond the upper threshold will lead to retarded decomposition. Available phosphorus was generally high (>40 mg/Kg) and attributed to inherent characteristics of soils of lake shores due to deposition of biotic and mineral sources. Fauna, flora, and soil is carried away from the highlands and deposited in most lakes in Kenya, responsible for siltation and diminishing in their sizes (GoK, 2007). This mineralizes over time accumulating to high concentration considering the low phosphorus mobility.

Table 3: Initial soil chemical parameters of the study site

Soil parameters	Soil depth = 0-15cm		
	Block1	Block2	Block3
pH (H2O) 1:1.5	6.12	6.14	5.98
OlsenP (mg /Kg)	45.22	45.54	42.73
N (%)	0.15	0.17	0.10
C (%)	3.00	2.89	3.15

4.2 Effects of treatments on paddy field post- harvest nutrient status

Residual effects of soil amendments were monitored to ascertain their residual value. The effects of treatments on post-harvest soil characterization are shown in Table 4. Treatment with azolla and rice straws had significant higher ($p \leq 0.05$) percentage soil carbon content compare to farmers' practice, but that of straws was still significantly($p \leq 0.05$) higher than that Azolla. This was attributed to higher carbon content in straw (Table 1).

Table 4: Effects of treatments on the paddy field soil post- harvest characterization

Treatment	Carbon (%)	Nitrogen (%)	OlsenP (mg/Kg)	Ph
T_1	2.40c	0.11d	59.55a	5.97c
T_2	3.72b	0.33a	47.80d	6.14b
T_3	4.12a	0.16c	51.52c	6.34a
T_4	2.42c	0.18b	57.61b	5.99c
SED	0.014	0.003	0.240	0.009
LSD	0.035	0.006	0.589	0.023
%CV	0.6	1.6	0.5	0.2

NB Values followed by the same letter are not significantly different (LSD, $p \leq 0.05$)

T_1= Farmers' practice (58 KgN/ha) **T_2**= Farmers' practice+ 2 ton/ha azolla incorporation. **T_3**= Farmers' practice + 2 ton/ha rice straw incorporation. **T_4**= Farmers' practice + fish-culture.

All the treatments had significantly ($p \leq 0.05$) higher soil total nitrogen content when compared with farmers' practice; 30.4, 16.8, and 15.3 computed percentages higher; for azolla, fish-culture, and rice straws respectively (Table 4), but Azolla and fish-culture were at higher margins. This was attributed to higher nitrogen content in Azolla associated with Biological Nitrogen Fixation (BNF), urea-rich fish droppings especially at higher growth stage of fish were they release more excrement, and the fixed nitrogen in rice straws (Table 1). The findings for Azolla were similar to those of Bohlool *et al.*, (1992) that azolla fixes atmospheric nitrogen which is made available to rice upon death and decay.

There was significant decrease in available phosphorus ($p \leq 0.05$) in all treatments when compared with farmers' practice (Table 4). Significant differences ($p \leq 0.05$) between treatments were also evident, 47.80, 51.52 and 57.61 for Azolla, rice straws, and fish culture in increasing order respectively. This inter-treatments variation was attributed to higher nitrogen-phosphorus synergy, lower nitrogen-phosphorus synergy and feeding nature of catfish for Azolla, rice straw, and fish-culture treatments respectively. Catfish feeding habits (mainly on insects) accumulates phosphate in their excrement in addition to what is supplemented in the feeds (Table 1) and can be supported by similar findings by Fernando (1993).

4.3 Effect of treatments on paddy field soil reaction

Treatments with azolla and of rice straw were significantly higher ($p \leq 0.05$) in soil pH when compared to farmers' practice. This was attributed to increase in soil cation exchange capacity (CEC), a buffer that reduces hydrogen ion activity (Brady and Weil (2002)) by adsorbing them and tends to retain soil pH at optimum value for nutrients availability for plants. Hydrogen ions are adsorbed in the soil micelle. This means low H^+ concentrations are within soil solution which is considered active. Soil pH is the negative logarithm to hydrogen ion activity ($-\log_{10} (H^+)$). Low hydrogen ion activity means high pH and vice versa.

4.4 Effect of treatments on paddy rice nitrogen uptake

Nitrogen uptakes by paddy rice as influenced by soil treatments are shown in Table 5. There were significant increases ($p \leq 0.05$) in nitrogen uptake in both treatments with

Azolla and that with fish- culture when compared with farmers' practice. This was attributed to increased availability of nitrogen attributed to Azolla's nitrogen content and N-urea-rich fish droppings respectively (Table 1). Treatment with rice straw had the lowest nitrogen uptake due to low nitrogen availability attributed to nitrogen immobilization by microbes in break down of carbon rich rice straw. This can be explained by the fact that the C:N ratio in rice straw is very high (Table 1) therefore promote immobilization. Although the low N organic compounds will release ammonium ions, they decompose slowly under anaerobic conditions (Russell, 1989) not meeting the crop requirement.

Table 5: Above surface biomass in g/plant (dwb) accumulation in three rice growth stages and N uptake as affected by treatments

Treatment	T	P I	H	N-uptake in (KgN/ha)
T1	10.96c	48.91c	92.71b	12.89c
T2	14.90a	65.41a	129.90a	35.17a
T3	7.12d	30.08d	53.64c	11.23c
T4	14.08b	57.30b	101.62b	22.53b
SED	0.31	1.73	6.08	0.74
LSD	0.75	4.23	14.88	1.82
%CV	3.2	4.2	7.9	4.5

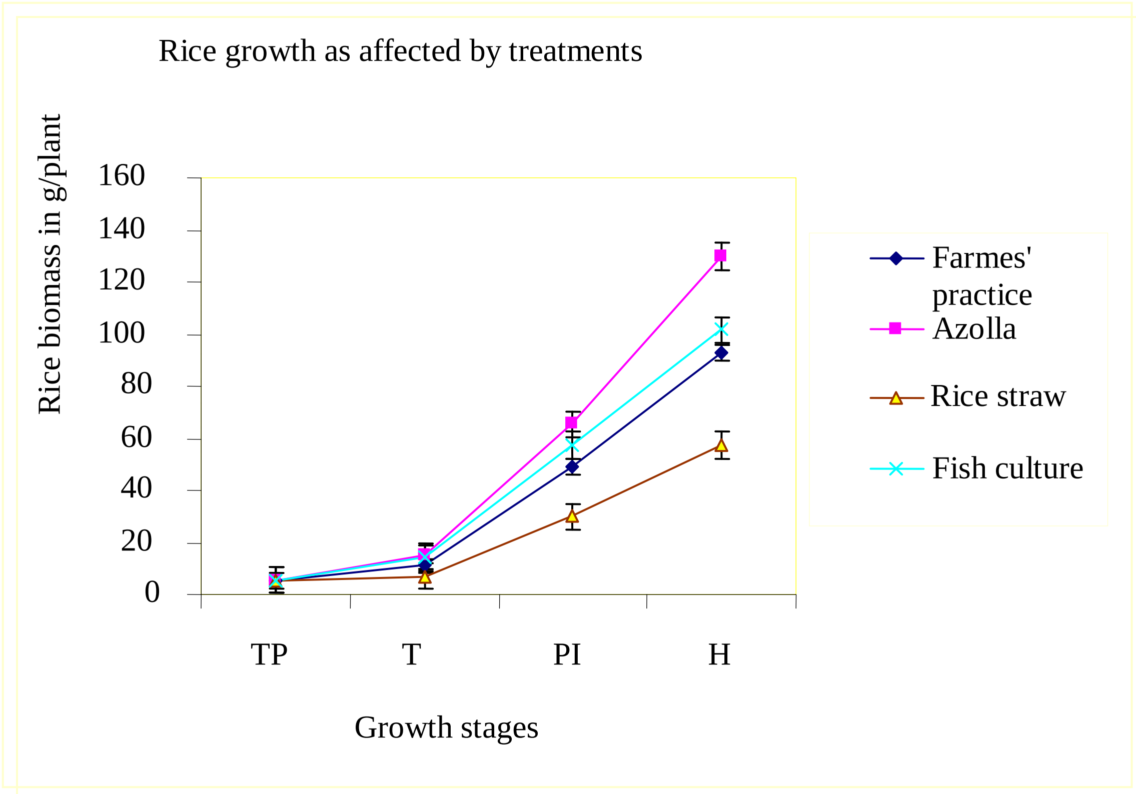
NB Values followed by the same letter are not significantly different (LSD, $p \leq 0.05$)

T= Tillering **PI**= Panicle initiation **H**= Harvest

T_1= Farmers' practice (58 KgN/ha) **T_2**= Farmers' practice+ 2 ton/ha azolla incorporation. **T_3**= Farmers' practice + 2 ton/ha rice straw incorporation. **T_4**= Farmers' practice + fish-culture.

4.5 Effect of treatments on paddy rice growth

There were significant increases ($p \leq 0.05$) in biomass accumulation in both treatments of azolla and fish- culture in almost all the growth stages when compared with farmers' practice (Table 5) with clear capture at harvest (Plate 5) and further illustrated in figure 2. This was attributed to availability of nitrogen element responsible for vegetative growth of rice crop, evident by Azolla nitrogen content mainly derived from Biological Nitrogen Fixation BNF (Table 1) and urea-rich fish excrement, for Azolla and fish-culture treatments respectively. Treatment with rice straw had significant lower rate ($p \leq 0.05$) of biomass accumulation when compared with farmers' practice. This is attributed to immobilization of nitrogen, an element responsible for vegetative growth. This is evident by the low nitrogen content in rice straw and consequent high C:N ratio (Table 1) not suitable for mineralization. Tanaka (2001) and Watanabe *et al* (1988) reported related findings in which microbe nitrogen immobilization and aromatic acids inhibitors were found to inhibit nitrogen uptake and reduced rice growth in paddy-field amended with fresh rice straw.



TP= Transplanting **T**= Tillering **PI**= Panicle initiation **H**= Harvest

Figure 2: Shows rice growth curves under the three treatments as compared to farmers' practice

Plate 5: Rice biomass accumulated per plant in each treatment at harvest. (Source: Author, 2010)

4.6 Effects of treatments on paddy rice yield

For the effect of treatments on paddy rice yield Table 6 shows that; treatment with azolla and that with fish-culture were significantly higher ($p \leq 0.05$) in yield compare to farmers' practice. They posted an increase in percentage yield of 18.4 and 5.5 for azolla and fish-culture respectively. This finding can be supported by Watanable, (1981) and Ladha *et al.,* (1993), in which incorporation of two crops of azolla led to rice yield increase by about 20-42% accompanied by improvement of soil structure and that of IRRI (1993), where a combined rice –fish culture was found to protect the environment and increase the farmer's income through increased rice yield, fish production and reduced fertilizers and pesticides. The yield increase is attributed to increase in nitrogen availability and the subsequent higher uptakes to plant tissues. Nitrogen in the plant tissue has a major function, being a constituent of pyrole ring (cyclic hydrocarbon), and a functional group in chlorophyll molecule an important photo-catalyst in photosynthesis of starch, that is then trans-located to the grain sink where it is harvested as grain (Hofmann *et al*., 2004). Increase in tissue nitrogen means the greener the plant which translates to increased plant capacity to absorb Photosynthetic Active Radiation (PAR) part of light spectrum responsible for photosynthesis.

Treatment with rice straw was significantly lower ($p \leq 0.05$) in rice grain yield compare to farmers' practice, a percentage decline of 17.15. The decline is attributed to low nitrogen availability associated with immobilization that reduces nitrogen uptake to the plant tissues. Biological nitrogen immobilization was reported to inhibit rice growth (Tanaka, 2001 using ^{15}N Tracer) when paddy-field was amended with rice straw.

Table 6: Treatments effect on yield of paddy rice

Treatment	Yield (ton/ha)
T1	3.60c
T2	4.26a
T3	2.98d
T4	3.79b
SED	0.03
LSD	0.08
%CV	11.1

NB Values followed by the same letter are not significantly different (LSD, $p \leq 0.05$)

$\mathbf{T_1}$= Farmers' practice (58 KgN/ha) $\mathbf{T_2}$= Farmers' practice+ 2 ton/ha azolla incorporation. $\mathbf{T_3}$= Farmers' practice + 2 ton/ha rice straw incorporation. $\mathbf{T_4}$= Farmers' practice + fish-culture.

4.7 Effects of treatments on paddy field soil bulk density, at 0-15cm depths, during selected rice growth stages

The effects of treatments on bulk density of the plough layer at four growth stages of rice are presented in data of Table 7 and illustrated in Figure 3. Results from 0-15 cm soil depth (ploughed and puddled) layer showed that; all the treatments had significantly lower soil bulk density at all growth stages except at transplanting ($p \leq 0.05$) when compared to farmers' practice. This was attributed to presence of organic matter that stabilizes the soil structures increasing porosity but lowering the bulk density. Similar finding was reported by Yang *et al.* (2010), in which among the soil physical properties, soil hardness, and bulk density decreases and porosity increased with the case of straw incorporation. An exception was noted for fish-culture, at transplanting bulk density was not significant, but this can be explained by the fact that at transplanting fish had not been introduced hence low organic activity.

There was also a significance different ($p \leq 0.05$) in bulk density between treatments; fish-culture, azolla and rice straw in decreasing order. This was attributed to the nature, composition, particle sizes of the three organic inputs, which influence the formation of soil structures. Rice straw treatment was distinctively lower in soil bulk density (figure 3) and this was attributed to the straw particle sizes that are also carbon rich hence have prolonged half- life in decomposition attributed to its high C:N ratio (Table 1).

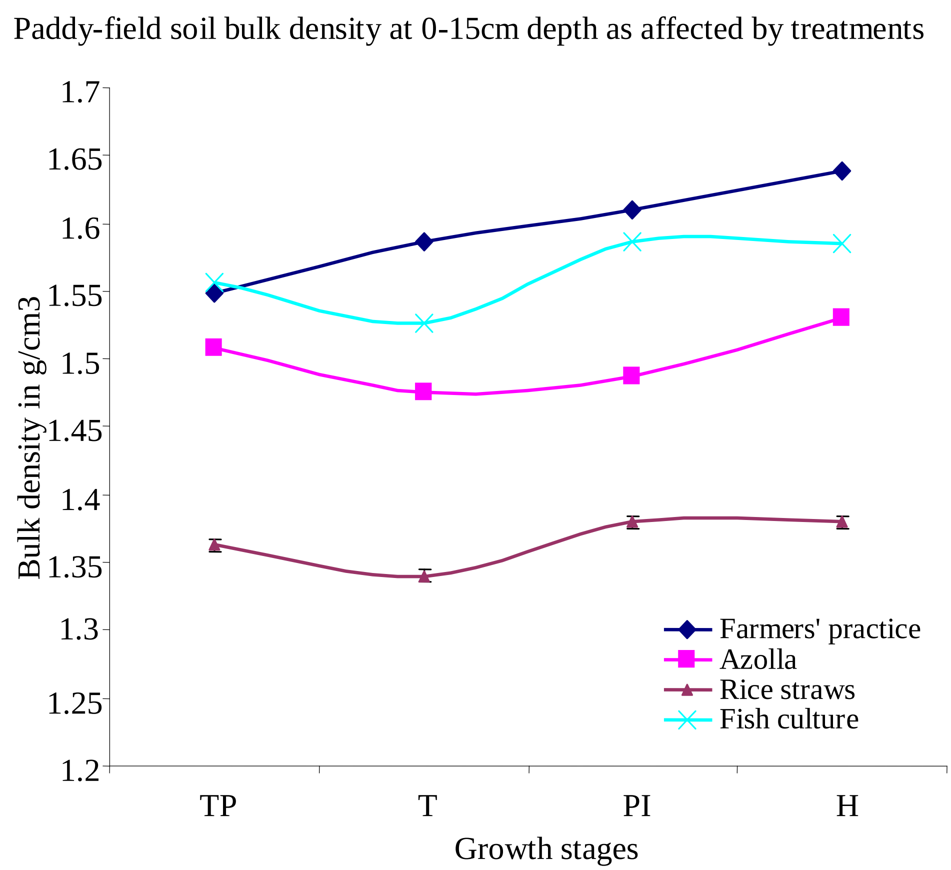
Table 7: The effects of treatments on bulk densities (g/cm^3) of the plough layer and underlying layer (sub- layer) at the three growth stages of paddy rice

Treatment	Depth 0-15 cm				Depth 15-30cm			
	TP	T	PI	H	TP	T	PI	H
T1	1.55a	1.59a	1.61a	1.64a	1.46a	1.45a	1.49a	1.45a
T2	1.51c	1.48c	1.49c	1.53c	1.47a	1.45a	1.46ab	1.46a
T3	1.36d	1.34d	1.38d	1.38d	1.47a	1.43b	1.44b	1.45a
T4	1.56a	1.53b	1.59b	1.59b	1.46a	1.45a	1.46ab	1.44a
SED	0.006	0.009	0.005	0.004	0.005	0.004	0.016	0.012
LSD	0.014	0.023	0.012	0.011	0.013	0.009	0.039	0.029
%CV	0.5	0.8	0.4	0.3	0.4	0.3	1.3	1.0

NB Values followed by the same letter are not significantly different (LSD, $p \leq 0.05$)

T_1= Farmers' practice (58 KgN/ha) **T_2**= Farmers' practice+ 2 ton/ha azolla incorporation. **T_3**= Farmers' practice + 2 ton/ha rice straw incorporation. **T_4**= Farmers' practice + fish-culture.

TP= Transplanting **T**= Tillering **PI**= Panicle initiation **H**= Harvest



TP= Transplanting **T**= Tillering **PI**= Panicle initiation **H**= Harvest

Figure 3: The bulk densities of the ploughed layer (0-15cm) as affected by treatment at different growth stages of paddy rice.

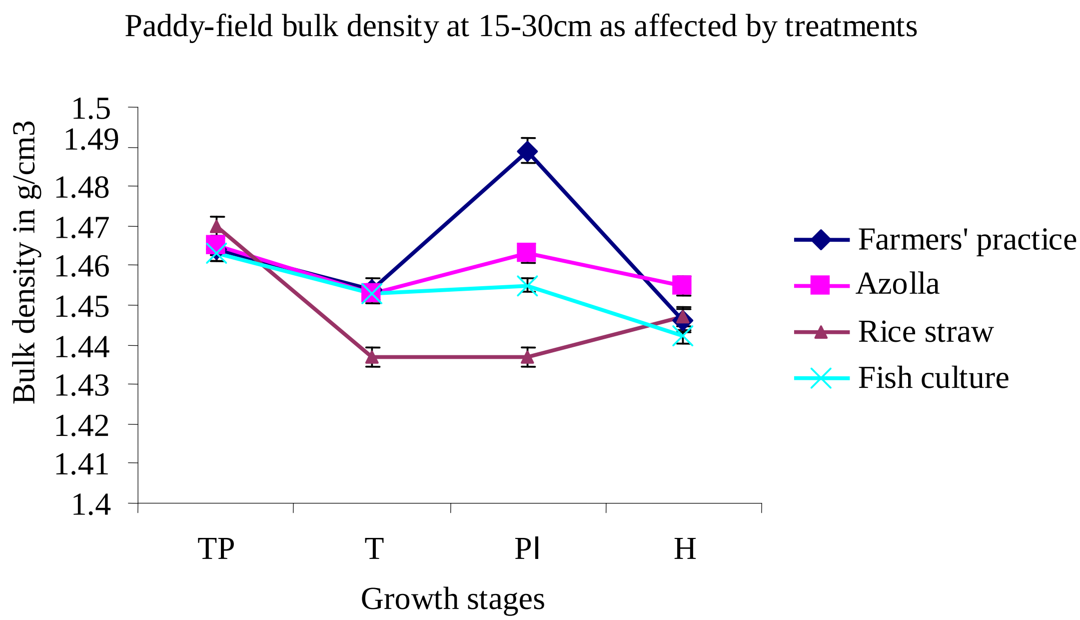
4.8 Effects of treatments on paddy field soil bulk density, at 15-30cm depths, during selected rice growth stages

Soil bulk density in subsoil was expected to have less variation, considering that the soil amendments are localized within the plough layer. Results in Table 7 illustrated in Figure 4 showed that; at 15-30 cm soil depth (un-ploughed) layer there was no significant difference ($p \leq 0.05$) within the treatments and between them and the farmers' practice, at the stage of transplanting. This was explained from the fact that, at transplanting stage no roots will have penetrated to this soil layer and the slight variation observed is due to soil inherent variation. This is the variation attributed to arrangement and orientation of soil particles (Sand, Silt and Clay).

Significantly lower bulk density ($p \leq 0.05$) was recorded in treatment with rice straw at tillering when compared with other two treatments and also with farmers' practice. This was attributed to deep penetration of root for stability and search of nutrients. Related findings were reported by Tanaka (2001) as adaptive stability mechanism of rice crop in rice straw amended paddy-field considered to be boggy.

At panicle initiation, the bulk density of rice straw treatment was still significantly different ($p \leq 0.05$) when compared with farmers' practice. This explained root growth beyond plough layer in treatments with straw despite the evident gradual increase in bulk density associated compaction resulting from weight of overlying saturated layer and the ponded water that always compact the sub-layer as reported by Humphrey *at al*,.(2004).

At harvest, the soils were considered to have stabilized from the dynamics of the two antagonistic forces of root growth and that compactive weight of saturated plough layer and ponded water.



TP= Transplanting **T**= Tillering **PI**= Panicle initiation **H**= Harvest

Figure 4: illustrates the trend of bulk density dynamics at layer underlying the plough layer.

4.9 Effect of treatments on paddy field effective hydraulic conductivity (K_{eff}) at saturated soil layer (0-30 cm)

Effects of treatments on effective hydraulic conductivity (K_{eff}) of the paddy field saturated root-zone are shown in Table 8 and further illustrated in Figure 5. At transplanting, only the treatment with rice straw had significantly higher hydraulic conductivity ($p \leq 0.05$) when compared to farmers' practice. This was associated with the large particle sizes of the chopped rice straw that created cavities through which gravitational water could percolate through the plough layer, but on reaching the subsurface layer this was further facilitated by cavities of macro-fauna activity during two week period of straw incorporation in absence of flooding. Cracks were also evident in this layer prior to flooding due to vertisols high co-efficient of linear expansivity (COLE) this cavities are responsible for high hydraulic conductivity. The former was associated with ants and termites searching for carbon rich material to grow fungus a food-source. The same observation was reported by Saroj *et al* (2005) in which termite destroyed rice seedlings transplanted to rice straw amended plots. The latter can be supported by the fact that during the dry-off-season cracks develop in vertisols profile one of the diagnostic features (FitzPatrick, 1988) and was also considered by Cabangon *et al*., (2000) to cause serious water loss in rice cultivation especially when puddled layer remains permeable.

At tillering there were significant differences in K_{eff} ($p \leq 0.05$) for treatments compared to farmers' practice. A slight increase in hydraulic conductivity was also observed within each treatment when compared with their values at transplanting (Figure 5). This showed that there was a variation in root formation and their orientation defined by treatment applied. Rice straw treatment had exceptionally higher K_{eff} due to previous macro-fauna (termite activity) coupled chemo-taxied growth of root to subsurface layer for available nutrients leached from ploughed layer and remaining active cracks. Tanaka (2001) and Yang *et al*., (2010) reported the varying orientation of rice roots with change in soil bulk density.

At panicle initiation, there were still significant differences in K_{eff} ($p \leq 0.05$) between the treatments and the farmers' practice. A declining trend in hydraulic conductivity was also noticed (Figure 5). The former observation was still associated with root growth patterns while the latter was attributed to surface sealing (crusting) at the interface between the ponded water soil surfaces that reduce infiltration mainly caused by prolonged ponding that destroy surface soil structures. This is also coupled to lesser extend by the ponded water gravitational weight (ρhg) that exerted compactive pressure to the saturated layer as observed in the trends of bulk densities (Figure 3 and 4), which result in lowering of hydraulic conductivity.

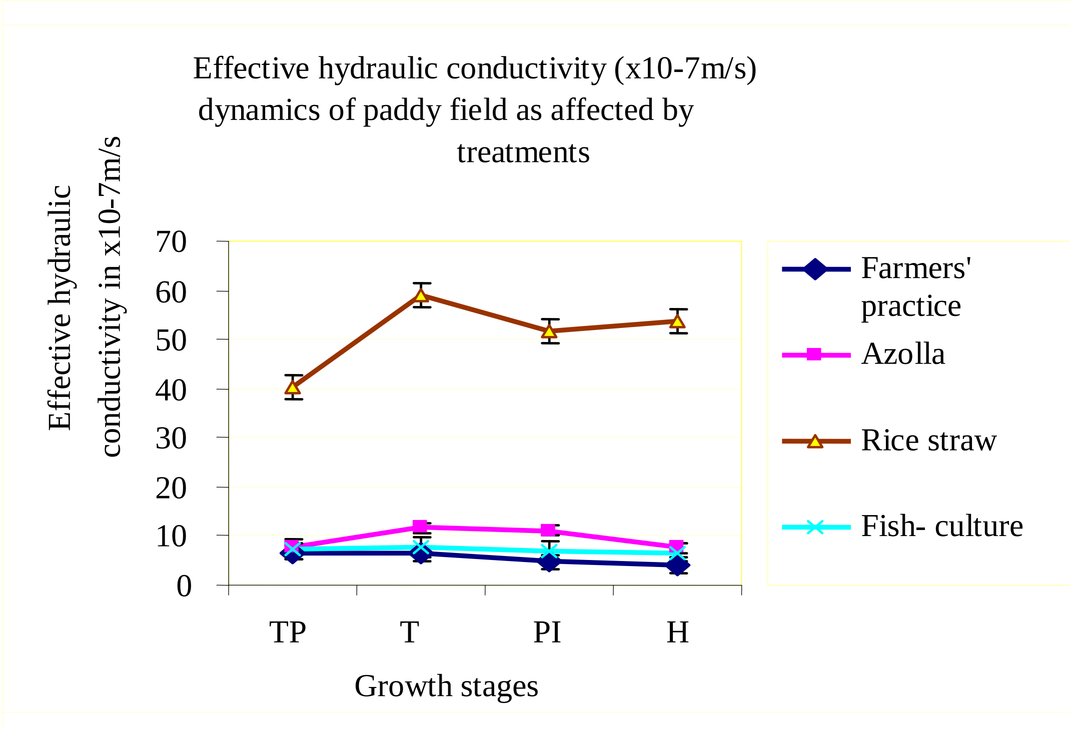
At harvest, effective hydraulic conductivities of all the treatments were still significantly different ($p \leq 0.05$) when compared with farmers' practice. The difference between the treatments and farmers' practice was still associated to root systems and the latter observation on the trend was attributed to the two phenomena i.e. crusting and compaction as evident by variation in bulk densities shown in Figure 3 and 4.

Table 8: Treatments affect on the effective hydraulic conductivity ($x10^{-7}$m/s) of paddy- field root-zone

Treatments	TP	T	PI	H
T1	6.65 b	6.43d	4.71d	4.08c
T2	7.74b	11.72b	11.08b	7.70b
T3	40.28a	58.98a	51.71a	53.24a
T4	7.17b	7.61c	6.80c	6.70b
SED	2.55	0.31	0.45	0.54
LSD	6.23	0.76	1.09	1.39
%CV	20.2	1.8	2.9	3.7

NB Values followed by the same letter are not significantly different (LSD, $P \leq 0.05$)

T_1= Farmers' practice (58 KgN/ha) **T_2**= Farmers' practice+ 2 ton/ha azolla incorporation. **T_3**= Farmers' practice + 2 ton/ha rice straw incorporation. **T_4**= Farmers' practice + fish-culture



TP= Transplanting **T**= Tillering **PI**= Panicle initiation **H**= Harvest

Figure 5: Illustrate the trend of effective hydraulic conductivity in paddy field root zone as affected by treatments.

4.10 Effect of treatments on paddy field water requirement

The effects of treatments on paddy field water requirement are shown in Table 9. Results showed significant differences among treatments ($p \leq 0.05$) and also when compared with farmers' practice. On computing difference in water consumption between each treatment and the farmers' practice, it was observed that the percentage differences were -10.76, -6.98, and +7.25 for Azolla, fish-culture and rice straw respectively. Treatment with rice straw was significantly highest in paddy field water requirement ($p \leq 0.05$), this was attributed to the high soil permeability (Figure 5) that led to high volumes of discharge from the root zone.

Table 9: Effects of treatments on paddy rice field water requirement

Treatments	Water requirement (Megalitres/ha)
T1	18.91b
T2	16.87d
T3	20.28a
T4	17.59c
SED	0.10
LSD	0.25
%CV	4.7

NB Values followed by the same letter are not significantly different (LSD, $p \leq 0.05$)

T_1= Farmers' practice (58 KgN/ha) **T_2**= Farmers' practice+ 2 ton/ha azolla incorporation. **T_3**= Farmers' practice + 2 ton/ha rice straw incorporation. **T_4**= Farmers' practice + fish-culture.

Treatment with Azolla and that with fish-culture had significantly lower paddy field water requirements ($p \leq 0.05$) when compared with farmers' practice, with that of Azolla registering the least. In the case of Azolla, during the culture period inoculated Azolla grows on the surface of water (Plate1) providing mulch to evaporation. The limited evaporation results in net water saving as reported in Kamalasanan *et al.* (2004). Movement of fish in the paddy field is not uniform and some parts of the paddy field may experience more traffic than others, causing destruction of surface soil structures and subsequent surface sealing retarding infiltration a phenomenon that may not have been captured by measurements of hydraulic conductivity. This be considered to be the cause of water save in fish-culture treatment. This finding is supported by Falayi and Bouma (1990) who reported crusting in flooded soil especially with trafficking (surface movement) that cause soil structure destruction on soil surface resulting in ‘skin-like’ sealing reducing saturated hydraulic conductivity.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- Application of organic amendments to paddy-field vertisols (clay soil) affects bulk density and hydraulic conductivity. The amendments lower bulk density while increasing the hydraulic conductivity.
- Azolla incorporation and fish-culture increases growth and yields of paddy rice while rice straw incorporation into paddy-field lowers rice growth and yields because of N immobilization.
- Azolla incorporation and fish-culture reduces paddy-field water requirement while rice straw incorporation in a paddy-field increases its water requirement.

5.2 Recommendations

5.2.1 Recommendations for production

- Farmers with low income should practice Azolla incorporation or fish-culture to supplement nitrogen fertilizer provided by National Irrigation Board (NIB) to boost their rice yields.
- Farmers should find other economical uses of rice straw like making hay for ruminants or subjecting to co-plant for energy generation to power water pumping machines.

5.2.2 Recommendations for further research

- Further research should be carried out to understand how Azolla lower evaporation, a factor that contributes to low paddy-field water requirement.
- Interaction between Azolla incorporation and fish- culture should also be studied.

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APPENDICES

Appendix I: Working formula for bulk density and hydraulic conductivity

(a) Bulk density

Bulk density = (mass of oven dried soils)/ (volume of soil core in cm^3)

= M/V (g/cm^3)

Where; M=mass in grammes and Volume in cm^3

(b) Hydraulic conductivity

Falling head method; used for low permeable soil with high content of soil.

Hydraulic conductivity (K) = 2.303QL/At $\log_{10}(h_1/h_2) \equiv$ QL/At $\log_e(h_1/h_2)$

Where: K = hydraulic conductivity (m/s),

Q = water discharge (m^3),

L = length of soil column (m),

A= Cross-sectional area of soil sample (m^2),

t = time taken for discharge Q,

h_1 = Initial water depth in column head, and

h_2 = Final water depth in column head.

(c) Effective hydraulic conductivity of the two layers

$1/K_{effective} = 1/K_{layer1} + 1/K_{layer2}$

$K_{effective}$ = Product (K_1 x K_2)/ sum (K_1+K_2)

Where K_1=hydraulic conductivity of layer 1

K_2 =hydraulic conductivity of layer 2

Appendix II: An outline of the general analysis of variance (ANOVA) used in all statistical analysis without interactions

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F 5%
Block	2				
Treatment (T)	3				
Repetition	2				
Error	28				
Total	35				

Grand mean

S.E

Lsd (0.05)

Appendix III: Outline of water requirement chart during growth season.

Water requirement (mm)	Block I											
	Treatment 1			Treatment 2			Treatment 3			Treatment 4		
	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Land preparation ∑(IR+R) in (mm) during tillage												
Rainfall in (mm) sourced from rainfall chart ∑[(rainfall)] during culture period.												
IR (mm) day/month/year												
Example;12/3/2011	23	34	32	52	45	48	60	65	63	23	25	30
“												
“												
Total irrigated water ∑ IR												
Grand total water to a plot												
Mean												

Where IR= Irrigation water and R= Rainfall.

NB: This is a case of only one block; the same apply to other two blocks.

Conversion to Mega Litres/ hectare;

1 hactare =10,000 M^2 , 1mm= 0.001M and 1M^3 = 1000litres

Therefore; Total volume of water in the paddy field;

Volume/ hactare = 10,000M^3 x (mean of treatment from chart above)x0.001M

Volume in **Megalitres/ hactare** =Volume in M^3 x1000/ (10^6)

Appendix IV: Sketch of plot layout