EFFECT OF WATER MANAGEMENT SYSTEMS WITH DIFFERENT NUTRIENT COMBINATIONS ON PERFORMANCE OF RICE ON SOILS OF MVUMI, KILOSA DISTRICT, TANZANIA

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ABSTRACT

A comprehensive study was conducted on soils of Mvumi Village, Kilosa District, Tanzania to investigate the effect of water and nutrients on the growth and yield of rice so as to improve rice production by manipulating water and nutrients. Soil characterization, fertility evaluation and pot experiment were conducted. The soils of the study area were classified respectively as *Ustic Endoaquerts* and *Haplic Vertisols* in the USDA Soil Taxonomy, and World Reference Base for Soil Resources. Nitrogen (N), Phosphorus (P) and Potassium (K) were deficient in all sampled fields whereas micronutrients were adequate except for Zn which was low. A pot experiment was set to test the effect of water and nutrients on performance of rice. The experiment was laid in a split plot design with two water management systems (SRI= Alternate wetting and drying, FLD= Continuous flooding) as main factor and five nutrient combinations ($N_0P_0K_0S_0$, $N_{400}P_0K_0S_0$, $N_{400}P_{80}K_0S_0$, $N_{400}P_{80}K_{50}S_0$, $N_{400}P_{80}K_{50}S_{40}$) as sub-factor. Nutrients and water had significant effect on growth, yield and nutrient content of rice. Overall, treatment $N_{400}P_{80}K_{50}S_{40}$ had significantly ($P < 0.05$) higher number of tillers (12.44 tillers plant^{-1}), plant height (98.86 cm), grain yield (26.26 g plant^{-1}) and biomass yield (23.57 g plant^{-1}) as well as total P (0.27%), K (1.07%) and S (0.15%) concentrations in biomass shoot than other treatments. On the other hand, the highest number of tillers (11 tillers plant^{-1}), grain yield (20.74 g plant^{-1}), biomass yield (17.37 g plant^{-1}) and S (0.13%) concentration in biomass shoot were recorded in SRI while the highest plant height (95.47 cm), N (2.02%), P (0.24%) and K (0.89%) concentrations in biomass shoot were recorded in FLD. The results of interaction of nutrients and water showed that, grain yield increased significantly ($P < 0.05$) from 4.71 g plant^{-1} to 27.37 g plant^{-1} in FLD + $N_0P_0K_0S_0$ and SRI + $N_{400}P_{80}K_{50}S_{40}$, respectively.

DECLARATION

I, Ikunda Herman Massawe, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

……………………………   …..………………………

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The above Declaration is confirmed

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DEDICATION

I wish to dedicate this work to Almighty God and my beloved mother ROSALIA HERMAN MASSAWE who laid the foundation of my studies.

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LIST OF ABBREVIATIONS AND SYMBOLS

AWD	Alternate Wetting and Drying
^{o}C	Degree Celsius
C/N	Carbon to Nitrogen ratio
CEC	Cation Exchange Capacity
CEC_{clay}	Cation Exchange Capacity of clay
EC	Electrical Conductivity
ESP	Exchangeable Sodium Per cent
et al.	And others
FAO	Food and Agricultural Organization of the United Nations
i.e.	That is
IUSS	International Union of Soil Science
MAFC	Ministry of Agriculture, Food and Cooperatives
MRP	Minjingu Rock Phosphate
OC	Organic Carbon
pH	Negative logarithm of hydrogen ion concentration
RLDC	Rural Livelihood Development Company
SA	Sulphate of Ammonia
SOM	Soil Organic Matter
SRI	System of Rice Intensification
SUA	Sokoine University of Agriculture
TEB	Total Exchangeable Bases
TSP	Triple Super Phosphate
USDA	United States Department of Agriculture
WRB	World Reference Base for Soil Resources

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information and Justification

Rice (*Oryza sativa* L.) is the third most important food crop in Tanzania after maize and cassava in terms of both area cultivated and production (FAO, 2008). It is a major source of income and employment for the rural poor farmers (Ministry of Agriculture Food Security and Cooperatives (MAFSC), 2009). Rice is grown in almost all regions of the country. The major producers of rice in the country are Coast, Morogoro, Tabora, Mbeya, Mwanza, Shinyanga and Arusha Regions. The national total annual average production of rice was reported to be 1.35 million tonnes (Wilson and Lewis, 2015). This national average is very low and cannot meet the demand of the increasing population of the country. Annual per capita rice consumption increased by 6.15 percent per annum, rising from 20.5 kg in 2001 to 25.4 kg in 2011 (Wilson and Lewis, 2015). At a lower scale, rice yields in Kilosa are 44 246 ton year^{-1} (Kahimba *et al*., 2015). The smallholder farmers in Mvumi Village, Kilosa District, depend on pastoralism, rice (as food and cash crop) and maize production for their livelihood. It is therefore important to improve rice production.

The low yields of rice have been attributed to low soil fertility and poor water management (MAFSC, 2009). Low soil fertility is attributed to the type of soil as related to soil parent materials (Msanya *et al*., 2003) and poor nutrient management practices used by many farmers who tend to apply N fertilizers alone and thereby leading to the depletion of other nutrients (Amuri *et al*., 2013). Balanced fertilizer application is critical for obtaining optimum yields of rice. Tabar (2012) for instance reported the increase of tiller numbers, fertile fillers, total grain, 1000-grain weight and yield upon application of nitrogen and phosphorus. Potassium application on rice fields leads to the increase in plant height, number of tillers, size of panicles and yield of rice (Uddin *et al*., 2013). Sulphur has also been reported to influence growth and yield of rice, in which case Resurreccion *et al*. (2001) reported an increase in the relative growth rate (RGR) due to the increase in the net assimilation rate (NAR) upon the increase of sulphate concentration in soil. Likewise, Jawahar and Vaiyapuri (2010) reported the influence of S on rice growth in terms of plant height, number of tillers per plant and dry matter production as well as yield attributing characters such as number of panicles and number of grain per panicle.

Balanced application of nutrients is therefore crucial so as to gain the advantage of each nutrient and to avoid the depletion of other nutrients (Alam *et al*., 2009) for optimum yield of crops such as rice. Also due to high depletion of nutrients through crop harvest, erosion and leaching, each nutrient should be applied constantly in agricultural field (Amuri *et al.,* 2013).

Water is crucial for growth and productivity of rice as it influences the availability of nutrients through its ability to solubilise nutrients making it easy for plants to absorb them from the soil as plants can only take up mineral nutrients dissolved in soil solution (Mengel, 2001). Also water can lead to loss of nutrients from soil through its influence on erosion and leaching if not managed properly.

In Tanzania, rice is predominantly produced by smallholder farmers under rain fed conditions. Smallholder farmers belonging to government controlled irrigation schemes have been reported to produce rice on medium sized farms ranging from 2 to 2.5 hectares (Wilson and Lewis, 2015). Due to unreliable rainfall, irrigation remains to be very important as far as rice production is concerned. However, irrigated rice production system has been stated to be the largest consumer of water in the agricultural sector

(Uphoff, 2007; Lampayan and Tuong, 2007). Due to climate change and increasing urban and environmental demands on water, water scarcity has increased and this has endangered the sustainability, food production and ecosystem services of rice fields (Lybbert and Sumner, 2010). Hence, there is a need for improving water use efficiency especially in rice fields.

Flooding is the commonly used irrigation system in irrigated rice cultivation. In this system water is delivered to the field by ditch, pipe or some other means and simply flows over the ground through the crop. With flood irrigation, large amount of water applied is lost through evaporation, runoff, infiltration of uncultivated areas and transpiration through the leaves of weeds. Due to this fact it is assumed that only half of the water applied actually ends up irrigating the crop. This makes the flooding method to be inefficient for rice production, and as a result, "System for Rice Intensification (SRI)" was developed so as to reduce losses of water and increase the productivity of rice.

SRI is an agro-ecological methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients (SRI online, 2015). This system involves applying small amounts of water regularly or alternating wet and dry field conditions so as to maintain a mix of aerobic and anaerobic soil conditions (Uphoff, 2007). After flowering, a thin layer of water is kept on the field. This practice has been reported to result in higher yields ranging from 6 to 8 ton ha^{-1} with reduction of water consumption by an average of 50% (SRI online, 2015).

Other than the report by Honde (2016) which showed the deficiency of some important nutrients for growth and productivity of rice and low yields that do not conform with SRI at Mvumi, there has been no study in Mvumi, Kilosa that has been conducted to investigate the effect of combining N, P, K and S with different water management systems on growth and yield of rice. Therefore, this study was conducted to compare the effect of different nutrient combinations under the two water management systems on the growth and yield of rice on the paddy soils of Mvumi Village, Kilosa District, Morogoro Region in Tanzania.

1.2 Objectives of the Study

1.2.1 General objective

The main objective of this study was to investigate the effect of water management systems and nutrient combinations on growth and yield of rice on the soils of Mvumi Village, Kilosa District, Morogoro Region in Tanzania.

1.2.2 Specific objectives

Specific objectives of this study were:

i. To carry out pedological characterization of soils of Mvumi Village where paddy is grown.
ii. To carry out soil fertility evaluation of the paddy soils of Mvumi Village.
iii. To determine the response of rice under two water management systems with different combinations of nutrients.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Review of Rice Crop

Rice is a semi-aquatic annual grass plant. It includes approximately 22 species of the genus *Oryza,* of which 20 are wild (Muthayya *et al.,* 2014). Only two species out of 22 are important for human consumption, these are *O. sativa* and *O. glaberrima*. *O. sativa* was first grown in Southeast Asia, somewhere in India, Myanmar, Thailand, North Vietnam, or China, between 8000 and 15 000 years ago (Organisation for Economic Co-operation and Development (OCED, 1999). *O. glaberrima* is thought to have been domesticated from its wild ancestor *Oryza barthii* by people living in the floodplains of the Niger River in Africa about 3000 years ago. Rice is now cultivated on every continent except Antarctica.

Rice is a major food staple and a mainstay for the rural population and their food security. It is mainly cultivated by small farmers in holdings of less than 1 hectare. Rice is also a wage commodity for workers in the cash crop or non-agricultural sectors. Rice is vital for the nutrition of much of the population in Asia, as well as in Latin America and the Caribbean and in Africa; it is central to the food security of over half the world population (Muthayya *et al.,* 2014).

2.1.1 Rice botany

Rice is an annual grass plant growing up to 1.8 m tall. Rice plant has long slender leaves which are 50–100 cm long and 2–2.5 cm broad. The leaves are borne on the culm in two ranks, one at each node. The leaf consists of the sheath and blade. The flowers re small and wind-pollinated produced in a branched arching to pendulous inflorescence 30–50 cm long. The panicle of rice plant is borne on the uppermost internode of the culm which is often mistermed a peduncle (OCED, 1999).

The grain (caryopsis) is 5–12 mm long and 2–3 mm thick (OCED, 1999). The dehulled rice grain is known as brown rice as brownish pericarp covers it. The pericarp is the outermost layer which envelopes the caryopsis and is removed when rice is milled and polished. The embryo lies at the ventral side of the spikelet next to the lemma. Adjacent to the embryo is a dot like structure the hilum. The embryo contains the plumule and radicle. The plumule is enclosed by a sheath known as coleoptile and the radicle by the coleorhizae.

Rice has fibrous roots, possessing rootlets and root hairs. The seminal roots are sparsely branched and persist only for a short time after germination. The secondary adventitious roots are produced from the underground nodes of the young culms and are freely branched.

2.1.2 Rice global production

Developing countries account for 95% of the total production of rice, with China and India alone responsible for nearly half of the world output (FAO, 2003). World production of rice has risen steadily from about 200 million tonnes of paddy rice in 1960 to over 700 million tonnes in 2012. The three largest producers of rice in 2009 were India, China and Indonesia. Among the six largest rice producers, the most productive farms for rice, in 2012, were in China producing 6.75 tonnes per hectare (FAO, 2015).

Record increases in rice production occurred during the last three decades of the twentieth century. The Green Revolution between the 1940s and the late 1960s resulted in an increase in agriculture production among the developing countries, mainly achieved through the transfer of a series of research and technology initiatives (Muthayya *et al.,* 2014). While populations of low-income countries increased by 90% between 1966 and 2000, paddy rice production during the same period increased by 130%. About 84% of the rice-production growth has been attributed to modern farming technologies that have produced semi-dwarf, early-maturing rice varieties that can be planted up to three times per year and are responsive to nitrogen fertilizers. These new rice varieties grown in irrigated land in half of the world's harvested area contribute to nearly three-quarters of the world's total rice production (Muthayya *et al.,* 2014). Yield levels have doubled or tripled from the pre-Green Revolution average in many Asian countries.

2.1.3 Physiographic and edaphic requirements for rice production

Temperature: Temperature is climatic factor which has a favourable and in some cases unfavourable influence on the development, growth and yield of rice. Rice being a tropical and sub-tropical plant requires a fairly high temperature, ranging from 25° to 35°C (Ghadirnezhad and Fallah, 2014). The optimum temperature of 30°C during day time and 20°C during night time seems to be more favourable for the development and growth of rice crop. Rice cultivation is conditioned by temperature parameters at the different phases of growth. The critical mean temperature for flowering and fertilization ranges from 16 to 20^0C, whereas, during ripening, the range is from 18 to 32 ^{0}C. Temperature beyond 35^0C affects grain filling.

Rainfall: Paddy requires more water than any other crop. As a result, paddy cultivation is done only in those areas where minimum rainfall is 115 cm. Although the regions are having average annual rainfall between 175 -300 cm are the most suitable. Paddy also needs flooded conditions with the depth of water varying over 25 mm at the time of transplanting to as much as 150 mm for 10 weeks of the growing period.

Soils: Paddy is grown in wide range of soil, from the podzolic alluvium of China to the impermeable heavy clay of central Thailand. Fertile riverine alluvial soil is best for rice cultivation. Clayey loam soil is the best for rice cultivation as water retention capacity of this soil is very high (Moormann and van Breemen, 1978). Experts point out that, rice is grown in such varied soil conditions that it is difficult to point out the soil on which it cannot be grown. However, soils having; good water retention capacity and good amount of clay and organic matter are considered ideal for rice cultivation. Rice grows well in soils having a pH range between 5.5 and 6.5 (Smith and Dilday, 2003). Unlike other crops, paddy needs a level surface to enable the fields to be flooded at least during the growing period. Paddy requires three essential plant nutrients: nitrogen, phosphorus and potassium.

2.2 Soils Used for Rice Cultivation

Rice is unique among the major food crops in its ability to grow in a wide range of hydrological situations, soil types and climates. Rice is the only cereal that can grow in wetland conditions. Soils having good water retention capacity with good amounts of clay and organic matter are ideal for rice cultivation. Clay or clay loams are most suited for rice cultivation, such soils are capable of holding water for long and sustain crop whereas sandy soils and coarser loamy soils are less productive to rice (Moormann and Breemen, 1978). Rice, being a semi-aquatic crop, grows best under submerged conditions. Rice plant is able to tolerate a wide range of soil reaction, but, it does have a preference for acidic soils. It grows well in soils having a pH range between 5.0 – 7.5 (Smith and Dilday, 2003). It can be grown on alkali soils also, after treating them with gypsum or pyrite. Rice is cultivated on a variety of soils in different rice growing regions. The soil orders for rice cultivation are Alfisols, Andisols, Aridisols, Entisols, Gelisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols and Vertisols (Fageria, 2014).

2.3 Water Management Systems in Rice Fields

An adequate water supply is essential for plant growth. When rainfall is not sufficient, additional water supply in form of irrigation is necessary (Yang, 2012).

2.3.1 Alternate wetting and drying (AWD)

Alternate Wetting and Drying also known as controlled irrigation or multiple irrigation, is a water management system that aims at reducing water use in irrigated rice fields without lowering the productivity (Dill *et al*., 2013). In this practice, rice fields are alternately flooded and un-flooded rather than kept continuously submerged like under conventional rice farming. This practice involves repeatedly flooding a farm field, typically to a water depth of around 5 centimetres, allowing the field to dry until the upper soil layer starts to dry out (typically when the water level drops to around 15 centimetres below the soil surface), and then re-flooding the field (Uphoff, 2015). The depth of water is monitored by using a field water tube which is made of 40 cm long plastic pipe or bamboo, and has a diameter of 15 cm or more so that the water table is easily visible (IRRI, 2009). This cycle can continue from 20 days after sowing until 2 weeks before flowering. The numbers of non-flooded days between irrigation vary between one and ten days depending on the plant's development stage and water availability (Dill *et al*., 2013; IRRI, 2009). N fertilizer is applied preferably on the dry soil just before irrigation is applied.

Benefits of AWD

Alternate wetting and drying (AWD) is a water management practice in irrigated lowland rice that saves water and reduces greenhouse gas (GHG) emissions while increasing rice productivity (Richards and Sander, 2014).

Reduction of water use

Alternate Wetting and Drying (AWD) can reduce water use by up to 30% due to reduction of the number of irrigation events required hence the amount of water applied since the field is not continuously flooded (Richards and Sander, 2014). Alternate Wetting and Drying reduces seepage and percolation during production hence helps to increase the water use efficiency (Nalleya *et al*., 2014). Thus AWD irrigation method helps farmers to cope with water scarcity and increase reliability of downstream irrigation water supply. There is also a potential of increasing the cropped area since the same amount of water can be used to irrigate a larger area.

Greenhouse gas mitigation potential

Alternate Wetting and Drying is assumed to reduce methane (CH_4) gas emissions by an average of 48% compared to continuous flooding (Richards and Sander, 2014). However combination of AWD with nitrogen-use efficiency and management of organic inputs can further help to reduce greenhouse gas emissions. This suite of practices can be referred to as AWD+ according to Richards and Sander (2014).

Increased net return for farmers

Safe AWD does not reduce yields compared to continuous flooding, and may in fact increase yields by promoting more effective tillering and stronger root growth of rice plants. Farmers who use pump irrigation can save money on irrigation costs and see a higher net return from using AWD. Alternate Wetting and Drying may reduce labour costs by improving field conditions (soil stability) at harvest, allowing for mechanical harvesting.

2.3.2 Flood irrigation system

Flood irrigation also known as basin irrigation, is the traditional technology of irrigating rice plants where rice plants are grown in flat areas of land surrounded by bunds and can stand in wet or waterlogged condition in the flooded basin (Yang, 2012). Continuous flooding irrigation system is the commonly used practice in traditional irrigation for rice production, but is now regarded as water consuming (Yang, 2012). In flood irrigation systems water is commonly very uneven in distribution, it can either be in excess or not sufficient. This method has been linked with methane production because the longer rice is flooded, the more methane-producing bacteria grow and the more they generate methane.

2.4 Nitrogen, Phosphorus, Potassium and Sulphur for Growth and Productivity of Rice

The growth of the rice plant and any other plant depends largely on the availability of three important resources which are: sunlight, water and chemical elements. Sixteen elements are recognized as essential in plant nutrition these are: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper, boron, zinc, molybdenum and chloride (Silva and Uchida, 2000). All these elements are supposed to be present in soil for plant to access them except for carbon, hydrogen and oxygen which can be absorbed directly out of the air and water. In considering the effects of individual elements, the relative amounts of other elements present is important for example, nitrogen alone produces certain effects, but the effects may be quite different if there is a proper balance between nitrogen, phosphorus, potassium and other elements.

In this section, the function of four nutrient elements (N, P, K and S) in growth and productivity of rice is described in detail.

2.4.1 Nitrogen

Nitrogen is taken by plants as nitrate (NO^{3-}) and ammonium (NH^{4+}) ions. Nitrogen is required throughout the growth period, but the greatest requirement is between the early to mid tillering and panicle initiation stages (Dobermann and Fairhurts, 2000).

2.4.1.1 Functions of nitrogen in plants

Nitrogen (N) promotes rapid growth, increases leaf size and quality, hastens crop maturity, and promotes fruit and seed development (Tucker, 1999). Nitrogen is an essential constituent of amino acids, nucleic acids, nucleotides and chlorophyll (Dobermann and Fairhurts, 2000). Because N is a constituent of amino acids, which are required to synthesize proteins and other related compounds, it plays a role in almost all plant metabolic processes. Amino acids are used in forming protoplasm, the site for cell division and thus for plant growth and development (Silva and Uchida, 2000). Since all plant enzymes are made of proteins, N is needed for all of the enzymatic reactions in a plant. N is an integral part of chlorophyll needed for photosynthesis, which is the process through which plants utilize light energy to convert atmospheric carbon dioxide into carbohydrates. Carbohydrates provide energy required for growth and development (Tucker, 1999). N is a necessary component of several vitamins and it improves the quality and quantity of dry matter in leafy vegetables and protein in grain crops (Silva and Uchida, 2000). In rice nitrogen promotes rapid growth i.e. increase plant height and number of tillers. Also it promotes increased leaf size, spikelet number per panicle, percentage of filled-spikelets in each panicle and grain protein content (Dobermann and Fairhurts, 2000).When applied in the soil nitrogen helps to increase plant height, tillering, and consequently panicles and yield. Nitrogen also improves root growth which is especially important in absorption of water and nutrients. Additionally N also improves panicle number and panicle length in upland rice. Thus N affects all parameters contributing to yield (Dobermann and Fairhurts, 2000).

2.4.1.2 Deficiency symptoms of nitrogen in rice plants

Rice plants with nitrogen deficiency become stunted with yellow leaves. Nitrogen deficiency in rice results in reduced tillering, small leaves, short plants and subsequently low yield. N deficiency occurs at critical growth stages such as tillering and panicle initiation when the demand for N is large (Dobermann and Fairhurts, 2000).

2.4.2 Phosphorus

Phosphorus (P) is one of the major essential nutrients required by higher plants for growth and reproduction (Fageria, 2014). It is available to plants as orthophosphate ions (HPO_4^{2-}, $H_2PO_4^-$).

2.4.2.1 Functions of phosphorus in plants

Phosphorus activates coenzymes for the production of amino acids used in protein synthesis; it decomposes carbohydrates produced during photosynthesis and it is involved in many other metabolic processes required for normal growth, such as photosynthesis, glycolysis, respiration, and fatty acid synthesis. It enhances seed germination and early growth, stimulates blooming, enhances setting of buds, aids in seed formation, hastens maturity, provides winter hardiness to crops planted in late fall and early spring and stimulates the growth of meristematic regions (Tucker, 1999). In photosynthesis and respiration, P plays a major role in energy storage and transfer as ADP and ATP (adenosine di- and triphosphate) and DPN and TPN (di- and triphosphopyridine nucleotide) (Silva and Uchida, 2000). P is part of the RNA and DNA structures, which are the major components of genetic information. P has been shown to reduce disease incidence in some plants and has been found to improve the quality of certain crops (Silva and Uchida, 2000).

Just like other cereal grains, rice requires a considerable amount of P for vigorous growth and high yield. Phosphorus is important to the rice seedling during the time it is recovering from transplanting shock. Phosphorus greatly stimulates root development in the young plant, thus increasing its ability to absorb nutrients from the soil also P helps to increase the number of tillers and consequently the number of panicles in rice (Fageria, 2014).

2.4.2.2 Deficiency symptoms of phosphorus in rice

Phosphorus deficiency has been identified as the major limitation for crop production around the world (Fageria, 2014). Phosphorus deficiency symptoms occur mainly at the onset of tillering when rice begins to rapidly accumulate dry matter (Fageria, 2014). Rice plants with P deficiency become stunted and dark green with erect leaves and reduced number of tillers (Fageria, 2014; Dobermann and Fairhurts, 2000). The older leaves of the plant become narrow, short and very erect with reddish or purple colour due to accumulation of anthocyanins (Dobermann and Fairhurts, 2000). Also P deficiency can reduce the total yield of rice plant as it may lead to the reduction of number of leaves, panicle and number of grains per panicle. Moreover plants with P deficiency tend to be highly susceptible to diseases such as brown spot (Fageria, 2014).

2.4.3 Potassium

Potassium is taken by plants in form of potassium ion K^+. Unlike N and P, K does not form any vital organic compounds in the plant.

2.4.3.1 Functions of potassium in plants

Although not an integral part of cell structure, K regulates many metabolic processes required for growth, fruit and seed development (Tucker, 1999). Potassium is vital for plant growth because it is known to be an enzyme activator that promotes metabolism. K controls the opening and closing of leaf stomata hence regulates water use in plants. In photosynthesis, K has the role of maintaining the balance of electrical charges at the site of ATP production. K promotes the translocation of photosynthates (sugars) for plant growth or storage in fruits or roots. Through its role assisting ATP production, K is involved in protein synthesis. K has been shown to improve disease resistance in plants, improve the size of grains and seeds and improve the quality of fruits and vegetables (Silva and Uchida, 2000). Also K gives plumpness to grain and seed, improves firmness, texture, size and colour of fruit crops and increases the oil content of oil crops (Tucker, 1999).

Because of the presence of K in most irrigation water, the response of rice to potassium is often not as marked as the responses to nitrogen and/or phosphorus, except in unusual situations (e.g. when certain toxicities are offset by potassium). Nevertheless, potassium should not be overlooked as an important nutrient element, since each crop requires approximately 15 kg of potassium for every tonne of yield.

2.4.3.2 Deficiency symptoms of potassium in rice

Potassium is highly mobile in plants hence its deficiency symptoms appear in lower older leaves then along the leaf edge and finally on the leaf base (Dobermann and Fairhurts, 2000). K deficiency symptoms are commonly detected during early reproductive growth at the beginning of panicle initiation stage and can lead to increased spikelet sterility (Fageria, 2014). However in most cases K deficiency is not easy to detect as P and N deficiencies because the symptoms always appear during later growth stages. K deficiency symptoms in rice include stunted plant with little reduction of tillers, droopy and dark green upper leaves and chlorosis of the interveinal areas and margins of the lower leaves starting at the tips (Fageria, 2014). Severe K deficiency can cause yield loss due to reduced grain size and weight.

2.4.4 Sulphur

Sulphur (S) is one of the abundant elements in the earth's crust and is essential for all biological activities (Fageria, 2014). Sulphur is a secondary macronutrient and is available to plants as the sulphate ion, SO_2^{-4}.

2.4.4.1 Functions of sulphur in plants

S is a constituent of three S-containing amino acids, namely cysteine, cystine and methionine, which are the building blocks of protein. About 90% of plant S is present in these amino acids (The Sulphur Institute (TSI), 2008). S is also required for production of chlorophyll and utilization of phosphorus and other essential nutrients; it ranks equal to nitrogen for optimizing crop yield and quality (Tucker, 1999). It increases the size and weight of grain crops and enhances the efficiency of nitrogen for protein manufacture and optimizes nitrogen utilization in crops with high nitrogen requirements (Tucker, 1999). With reference to crop quality, S improves protein and oil percentage in seeds, cereal quality for milling and baking, marketability of dry coconut kernel (copra), quality of tobacco, nutritive value of forages (TSI, 2008). Sulphur is actively involved in metabolism of the B vitamins biotin and thiamine and co-enzyme A, also it aids in seed production, nodule formation in legumes and stabilizing protein structure (Silva and Uchida, 2000).

2.4.4.2 Deficiency symptoms of sulphur in rice

Sulphur deficient rice plants become pale green with light coloured young leaves. Sometimes S deficiency can be confused with N deficiency. Unlike N deficiency where older leaves become chlorotic, whole plant turn pale yellow in S deficiency and chlorosis is more pronounced in young leaves and can lead to tip necrosis (Dobermann and Fairhurts, 2000). Severe S deficiency can lead to delayed maturity.

2.5 Overview of Fertilizer Use for Rice Production in Tanzania

Common fertilizers used particularly in rice fields range from organic to inorganic (RLDC, 2009). Organic fertilizers are farm yard manure and compost which are found locally but are not very widely used. Inorganic fertilizers such as Urea, Triple Super Phosphate (TSP), Di-Ammonium Phosphate (DAP), Ammonium Sulphate (S.A), Minjingu Rock Phosphate (MRP) and Calcium Ammonium Nitrate (CAN) are widely preferred as reported by RLDC (2009). Also Lwezaura *et al*. (2011) have reported Urea, DAP and Minjingu to be the mainly used fertilizers and other fertilizers such as NPK, CAN, booster and Farm yard manure to be minimal used. Chemical fertilizer application is limited as per recommended level by agronomists (125 - 250 kg of urea per ha). About 47.2 per cent of farmers apply fertilizers but lack of capital is among the reason reported by many farmers which might be the cause for the higher percentages for non-fertilizer user. The use of fertilizer also differed across regions; Mbeya and Morogoro are leading in the use of fertilizers registering about 22.5 and 19.3 percent respectively (Lwezaura *et al*., 2011).

2.6 Review of the System of Rice Intensification (SRI)

2.6.1 Definition and origin of SRI

The System of Rice Intensification, known as SRI, le Système de Riziculture Intensive in French and la Sistema Intensivo de Cultivo Arrocero (SICA) in Spanish is an agro-ecological methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients (SRI online, 2015). SRI is based on the cropping principles of significantly reducing plant population, improving soil conditions and irrigation methods for root and plant development, and improving plant establishment methods (SRI online, 2015).

SRI was developed in Madagascar by a remarkable French priest/agronomist, Father Henri de Laulanié, S.J., who spent 34 years (1961 - 1995) working with farmers, to help them improve their rice productivity and their livelihoods without having to rely on purchased inputs (Uphoff, 2015). Most of the SRI practices were assembled and synthesized into this system by the 1983-84 main season, some 30 years ago (Uphoff, 2015).

2.6.2 Management practices on SRI

2.6.2.1 Plant management

SRI involves manipulation of rice plant so as to enhance its growth and productivity. SRI includes transplanting young seedlings, at the 2 leaf-stage, preferably 8-12 days old (SRI online, 2015). These small plants should be grown in an unflooded nursery and then removed gently, with minimum trauma to their roots, being replanted in the main field carefully, quickly and shallow (1-2 cm) (Uphoff, 2015). There should be wider spacing between plants, with seedlings planted singly i.e. one per hill instead of 3-6 to avoid root competition, and in a square pattern, usually 25 x 25 cm or wider in good quality soil (SRI online, 2015). With this spacing plant densities in the field are reduced by 70-90%. This gives plants' roots and canopies more room to grow and spread, acquiring more nutrients and sunlight (Uphoff, 2015).

2.6.2.2 Soil management

SRI involves application of soil organic matter so as to improve soil quality (Dill *et al*., 2013). Enriching of the soil with organic matter helps to improve soil structure, nutrient and water holding capacity and favour soil microbial development. Organic matter represents the base fertilization for the crop and is complemented if needed by fertilizer.

2.6.2.3 Water management

In SRI management practice soil is intermittently wetted and dried, so that the soil is mostly aerobic, never hypoxic (Uphoff, 2015). This practice involves application of minimum amount of water during the vegetative growth period. A 1-2 cm layer of water is introduced into the paddy, followed by letting the plot dry until cracks become visible, at which time another thin layer of water is introduced. During flowering a thin layer of water is maintained, followed by alternate wetting and drying in the grain filling period, before draining the paddy 2-3 weeks before harvest (SRI online, 2015). This method is called ‘intermittent irrigation’ or ‘Alternative Wetting and Drying’ (AWD) (SRI online, 2015). This irrigation system gives good drainage and helps to avoid lack of oxygen in the soil which will otherwise suffocate the plant roots and the aerobic soil organisms that plays many beneficial roles in the soil.

2.6.2.4 Nutrient management

Addition of organic matter helps to increase the availability of nutrients. Most common organic matter sources are compost, animal manure, green manure and crop residues such as rice straw (SRI online, 2015). Also organic matter enhances the ability of soil to hold more nutrients in the rooting zone and release them when the plants need them (SRI online, 2015). Depending on the yield level and on the farming system, some farmers use exclusive organic fertilization for their SRI plots. The majority of farmers complement the organic matter amendment with chemical fertilizers, most often urea, in order to achieve a balanced fertilization of the crop (SRI online, 2015).

2.6.2.5 Weed management

While avoiding flooded conditions in the rice fields, weeds grow more vigorously, and need ideally to be kept under control at an early stage (SRI online, 2015). In SRI weeding is done at least two, ideally three times so as to aerate the soil, stimulate soil biota and strengthen the nutrient fixation in the soil (Dill *et al.*, 2013). Weeding can be done by using a rotary hoe - a simple, inexpensive, mechanical push-weeder (SRI online, 2015).

2.6.3 Benefits of SRI

The benefits of SRI include: 20%-100% or more increased yields, up to a 90% reduction in required seed, and up to 50% water savings (SRI online, 2015). Kahimba *et al*. (2014) has reported higher number of tillers per hill and better root development, high grain yield and low water use upon use of SRI technology.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

Mvumi Village lies at latitude 06° 35' 48.9" South and longitude 37° 13' 31.5" East with elevation of 413 m above sea level. It is located near Hussein Paulo's Farms about 46 km from Dumila town. The parent material of the soil at the site is alluvium derived from Gongwe Mountains. The site has a slope gradient of 0.5%. When dry, the surface is characterized by wide deep cracks extending from surface to more than 50 cm depth which implies the presence of Vertisols. No erosion signs were observed in the area but deposition occurs due to flooding during the rainy season. The soils are moderately well drained to somewhat poorly drained.

The climate of the area is characterized by a monomodal rainfall pattern consisting of a warm rainy season from November to May with its peak in April (Fig. 1). Annual rainfall ranges from 532.4 mm to 1536.8 mm (Appendix 1). The maximum temperature varies between 29.2°C to 31.8°C and minimum temperature range between 20°C to 24.2°C (fig. 2). Agricultural activities in the study area are dominated by rice cultivation which is grown both as a food and cash crop.

3.2 Pedological Characterisation of the Study Area

Pedological characterization of the area was done so as to understand the type of soils present in the study area and their characteristics.

3.2.1 Soil sampling for pedological characterisation

Reconnaissance survey was conducted by using transect walk, auger observation and description to establish representative study sites on the basis of landforms and other physiographic attributes.

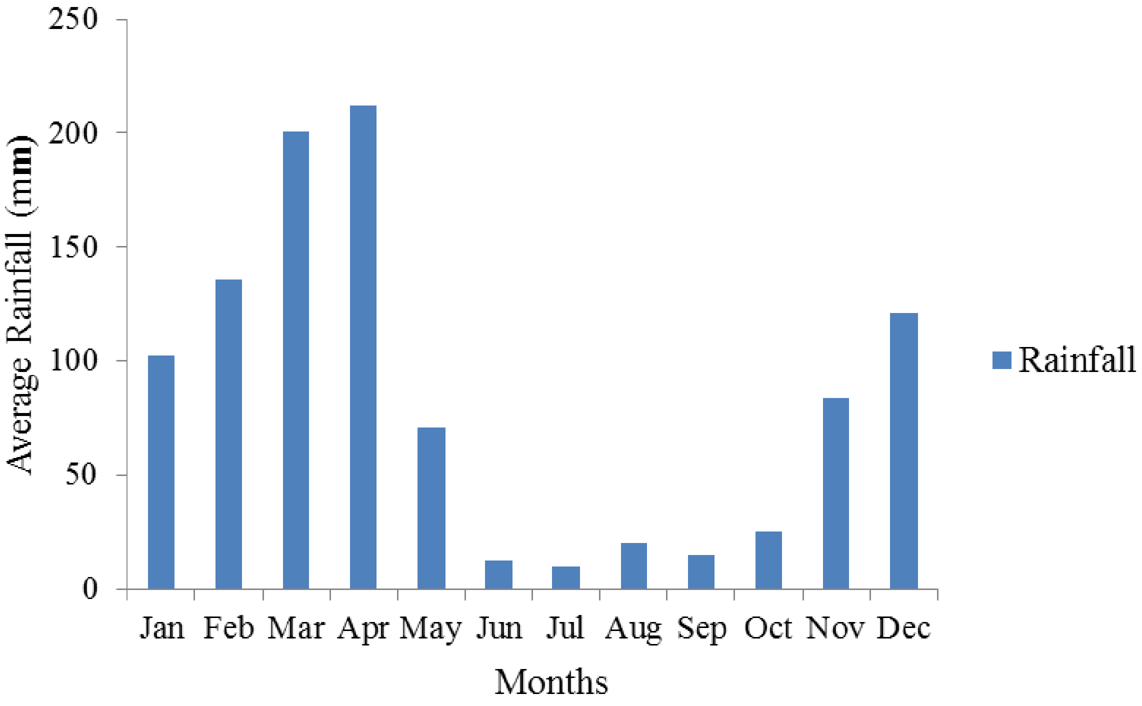

Figure 1: Mean monthly rainfall data of the study site (2007-2015)

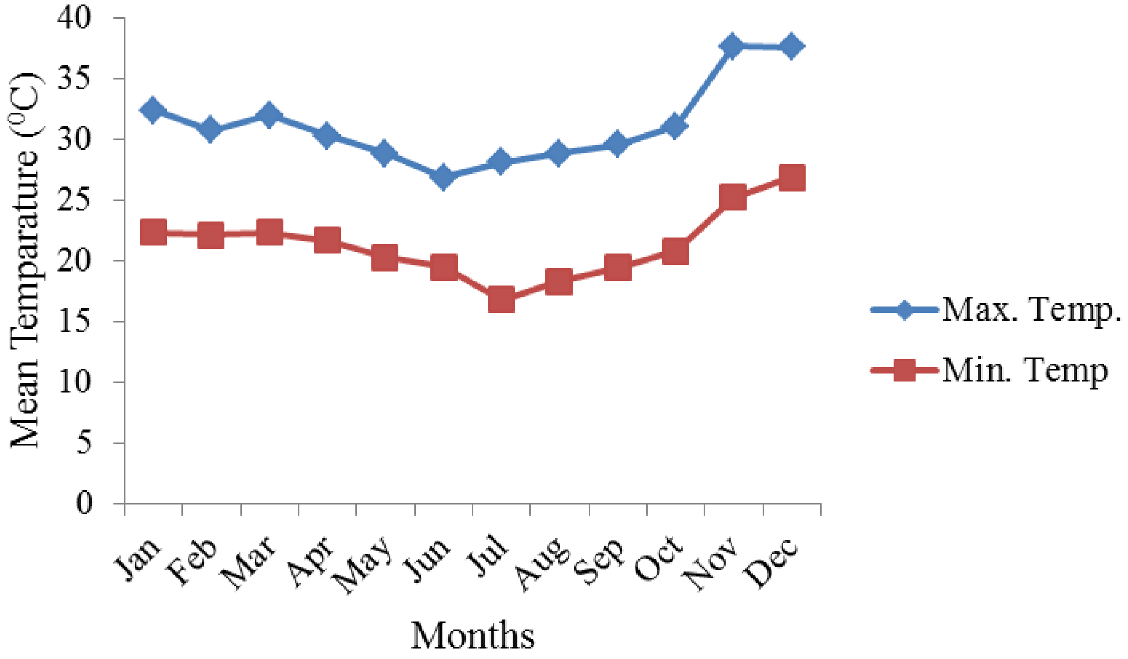

Figure 2: Mean monthly maximum and minimum temperatures of the study site (2007-2015)

A soil pit was dug measuring 3 m wide x 5 m in length and 2 m deep and described following standard guidelines by FAO-UNESCO (2006). Data were entered onto field description forms based on the FAO Guidelines for Soil Description (FAO-UNESCO, 2006) and samples from each horizon were collected.

Disturbed soil samples from each genetic horizon (weighing 1 kg) of the representative soil profile were collected and analysed in the Department of Soil and Geological Sciences Laboratory to generate data required for soil classification and characterisation. Undisturbed core samples were collected from three sections of the profiles.

3.2.2 Soil Analysis for Pedological Characterization

The undisturbed soil samples were used for the determination of bulk density (BD) and soil moisture retention characteristics. Bulk density was determined by using Gravimetric method by weighing soil cores after drying to constant weight at 105ºC (Blake and Hartge, 1986).

Disturbed soil samples were used for determination of other physical and chemical properties after air-drying, gently crushing and sieving through a 2 mm sieve. Particle size analysis was determined by hydrometer method (Day, 1965) after dispersion with 5% sodium hexametaphosphate and textural classes were determined using the USDA textural class triangle (USDA Soil Taxonomy, 1975). Soil pH was measured potentiometrically in water and in 1 N KCl at the ratio of 1:2.5 soil:water and soil:KCl (McLean, 1986), respectively. Organic carbon (OC) was determined by the Walkley and Black wet oxidation method as described by Nelson and Sommers (1982) and organic matter (OM) was determined by multiplying by a factor of 1.724 values of organic carbon obtained. Total N was determined using the micro-Kjeldahl digestion-distillation method as described by Moberg (2000). Available phosphorus was determined using filtrates extracted by the Bray and Kurtz-1 method and determined by spectrophotometer at 884 nm wavelength following colour developed by the molybdenum blue method (Bray and Kurtz, 1945). Extractable S was analyzed using the turbidimetric method as described by Moberg (2000). Cation exchange capacity of soil (CEC_{soil}) and exchangeable bases were determined by saturating soil with neutral 1 M NH_4OAc (ammonium acetate) and the adsorbed NH_4^+ were displaced using 1 M KCl and then determined by Kjeldahl distillation method for estimation of CEC of the soil. The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were measured by atomic absorption spectrophotometer (AAS) (Thomas, 1982). Total exchangeable bases (TEB) were calculated as sum of exchangeable bases Ca^{2+}, Mg^{2+}, K^+ and Na^+. DTPA extractable micronutrients (Zn, Mn, Fe and Cu) were determined using the procedure described by Lindsay and Norvell (1978). Total elemental composition (oxides) was determined as follows: Samples were ground to particle size ≤ 177 µm using swing mill pulverizer. Powdered samples were pressed into XRF sample cups and mounted with PANalytical B.V. X-Ray film-polyester PETP (Polyethylene Terephthalate Polyester), and then elemental oxides were measured by PANalytical, Minipal 4 Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRF) Model PW4030/45B.

Penetration resistance of each identified horizon was measured by using Japanese Penetration Model DKI-5551 of Daiki Rika Kogyo Company. The following formula was used to calculate penetration resistance in kg cm^{-2}:

Penetration resistance (kg cm^{-2}) = (100*X)/0.7952(40-X)^{2}…………………………(1)

Where X = mm of penetration reading

3.2.3 Soil classification

Using field and laboratory analytical data for pedological characterisation, the identified soils were classified using the USDA Soil Taxonomy (Soil Survey Staff, 2014) and the World Reference Base for Soil Resources scheme (IUSS Working Group WRB, 2015).

3.3 Soil Fertility Evaluation

Soil samples (0 - 30 cm depth) were collected from rice growing farms at Mvumi Village in order to identify problem areas i.e. areas with low nutrient contents. Eight samples from eight rice farms (four from the farms inside the irrigation scheme and four from farms outside the irrigation scheme) were collected using a soil auger from 0-30 cm depths from four sampling spots in each farm. The four sub-samples collected from sampling spots in each farm were mixed and quartered to obtain representative samples of 1 kg for laboratory analysis. The representative composite samples were dried, ground and passed through a 2 mm sieve to obtain a fine earth. The sieved samples were labelled well and packed for analysis of various soil physical and chemical characteristics as shown in Table 1.

3.6 Pot experiment

A pot experiment was set to test the effect of two water management systems and combination of nutrients on the performance of rice. 4 kg of well characterized soil sample portions of the 8 mm sieved bulk composite soil samples were weighed into 4.5 litre capacity plastic pots. The experiments were conducted in the screen house of the Department of Soil and Geological Sciences at Sokoine University of Agriculture (SUA) but soils for pot experiment were collected from a well characterized field of Mvumi Village, Kilosa District, Morogoro Region, Tanzania.

3.6.1 Collection and preparation of soil for pot experiment

From each of the four identified sampling spots in the study site about 50 kg of soil were collected from a depth of 0 - 30 cm. This makes a total of 200 kg of soil. The soil were taken to the laboratory, dried and ground to pass through 8 mm sieve. Then the soil was mixed thoroughly to form one uniform composite soil sample for pot experiment.

Table 1: Laboratory methods for soil analysis

S/n	Parameter	Method	Reference
1.	Particle size distribution	Hydrometer method	Day (1965)
2.	pH	Glass electrode method	McLean (1986)
3.	Total N	Micro-Kjeldahl method	Moberg (2000)
4.	Available P	Bray and Kurtz-1 method	Bray and Kurtz (1945)
5.	Extractable Sulphur	Turbidimetric method	Moberg (2000)
6.	Exchangeable Ca, Mg, Na and K	Atomic Absorption Spectrophotometer	Moberg (2000)
7.	Organic carbon	Walkley and Black method	Nelson and Sommers (1982)
8.	Cation exchange capacity	NH_4-acetate saturation method	Summer and Miller (1996)
9.	extractable micronutrients (Zn, Mn, Fe and Cu)	DTPA extraction method	Lindsay and Norvell (1978).

3.6.2 Separation of filled and unfilled grains

Separation of filled and unfilled grains was done by using salt water so as to ensure seed germination. In this exercise (Plate 1), winnowed seeds were put in clean water, stirred well and all floating seeds were removed. In 5 litres of water 0.5 kg of salt was added gradually in small quantities and mixed thoroughly. A fresh egg was immersed in the formed brine solution, the right concentration was determined when the egg floated in the brine. The egg was removed and the seeds that remained after removing the floating seeds were put in the brine solution and stirred. Again all floating seeds were removed and all seeds that sunk were washed with clean water five times before soaking overnight.

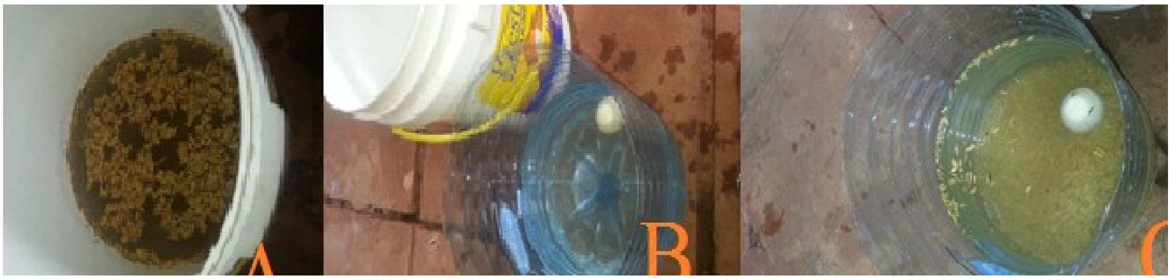

Plate 1: Separation of filled and unfilled grain using salt water and egg

3.6.3 Pre-germination of the seeds

Seeds which were found to have right quality from section 3.6.2 were soaked overnight and Incubated in a warm and shaded place for two days. Incubation helps to keep the seeds warm, increases growth of the embryo, and results in uniform germination (Plate 2). Thereafter the pre-germinated seeds were sown uniformly on the seedbed.

(A) **(B)**

Plate 2: Seeds spread on wet sheet ready for incubation (A), pre-germinated seeds ready for planting in the seed bed (B).

3.6.4 Experimental design

The experiment consisted of two factors i.e. water management systems and different nutrient combinations. There were two water management systems (SRI= Alternate wetting and drying (SRI technology) and FLD= Continuous flooding) and four nutrients combinations (N, NP, NPK, NPKS) and a control where no nutrient was applied to form ten treatment combinations. The application rates were 400 mg N kg^{-1} soil, 80 mg P kg^{-1} soil, 50 mg K kg^{-1} soil and 40 mg S kg^{-1} soil. The treatments were designated as follows:

1. Absolute Control (No nutrients added) - $N_0P_0K_0S_0$
2. $N_{400}P_0K_0S_0$
3. $N_{400}P_{80}K_0S_0$
4. $N_{400}P_{80}K_{50}S_0$
5. $N_{400}P_{80}K_{50}S_{40}$

The treatments were subjected to split plot experimental design with water management systems in main plot and nutrients combinations in sub plot with three replications. Total number of pots was 30.

3.6.5 Transplanting and fertilizer application

In the two water management systems i.e. SRI and conventional (flooding) transplanting was done at different times. In SRI technology transplanting was done 10 days after sowing where as in flooding transplanting was done 20 days after sowing as how conventional farmers do. In each pot three plants were transplanted. Fertilizers used and the amounts applied are as shown in the Table 2. Triple super phosphates, muriate of potash and ammonium sulphate were applied during transplanting. Whereas urea was applied in two splits, one half after three weeks and the second half after 56 days.

Table 2: Amount and type of fertilizer applied

s/n	Fertilizer	Amount applied (g fertilizer/4 kg soil)
1	TSP	1.596
2	MoP	0.402
3	SA	0.667
4	Urea	3.48

3.6.6 Water management

In the flooding irrigation system the pots were flooded continuously followed by draining of the pots after maturity. In SRI technology alternate wetting and drying (AWD) was performed where: 2 cm layer of water was introduced followed by letting the pots to dry until cracks become visible then another thin layer was introduced. During flowering the thin layer of water was maintained. During grain filling stage again the AWD was performed followed by draining for 3 weeks before harvesting.

3.6.7 Data collection

The following data were collected to test the effect of treatments on the growth and yield of rice: plant height, number of tillers, grain and biomass yield.

3.6.7.1 Plant height

Plant height was determined by measuring all three plants in each pot every week from transplanting up to booting stage. This was done by measuring the plant height by using measuring tape from ground level to the apex of the longest leaf. The average plant height of the three plants was calculated and recorded in cm plant height per plant.

3.6.7.2 Number of tillers

Numbers of tillers for the three plants in each pot were counted every week from week 7 to week 16. The average number of tillers per plant was calculated and recorded.

3.6.7.3 Shoot biomass

One plant was randomly sampled (cut to ground level) in each pot at 75 days for shoot biomass. Samples were sun dried in the screen house for a week and then dried in the oven dry at 70^0C to constant weight. Data were recorded as dry mass in gram per plant.

3.6.7.4 Grain yield

Grain yield was determined by weighing grains harvested from each plant after being air dried for seven days to attain the storage moisture content of 12%. Then the average grain yield of the two plants in each pot was calculated and data were recorded in gram per plant.

3.6.7.5 Plant tissue analysis

Plant tissue analysis to determine concentration of N, P, K and S was conducted so as to determine the effect of water management systems and different nutrient combinations on nutrients uptake. Rice shoot samples that were collected for biomass yield determination were also used to determine the nutrients concentration. After drying from section 3.6.6.3, the shoot samples were ground and sieved by using 0.5 mm sieve. The fine powder was digested by the HNO_3 - H_2O_2 procedure and the digests were analysed for N, P, K and S contents following procedures described by Okalebo *et al*. (1993).

3.6.8 Statistical analysis

Collected data were subjected to one way Analysis of Variance (ANOVA) using the GenStat (14th edition) statistical software. All variables recorded were analysed according to the following statistical model:

$$Y_{ijk} = U + P_j + T_i + \delta_{ij} + S_k + (ST)_{ik} + €_{ijk} \ldots\ldots (2)$$

Where:

Y_{ijk} = Response

U = Mean

P_j = Effect of block j (replication)

T_i = Effect of whole plot i (water management systems)

δ_{ij} = error a

S_k = effect of split plot k (nutrient combinations)

$(ST)_{ik}$ = effect of interaction of water management systems and nutrient combinations

$€_{ijk}$ = error b

Multiple comparisons of means for each parameter were performed using Duncan’s Multiple Range Test at 5% level of significance.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Pedological characteristics of the area

4.1.1 Morphological characteristics

Key morphological properties of the studied pedon are summarized in Table 3. This profile was very deep (>150 cm) and moderately well drained to somewhat poorly drained (FAO-UNESCO, 2006). The profile had very dark grey clays, with strong granular topsoil over weak coarse angular and wedge-shaped subsoil. Soil horizon boundaries were clear with smooth horizon topography. Soil pores were common and well distributed within the profile. Roots were distributed throughout the profile although the intensity was decreasing with increasing depth.

Table 3: Morphological characteristics of the studied soil pedon at Mvumi in Kilosa District, Morogoro Region

Horizon	Depth (cm)	Dry colour1)	Moist colour2)	Consistence3)	Structure4)	Horizon boundary5)
Ap	0 - 22	vdg (10YR3/1)	vdb (10YR2.5/3)	fr, st &pl	st, f, gr	Cs
BA	22 - 59	vdgb (10YR3/2)	dgb (10YR4/2)	vfl, vst & vpl	w, co, ab	Gs
Bwg	59 - 115	vdg (10YR3/1)	vdg (10YR3/1)	vfl, vst & vpl	w, co, ab & we	Cs
BCgk	115 - 200	sb (7.5YR5/6)	sb (2.5YR5/4)	vfl, vst & vpl	w, co, ab & we	-

1&2) Soil Colour: vdg = very dark grey; vdb = very dark brown; = very dark grey brown; dgb = dark grey brown; sb = strong brown
3) Consistence: fr = friable; stpl = sticky plastic vfl = very firm; vst = very sticky; vpl = very plastic
4) Structure: grade: st = strong; w = weak
size: f = fine; coarse = co
Type: gr = granular; ab = angular blocks; we = wedge-shaped
5) Horizon boundary: Width: c = clear; d = diffuse; g = gradual
Topography: s = smooth

4.1.2 Physical characteristics

4.1.2.1 Soil moisture characteristic curves for Mvumi soil pedon

Soil moisture characteristics of the studied pedon are presented in Fig. 3. The curves show that, there is gradual decrease in moisture as the suction potential increases in all horizons. However the lower horizon has retained more water followed by mid horizon and upper horizon. Soil moisture characteristic curve is strongly affected by soil texture. When the clay content increases also the ability of that soil to retain water increases at any particular matric potential and the more gradual is the slope of the curve (Hillel, 2007). Thus low water retention in upper horizon could have been contributed by its high sand content (Table 4).

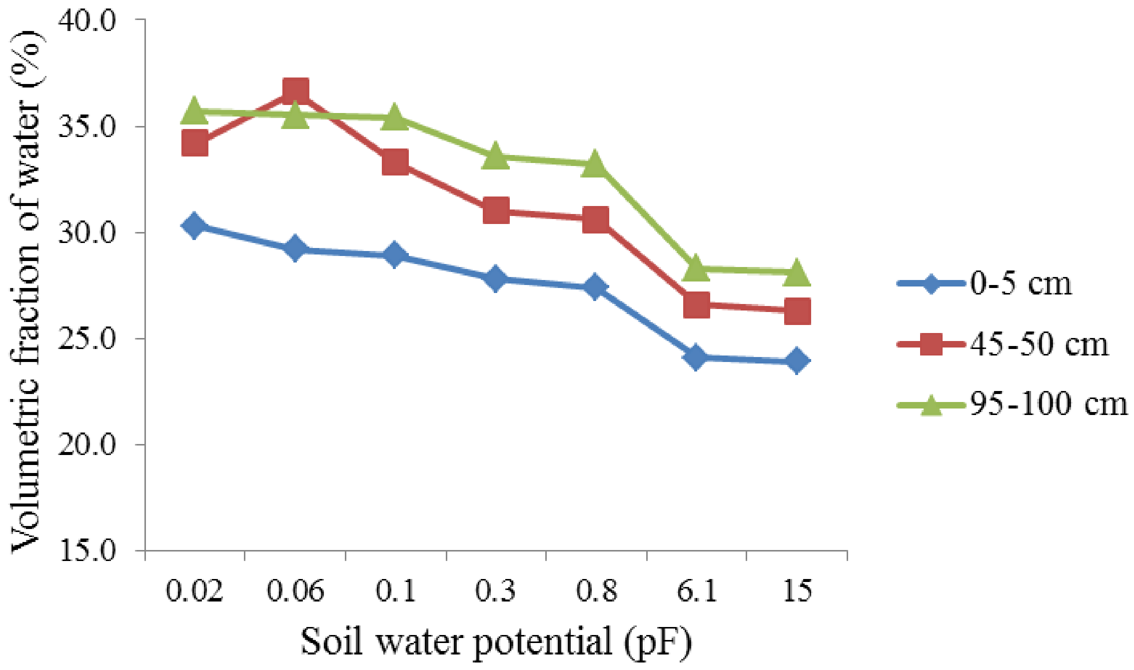

Figure 3: Moisture characteristic curves of the studied soil pedon at Mvumi, Kilosa District, Morogoro Region

4.1.2.2 Soil texture

Results of particle size distribution of the studied pedon are shown in Table 4. This pedon had clay texture throughout its depth. The upper horizon (horizon Ap) had lower amount of clay and higher sand content. Horizons BA and Bwg had the same amount of clay which was higher than in the upper and lower horizons and the lower horizon (horizon BCkg) had lower clay content than mid horizons (Horizons BA and Bwg) but higher than in the upper horizon and the sand content in this horizon was higher than in Horizons BA and Bwg. Silt content was very low in all horizons. Silt/clay ratio in upper horizon was higher than in the mid and lower horizons, this implies that the mid and lower horizons are resistant to weathering than the upper horizon. However high clay content in sub horizons is very important as far as rice cultivation is concerned because it helps to minimize the percolation of water (Smith and Dilday, 2003).

4.1.2.3 Bulk density and soil moisture content

Values of bulk density of the studied pedon are shown in Table 4. According to Hazelton and Murphy (2007) the upper horizon i.e. the plough layer had moderate bulk density whereas the sub horizons had high bulk density. Bulk density is an important physical property of the soil which is used as a measure of soil compactness and hence roots penetration, soil structure and soil aeration. According to Hazelton and Murphy (2007) the upper horizon is somehow too compacted and the values are below the critical value of 1.4 g cm^{-3} for root growth therefore root. Penetration is not restricted in this horizon whereas mid horizons are highly compacted and are above the critical value for root growth therefore root penetration is highly restricted in these horizons. On the other hand soil moisture was seen to increase with depth (Table 4).

Table 4: Physical properties of the studied pedon at Mvumi in Kilosa District, Morogoro Region

Horizon	Ap	BA	Bwg	BCkg
Soil depth (cm)	0 - 22	22 - 59	59 - 115	115 - 200
Sand %	43	31	29	35
Silt %	7	3	5	3
Clay %	50	66	66	62
Textural class	Clay	Clay	Clay	Clay
Silt/clay	0.14	0.05	0.08	0.05
Bulk density (g/cc)	1.34	1.78	1.68	Nd
Penetration resistance (kg cm^{-1})	3.81	43.55	64.68	4.35
Moisture %	10.28	13.38	26.67	Nd

nd = not determined

4.1.2.4 Penetration resistance

Penetration resistance of the four horizons of the studied pedon is presented in Table 4. The upper and lower horizons had lower penetration resistance (3.81 and 4.35 kg cm^{-2} respectively) than the mid horizons (43.55 and 64.68 kg cm^{-2}). Hazelton and murphy (2007) classified penetration resistance in respect to degree of soil consolidations as follows: < 5.1 kg cm^{-2} as loose consolidated, 5.1 - 12.75 kg cm^{-2} as medium consolidated, 12.75 - 20.40 kg cm^{-2} as dense, 20.40 - 30.60 kg cm^{-2} as very dense and > 30.60 kg cm^{-2} as extremely dense. According to this classification the upper and lower horizons are loose consolidated and do not affect root growth whereas the mid horizons are extremely dense and root growth in these horizons ceases. These results support the results of bulk density in section 4.1.2.3 which indicated that the upper horizon is not much compacted like the mid horizons. For example Kebeney *et al.* (2015) reported low penetrometer resistance in the upper top-soil which was attributed to low bulk density and reduced matric potential.

4.1.3 Chemical properties

4.1.3.1 Soil pH

Results of soil pH in water and in KCl of the studied Mvumi pedon are presented in Table 5. The pH of this pedon increases down the profile ws an acidic upper horizon and alkaline lower horizon. Low pH in the upper horizon than in the lower horizon is due to low amount of bases in upper horizon than in lower horizon as shown in Table 5. This situation might have been caused by leaching of the bases (Ca, Mg, K, and Na) down the profile hence reducing its amount in upper horizon.

Table 5: Soil pH and some nutrient contents of the studied pedon at Mvumi, Kilosa District, Morogoro Region

Horizon	Soil depth (cm)	Soil pH		OC	OM	N	C/N ratio	Avail. P	Extr. S
		H_2O	KCl		%			mg kg^{-1}	
Ap	0 - 22	5.48	4.34	2.58	4.45	0.25	10.3	4.280	14.06
BA	22 - 59	6.72	5.39	0.57	0.98	0.13	4.4	0.075	12.99
Bwg	59 - 115	7.16	6.22	0.29	0.50	0.14	2.1	0.007	28.54
BCgk	115 - 200	8.34	7.46	0.16	0.28	0.07	2.3	0.001	37.76

4.1.3.2 Soil available phosphorus

Results of available phosphorus of the studied pedon are presented in Table 5. It was observed that the value of available phosphorus ranges from 0.001 to 4.28 mg kg^{-1}. According to Landon (1991) categorization of P in the soil, the studied pedon had very low available P in all horizons. Also it was observed that the amount of available P decreases down the profile. Decrease in P with depth can be due to the decrease in organic matter content down the profile. Organic matter plays a major role in P availability due to its ability to coat aluminium and iron oxides, which reduces P sorption (Debicka *et al*., 2015).

4.1.3.3 Soil organic carbon, total nitrogen and carbon: nitrogen ratio

Results of organic carbon and organic matter of the studied pedon are presented in Table 5. There is a decrease in organic matter and organic carbon with increase in depth. The upper horizon had high organic carbon and organic matter than mid and lower horizons. Total nitrogen in the studied pedon ranged from 0.07% to 0.25% in lower and upper horizon respectively. According to Landon (1991) this range of N is rated as low. Low nitrogen in this pedon could be due to low organic matter content. It was further observed that, like organic carbon N was decreasing with increasing depth with higher values in upper horizon than lower horizon. Higher organic matter and nitrogen in upper horizon than in mid and lower horizons could have been contributed by anthropogenic activities where farmers tend to leave rice straw in the farms after harvesting and application of nitrogenous fertilizers such as Urea so as to enrich the soil with nitrogen.

4.1.3.4 Soil exchangeable bases and cation exchange capacity (CEC) of the studied pedon at Mvumi, Kilosa

Amounts of exchangeable bases (Ca, Mg, K, and Na), total exchangeable bases (TEB) and base saturation per cent (BS%) of the studied pedon are presented in Table 6. Ca, Mg and Na were increasing with depth while K was decreasing. Increase of Ca, Mg and Na with depth could be due to the leaching of these bases hence concentrating them in the lower horizons. Also TEB and BS% increased with depth with highest values in Bwg. Leaching of bases is the likely explanation for this scenario. BS% in the studied pedon ranged from 50.2 to 95.3%. BS% is an indicator of extent of leaching of bases. According to Metson (1961) the Ap horizon is moderately leached, whereas BA, Bwg and BCgk are very weakly leached.

Table 6: Exchangeable bases, CEC and micronutrient content of the Mvumi soil pedon at Kilosa, Morogoro

Horizon	Soil depth (cm)	Exch. Bases cmol (+) kg^{-1}					BS%	CEC_{soil}	CEC_{clay}	Micronutrients (mg kg^{-1})			
		Ca	Mg	K	Na	TEB		Cmol (+) kg^{-1}		Cu	Mn	Fe	Zn
Ap	0 - 22	11.5	8.3	0.47	0.26	20.53	50.2	40.92	81.84	6.69	26.91	398.98	2.02
BA	22 - 59	14.2	13.3	0.24	0.34	28.08	71.4	39.32	59.58	2.85	12.63	30.90	0.13
Bwg	59 - 115	16.4	18.6	0.25	0.98	36.23	95.3	38	57.58	3.13	9.51	23.16	0.38
BCgk	115 - 200	16.4	17.4	0.22	1.22	35.24	90.8	38.82	62.61	1.86	2.57	10.99	0.63

Cation exchange capacity (CEC) of the studied pedon ranged from 38 cmol (+) kg^{-1} to 40.92 cmol (+) kg^{-1} (Table 6). According to Metson (1961) rating of CEC, all horizons have high CEC. High CEC is due to high clay content in this pedon. CEC$_{clay}$ of the four horizons are shown in Table 6. CEC$_{clay}$ is used as a rough guide to clay mineralogy. According to Shaw *et al.* (1998) all the horizons of the studied pedon have clay mineralogy dominated by smectite which is a 2:1 silicate clay mineral.

4.1.3.5 Soil micronutrients

Four important micronutrients namely Cu, Mn, Fe and Zn were analysed and the results are presented in Table 6. Cu ranged from 1.86 to 6.69 mg kg^{-1}, Mn ranged from 2.57 to 26.91 mg kg^{-1}, Fe ranged from 10.99 to 398.98 mg kg^{-1} and Zn ranged from 0.13 to 2.02 mg kg^{-1}. According to Landon (1991) rating of micronutrients, Cu, Mn and Fe were high in all horizons whereas Zn was low. Low Zn in this pedon might have been contributed by the flooded conditions which tend to reduce Zn solubility (Smith and Dilday, 2003). It was further noted that Cu, Mn and Fe decreased with increasing depth. The decrease of these micronutrients could be due to the increasing soil pH. Fe becomes more available in low pH soils and decrease when soil becomes alkaline. Cu and Mn are more available at pH of 5 to 6.5 and decrease when pH is below 5 or above 6.5.

4.1.3.6 Soil nutrient balance

Nutrient ratios (Ca/TEB, Ca/Mg, Mg/K and % K/TEB) of each horizon of the studied pedon are presented in Table 7. Ca/Mg ratio ranged from 0.88 to 1.39 and Mg/K ratio ranged from 17.66 to 79.09. According to Msanya *et al*. (2001), the Ca/Mg ratio ranges of 2 to 4 and Mg/K in the range of 1 to 4 are considered favourable for most crops. According to this rating it is observed in this profile that, Ca/Mg ratio is below the optimum range in all horizons while the Mg/K ratio is above the optimum range in all horizons. Low ratio of Ca/Mg observed in this pedon can limit the uptake of Mg by plants. Mg/K ratio in this profile are very high, this imply that Mg was very high and can lead to nutrient imbalance and toxicity.

Per cent K/TEB and Ca/TEB of the studied pedon ranged from 0.62% to 2.29% and 0.45 to 0.56 respectively. Only the Ap horizon had the per cent K/TEB ratio above 2% which is favourable for most crops, other horizons had per cent K/TEB below 2%. According to Landon (1991), Ca/TEB ratios in Ap and BA horizons will negatively affect uptake of other bases particularly Mg and K as they are above 0.5. Horizons Bwg and BCgk have favourable Ca/TEB ratio.

Table 7: Soil nutrient ratios of the Mvumi soil pedon at Kilosa District, Morogoro Region

Horizon	Soil depth (cm)	Ca/TEB	Ca/Mg	Mg/K	% K/TEB
Ap	0 - 22	0.56	1.39	17.66	2.29
BA	22 - 59	0.51	1.07	55.42	0.85
Bwg	59 - 115	0.45	0.88	74.40	0.69
BCgk	115 - 200	0.47	0.94	79.09	0.62

TEB = total exchangeable bases

4.1.3.7 Total elemental composition and chemical index of alteration

Results of total elemental composition and chemical index of alteration of the studied pedon are presented in Table 8. It is observed that SiO_2 is the most abundant oxide in this pedon followed by Fe_2O_3 and Al_2O_3. Other oxides i.e. K_2O, CaO, TiO_2, MnO, P_2O_5, MgO and Na_2O are in very low concentration i.e. below 4%. Higher concentration of SiO_2 in this pedon implies the dominance of quartz minerals in the area whereas the

Table 8: Total elemental composition of the studied soil pedon in Mvumi Village at Kilosa District, Morogoro Region

Soil depth (cm)	SiO_2	Al_2O_3	Fe_2O_3	K_20	CaO	TiO_2	MnO	P_2O_5	MgO	Na_2O	CIA
	%										
0 - 22	50.50	16.00	23.73	2.12	2.24	3.23	0.16	0.00	0.014	0.017	78.52
54 - 115	46.80	19.00	25.22	1.77	1.76	3.41	0.13	0.00	0.016	0.008	84.30
115 - 200	46.30	19.00	25.71	1.82	2.13	3.33	0.15	0.00	0.029	0.011	82.75

CIA = Chemical index of alteration = $\{Al_2O_3 / (Al_2O_3 + K_2O + Na_2O + CaO)\} * 100$

Observed concentration Fe_2O_3 explains the presence of Fe-containing minerals such as hematite and goethite. Chemical Index of Alteration (CIA) values of the studied pedon range from 78.52% to 84.30%. CIA is used as a measure of degree of weathering of minerals (Nesbitt and Young, 1982). Low CIA values indicate low weathering or unaltered minerals whereas high values indicated high degree of weathering.

4.2 Soil Classification

Classification of the soils of the studied area was performed based on the diagnostic horizons and other diagnostic features of the studied pedon as summarized in Table 9. This pedon was flat (slope < 1%), moderately alkaline and very deep with clayey texture, deep wide cracks and wedge-shaped aggregates. Slickensides and gilgai micro-relief were observed in this pedon. According to USDA Soil Taxonomy this pedon has an Ochric epipedon and Calcic horizon whereas according to World Reference Base for Soil Resources (WRB) it has Vertic and Calcic horizon. Therefore, this pedon (Mvumi pedon), is classified as ***Ustic Endoaquerts*** and ***Haplic Vertisols (Hypereutric, Gilgaic, Gleyic, Mazic)*** in USDA Soil Taxonomy and WRB, respectively. According to Fageria (2014), these soils are favourable for rice growth.

4.3 Soil Fertility Status of Rice Growing Areas in Mvumi Village Based on Topsoil Data.

The results on soil fertility evaluation are discussed in this section. Soil fertility evaluation was done so as to understand soil fertility status of the area which will guide on the amount of fertilizers to be added in pot experiment for better response.

Table 9: Summary of diagnostic horizons and features and classification of the studied pedon of Mvumi village, Kilosa District, Morogoro Region

Keys to Soil Taxonomy (Soil Survey Staff, 2014)

Diagnostic epipedon(s) and subsurface horizon(s)	Other diagnostic features	Order	Suborder	Greatgroup	Subgroup	Family
Ochric epipedon, Calcic horizon	Flat (slope <1%), very deep, clayey, ustic SMR, moderately alkaline, isohyperthermic STR, deep wide cracks, wedge-shaped aggregates, slickensides, gilgai micro-relief	Vertisols	Aquerts	Endoaquerts	Ustic Endoaquerts	***Flat, very deep, clayey, mildly alkaline, isohyperthermic, Ustic Endoaquerts***

World Reference Base for Soil Resources (IUSS Working Group WRB, 2015)

Diagnostic horizons	Other diagnostic features/ materials	Principal qualifiers	Supplementary qualifiers	Reference Soil Group (RSG)- TIER1	WRB soil name - TIER 2
Vertic horizon, Calcic horizon	Slickensides, cracks, wedge shaped aggregates, gilgai microrelief	Haplic	Hypereutric, Gilgaic, Gleyic, Mazic	Vertisols (VR)	***Haplic Vertisols (Hypereutric, Gilgaic, Gleyic, Mazic)***

4.3.1 Soil texture

Soil particle size (texture) of the studied sites is shown in Table 10. All sites had sandy clay texture except site S3 which had clay texture. These textural classes (sandy clay and clay) are favourable for growth of rice as they have sufficient amount of clay content and can hold water for long time as rice demand soils which can retain moisture. Moormann and van Breemen (1978) reported that sand soils and coarser loamy soils are less productive to hold water for long time as rice demand soils which can retain moisture. Moormann and van Breemen (1978) reported that sand soils and coarser loamy soils are less productive to rice compared to finer textured soils. However more water and nutrients especially nitrogen are required for rice in sand and coarser loamy than in finer textured soil which make the management more costly (Moormann and Breemen, 1978).

4.3.2 Soil pH

Soil pH of studied soils ranged from 5.2 to 7.4 as shown in Table 10. According to categorisation of soil pH by Landon (1991) these soils have low to high pH. This range of soil pH is suitable for rice growth as it is within the range of 5.0 – 7.5 as reported by Smith and Dilday (2003). Soil pH within the scheme is high compared to the areas outside the scheme. High soil pH of the scheme area could have been contributed by the quality of the irrigation water. The high pH irrigation water contributes to increased soil pH (Tacker, 2003).

4.3.3 Organic carbon

Results of organic carbon and organic matter content of the studied soils are also presented in Table 10. According to Landon (1991) the amount of organic carbon in all sites are very low. Organic matter has an effect on the availability of nutrients such as nitrogen,

Table 10: Some chemical and physical properties of top soils from the study sites

Site		Location	pH	Avail. P	S	N	OC	OM	Sand	Silt	Clay	Textural class
				mg kg^{-1}		%						
Inside the scheme	S1	06° 36' 0.2" S and 37° 13' 35.2" E	6.9	8.87	27.92	0.06	0.53	0.91	46.96	3.28	49.76	Sandy clay
	S2	06° 36' 7.8" S and 37° 13' 31.6" E	7.2	8.61	21.33	0.10	0.84	1.45	54.96	5.28	39.76	Sandy clay
	S3	06° 36' 15.3" S and 37° 13' 31.5" E	7.4	14.82	17.02	0.10	0.95	1.64	40.96	7.28	51.76	Clay
	S4	06° 36' 13.7" S and 37° 13' 33.9" E	7.1	10.94	20.12	0.11	0.88	1.52	48.96	5.28	45.76	Sandy clay
Outside the scheme	S5	-	6.4	4.63	20.78	0.10	1.14	1.97	54.96	3.28	41.76	Sandy clay
	S6	06° 36' 19.2" S and 37° 13' 24.2" E	5.2	1.54	31.52	0.17	1.75	3.02	46.96	7.28	45.76	Sandy clay
	S7	06° 36' 2.9" S and 37° 13' 32.4" E	5.5	3.58	22.08	0.13	1.14	1.97	52.96	5.28	41.76	Sandy clay
	S8	06° 35' 55.9" S and 37° 13' 34.2" E	5.6	5.79	15.92	0.19	1.22	2.10	48.96	7.28	43.76	Sandy clay

phosphorus and CEC. Low organic matter content reduces the availability of these essential nutrients for plant growth.

4.3.4 Available phosphorus

Phosphorus is one of the essential nutrients for rice growth and productivity. Available phosphorus which is the phosphorus that can be accessed by plant was determined by two methods namely Bray-1 for acid soils and Olsen for alkaline soils. Bray-1 P ranged from 1.54 to 5.79 mg P kg^{-1} soil and was classified as very low to low. Whereas Olsen P ranged from 8.61 to 14.82 mg P kg^{-1} and these were classified as medium to high P concentration. Phosphorus was low in areas outside the scheme whereas it was high in areas within the scheme (Table 10). Phosphorus is highly affected by pH. P availability decreases as soils become acidic and in calcareous soils (Tisdale *et al.,* 1993). Therefore, the high P observed within the scheme can be attributed to high pH in these areas.

4.3.5 Total nitrogen

Nitrogen is a problem in many cultivated areas. In the studied areas nitrogen ranged from 0.06% to 0.19% (Table 10). These are classified as very low to low (Landon, 1991). Low nitrogen in these areas could have been contributed by low organic matter content in these areas, continuous cultivation of rice in this area which do not permit accumulation of N as well as many chemical, biochemical and microbial transformation of N in the flooded soils (Smith and Dilday, 2003). Therefore there is need to apply nitrogenous fertilisers so as to facilitate growth and subsequently improve yield of rice in these areas.

4.3.6 Extractable sulphur

Sulphur content for the eight studied areas ranged from 15.92 to 31.52 mg S kg^{-1} (Table 10). Horneck (2011) classified sulphur as follows: 0 - 5 mg kg^{-1} low, 5 - 20 mg kg^{-1}

medium and >20 mg kg^{-1} as high. In view of this sulphur is not a big problem in the studied sites as it is high in six sites and the remaining two sites has medium content.

4.3.7 Exchangeable bases

4.3.7.1 Calcium

Calcium content of the tested soils is shown in Table 11. Calcium ranged from 5.59 to 12.51 cmol (+) kg^{-1}, values that are rated as moderate to high calcium by Metson, (1991). It was observed that sites within the scheme have high calcium than the sites outside the scheme. This variation is due to difference in pH where inside the scheme there was high pH than in sites outside the scheme.

4.3.7.2 Magnesium

Exchangeable magnesium in the studied sites ranged from 3.67 to 8.63 cmol (+) kg^{-1} (Table 11). Metson, (1991) rated Mg as follows: 0.3-1 as low, 1-3 as moderate, 3-8 as high and >8 as very high. According to this rating all the studied sites had high Mg content.

4.3.7.3 Potassium

Results of exchangeable potassium in the studied soils are presented in Table 11. According to Metson (1991) categorization of K all studied sites had low K content except site S2 which had moderate K. This shows that K is a problem in these areas and it should be applied so as to boost yield of rice. Uddin *et al*. (2013) reported an increase in plant height, number of tillers, size of panicles and yield of rice upon application of K.

Table 11: Micronutrient contents and exchangeable bases of the sites

Site	Ca	Mg	K	Na	CEC	Zn	Cu	Fe	Mn
			(cmol (+) kg^{-1})				(mg kg^{-1})		
S1	12.51	8.41	0.12	0.29	21.6	0.35	3.59	19.65	23.30
S2	8.69	3.67	0.40	0.19	15.2	0.35	2.05	24.91	30.47
S3	9.41	8.63	0.31	0.37	23	0.66	3.35	60.88	62.01
S4	10.84	5.45	0.24	0.18	21	0.55	2.99	51.23	60.57
S5	7.74	4.01	0.24	0.11	15.2	0.66	3.59	126.32	59.14
S6	9.65	6.40	0.24	0.10	21.6	1.11	4.30	306.14	46.24
S7	5.59	3.84	0.15	0.12	15.2	1.17	4.42	279.82	31.90
S8	7.74	4.51	0.24	0.15	21	1.57	5.24	174.56	27.60

4.3.7.4 Sodium

Amount of sodium in the studied soils varies from 0.10 to 0.37 cmol (+) kg^{-1} (Table 11). According to Metson (1991), all soils had low sodium content. Soils with high amount of sodium are considered as alkaline or sodic soils and are not good for growth of crops as they are salt affected soils.

4.3.8 Cation exchange capacity (CEC)

CEC of the studied sites ranged from 15.2 to 23 cmol (+) kg^{-1} (Table 11). These are classified as medium according to Landon (1991). CEC is highly affected by organic matter and clay content of the soil. Due to low organic matter of these soils the observed value of CEC comes from the clay. CEC is very important as it reflects the ability of the soil to hold nutrients. It is a very important soil property influencing soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilisers and other ameliorants (Hazleton and Murphy, 2007).

4.3.9 Micronutrients

The amount of micronutrients in the studied sites is tabulated in Table 11. According to Landon (1991) all micronutrients are rated as very high in all sites except for Zn in areas within the irrigation scheme. Zn is observed to be low in the scheme than in areas outside the scheme. Smith and Dilday (2003) have reported that high pH reduces the availability of Zn in the soil due to flooded condition which reduces Zn solubility, therefore low Zn content observed in irrigated areas could have been contributed by relatively high pH in these areas. However Zn is very important in growth and yield of rice as it helps in cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation and maintenance of membrane integrity (Dobermann and Fairhurts, 2000). Considering the roles that Zn plays in growth and yield of rice there is a need to apply Zn fertilizers such as zinc sulphate in these areas so as to supply zinc especially in the scheme where Zn was observed to be highly deficiency.

4.2 Effect of Nutrient Combinations on Growth, Yield and Nutrient Contents of Rice Shoot

The response of rice to nutrient combinations applied to the Vertisols of Mvumi Village, Kilosa District in terms of plant height, number of tillers, biomass yield, grain yield and nutrient content are discussed in this section.

4.2.1 Biomass yield

Results of effect of nutrient combinations on the biomass yield are presented in Table 12. It is observed that application of N, P, K and S significantly ($P < 0.05$) increased the biomass yield. The Control had the lowest biomass yield (3.56 g plant^{-1}) whereas the treatment with all nutrients applied together yielded highest biomass (23.57 g plant^{-1}).

Table 12: Effect of nutrient combinations on growth and yield of rice

Treatments	Biomass yield (g plant^{-1})	No. of tillers per plant	Plant height (cm)	Grain yield (g plant^{-1})
$N_0P_0K_0S_0$	3.56a	3.94a	69.72a	4.91a
$N_{400}P_0K_0S_0$	13.21b	8.28b	90.94b	20.28b
$N_{400}P_{80}K_0S_0$	18.06c	9.83c	94.36c	22.52bc
$N_{400}P_{80}K_{50}S_0$	23.47d	10.67c	92.94bc	23.24bc
$N_{400}P_{80}K_{50}S_{40}$	23.57d	12.44d	98.86d	26.26c
s.e	3.99	2.54	0.66	3.05

Means in the same column bearing the same letter(s) are not significantly different at ($P=0.05$); s.e = standard error. Treatment abbreviations with subscript numbers indicate the nutrient rates applied in mg kg^{-1}soil.

These results further depict that there was a significant ($P < 0.05$) increase in biomass yield upon application of N over the Control. Also when P was applied in combination with N biomass yield increased significantly. Similarly there was a significant increase in biomass yield when K was combined with N and P, but there was no significant difference ($P < 0.05$) that was observed when S was combined with N, P and K. Little response to the applied S could be due to the medium content of sulphur in the studied soil. Sulphur in the studied soil was 15.92 mg S kg^{-1} soil (Table 9). According to Horneck (2011) this amount is classified as medium. However, there was the highest biomass yield when all four nutrients were applied in combinations. This agrees with the law of minimum which states that “If two or more factors are limiting or nearly limiting, addition of one will have a little effect on growth and yield, whereas provision of both or all will have much greater influence on yields” (Tisdale *et al.,* 1993).

4.4.2 Number of tillers

Results on the effect of nutrient combinations on the number of tillers are presented in Table 12. Application of nutrients in combination significantly ($P < 0.05$) increased the number of tillers. The lowest numbers of tillers (3.94 tillers plant^{-1}) were recorded in the control and the highest (12.44 tillers plant^{-1}) in the application of all four nutrients together (in combination). The number of tillers per plant increased significantly from 3.94 in the absolute control to 8.28 when N was applied. These results conform to the findings by Chaturvedi (2005) who reported a significance increase in number of tillers upon application of nitrogen. However when P was applied in combination with N the number of tillers increased significantly to 9.83 tillers plant^{-1} but there was no significant ($P < 0.05$) increase in number of tillers when K was applied with N and P in combination. Tabar (2012) similarly reported an increase of number of tiller upon application of N and P together.

Also when sulphur was applied together with N, P and K the number of tillers increased significantly ($P < 0.05$) to 12.44 tillers plant^{-1}. The results of this investigation are in agreement with those by Chaturvedi (2005). The significant increase in number of tillers upon application of these nutrients implies that N, P and S were the limiting nutrients for tiller formation in the studied soil.

4.4.3 Plant height

Plant height is one of the important growth and development indicators of rice. The response of the studied rice variety to the applied nutrient combinations in terms of plant height is presented in Table 12. The plant height increased significantly ($P < 0.05$) from 69.72 cm in absolute control to 90.94 cm when N was applied. The increase in plant height in response to application of N can be attributed to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby in more dry matter accumulation (Chaturvedi, 2005). Similar results were obtained by Chen *et al.* (2013) who studied the effect of N on seed yield and yield components of *Leymus* *chinensis*. Also Chaturvedi (2005) and Malik *et al*. (2014) reported an increase in plant height when N was applied in rice. Plant height increased to 94.36 cm when P was applied in combination with N but slightly decreased to 92.94 cm when K was added in this combination. Tabar (2012) reported the increase in plant height when P is applied together with N to be due to the influence of these nutrients on plant growth and promotion of root development. Decrease in plant height when K was introduced in the combination could be due to reduction of N which is an important nutrient promoting plant growth. However when all four nutrients (N, P, K and S) were applied together plant height increased significantly ($P < 0.05$) to 98.86 cm. These results are in close conformity with the findings of Dash *et al*. (2015).

4.4.4 Grain yield

The response of rice to the applied nutrients in terms of grain yield is presented in Table 12. There was a significant increase ($P < 0.05$) in grain yield upon application of nutrients in combination. The lowest grain yield (4.91 g plant^{-1}) was obtained in $N_0P_0K_0S_0$ whereas the highest Grain yield (26.26 g plant^{-1}) was recorded in $N_{400}P_{80}K_{50}S_{40}$. Application of N increased the grain yield significantly from 4.91 g plant^{-1} in absolute control to 20.28 g plant^{-1}. However the yield increased further to 22.28 g plant^{-1} and 23.24 g plant^{-1} when P was applied together with N and K with P and N respectively. Similar results were obtained by Uddin *et al.* (2013) who found that application of N and N with K increased the grain yield by 1.39 ton ha^{-1} and 2.67 ton ha^{-1} respectively over the control. Tabar (2012) also reported significantly higher yield upon application of N and P in combination. Significant higher yield of 26.26 g plant^{-1} was obtained in this study when all four nutrients (N, P, K and S) were applied together in combination. These results are in line with the previous study of Kumar *et al.* (2012) who reported an increased grain and straw yield by 16.2 and 18.5% respectively when S was applied in combination with N, P and K over the treatments without application of S. Also Kalala *et al.* (2016) reported that sulphur application at 20 mg S kg^{-1} doubled and tripled rice grain yield in paddy soils of Kilombero.

4.4.5 Nutrient content of rice shoot

4.4.5.1 Nitrogen

Table 13 presents results of nitrogen content in rice shoot as influenced by nutrient combination. The nitrogen content ranged from 1.18% in absolute control ($N_0P_0K_0S_0$) to 2.33% in treatment with N alone ($N_{400}P_0K_0S_0$). According to Thiagalingam (2000) categorization of N in plant tissue, N was deficiency in absolute control, $N_{400}P_{80}K_{50}S_0$ and $N_{400}P_{80}K_{50}S_{40}$ while in $N_{400}P_0K_0S_0$ and $N_{400}P_{80}K_0S_0$ was sufficiency.

It is further observed that the highest nitrogen content was obtained when nitrogen alone was applied but when nitrogen was combined with phosphorus, nitrogen content in biomass straw decreased from 2.33% to 2.04%, also when K was applied together with N and P and S with N, P and K the Nitrogen content in biomass straw decreased further to 1.83% and 1.93% respectively. These results are in agreement with the findings of Mamunur (2016) who reported an increase in N content in rice plants upon application of Nitrogen fertilizer. Also he reported a decrease in N content in rice plants when K was applied.

4.4.5.2 Phosphorus

Phosphorus content in the rice biomass straw in respect to the applied nutrient combinations is tabulated in Table 13. The lowest P (0.12%) content was observed in absolute control, whereas as the highest (0.27%) P content was observed in $N_{400}P_{80}K_{50}S_{40}$ which received all nutrients (N, P, K and S) together. When nitrogen alone was applied the P content in the biomass straw increased from 0.12% in absolute control to 0.17%.

Table 13: Effect of nutrient combinations on nutrient content of rice shoot

Treatment	N	P	K	S
			%	
$N_0P_0K_0S_0$	1.18	0.12	0.38	0.13
$N_{400}P_0K_0S_0$	2.33	0.17	0.99	0.09
$N_{400}P_{80}K_0S_0$	2.04	0.25	0.84	0.11
$N_{400}P_{80}K_{50}S_0$	1.83	0.22	1.07	0.12
$N_{400}P_{80}K_{50}S_{40}$	1.93	0.27	1.07	0.15

Treatment abbreviations with subscript numbers indicate the nutrient rates applied in mg kg^{-1} soil.

This implies that N supply increased the ability of the plant to uptake/absorbs P from the soil. Similar results were obtained by Sanga (2013) who was working on sesame. Phosphorus content increased further to 0.25% when phosphorus was applied in combination with N, but when K was applied together with N and P the Phosphorus content decreased to 0.22%. Sanga (2013) reported an increase in P content in plant when phosphorus was applied and a decrease in P content when K was added. Similarly Hakan *et al*. (2010) reported a decrease in P content upon supply of K. Moreover P content increased to 0.27% when S was added in the combination. The increase or decrease in P content when another nutrient is applied is due to synergism or antagonism effect that a nutrient has with phosphorus.

4.4.5.3 Potassium

The potassium concentration in rice shoot differed significantly ($P \leq 0.05$) among the applied nutrient combinations (Table 13). The lowest K content (0.38%) was observed in the absolute control. But this concentration increased to (0.99%) and (0.84%) upon application of N alone and N with P, respectively. This implies that these nutrients (N and P) influenced the uptake of K form the soil. These results agree with the findings by Sanga (2013) who reported an increase in K content on sesame leaves from 1.42% to 2.94% and

3.70% after application of N alone and N with P respectively. The above results are also in close conformity with the findings by Dash *et al.* (2015) who reported a decrease in K concentration by 12.8 – 23% and 12.4 -16.6% in rice grain and straw upon omission of N and P in rice plant.

It is further reported that, in the current study K concentration in rice shoot increased to 1.07% when K was applied in combination with P and N. This observation is in agreement with the findings of Lema (2013) who found least potassium concentration (0.80%) in rice shoots tissues without potassium nutrition and the highest potassium concentration (1.05%) in 50 kg K ha^{-1} potassium treatment. Also the K content of 1.07% in this study was recorded in $N_{400}P_{80}K_{50}S_{40}$ which received all nutrients together.

4.4.5.4 Sulphur

Results of S content in the rice shoot biomass in respect to the applied nutrients are presented in the Table 13. S content in this study ranged from 0.09% in $N_{400}P_{80}K_0S_0$ to 0.15% in $N_{400}P_{80}K_{50}S_{40}$. Dobermann and Fairhurts (2000) reported the optimum level of S in rice shoot to be 0.15% - 0.30% and the critical level of deficiency to be 0.11% at tillering stage. According to this categorization of S in rice shoot, it is observed in this study that treatment $N_{400}P_0K_0S_0$ had S deficiency whereas the remaining treatments had sufficient S content as they were above the critical level of deficiency.

This study further showed that $N_0P_0K_0S_0$ which did not receive any nutrient had sufficient sulphur content. This is due to fact that the soil had medium S content (15.92 mg kg^{-1}, Table 4) therefore there was some amount of S in the soil for plant uptake. It is also observed in this study that, when N alone was applied the S content decreased from 0.13% to 0.09%. This decrease in S content upon application of N could be due to antagonism effect of N in S, therefore in order to avoid this effect S must be supplied in the soil. However when P was applied in combination with N and K in combination with P and N the S content in rice shoot increased to 0.11% and 0.12% respectively. The highest S content (0.15%) was obtained in $N_{400}P_{80}K_{50}S_{40}$ which received all nutrients (N, P, K and S) together. Similar results were obtained by Sanga (2013) who reported an increase in S content in sesame leaves from 0.06% to 0.28% when S was applied in combination with N, P and K. Also the findings of the present study are in close conformity with the results reported by Rahman (2007) who noted that concentration of S in rice plant increased with application of S.

4.5 Effect of Water Management Systems on Growth, Yield and Nutrient Contents of Rice

The response of rice to water management systems applied to the Vertisols of Mvumi Village, Kilosa District in terms of plant height, number of tillers, biomass yield, grain yield and nutrient content are discussed in this section.

4.5.1 Growth and yield of rice

Results on the influence of water management systems (SRI and continuous flooding) on the growth and yield of rice are presented in Fig. 4 and App. 3. It is observed that the straw biomass yield, number of tillers and grain yield were higher in a SRI water management system than in continuous flooding. In contrary plant height was higher in continuous flooding water management system than in SRI. Apart from being irrigated in alternate wet and dry manner also plants in SRI were transplanted early (at 8 days) whereas in continuously flooding seedlings were transplanted conventionally at 18 days. A relative higher straw biomass yield, number of tillers and grain yield in SRI could be due to early transplanting of the seedling which is far more important in preserving plant's potential for tillering and root growth that is reduced by later transplanting, also old seedling results in lower rice yields because they suffer from stem and root injury during pulling (Ashraf *et al*., 1999). Ali-Elhefnawy (2012) reported an increase in number of tillers and grain yield when seedlings were transplanted with young age. Uphoff and Fernandes (2002) suggested that the use of young seedlings is the single most important component practice of SRI, increasing yield in Madagascar by 2.5 ton ha^{-1}. Similar results were obtained by Ram *et al*. (2014).

Water management systems had a significant effect on days to flowering and harvest. Days to flowering and harvesting were reduced by 10 days and 14 days respectively in SRI. SRI plants began to flower at 83 days after sowing and harvested after 120 days compared to 93 days and 134 days for flowering and harvest respectively, in continuous flooding. The results of this study are in agreement with a previous study by Chapagain (2011) who reported the reduction of flowering and harvesting days by 8 and 12 days in SRI respectively.

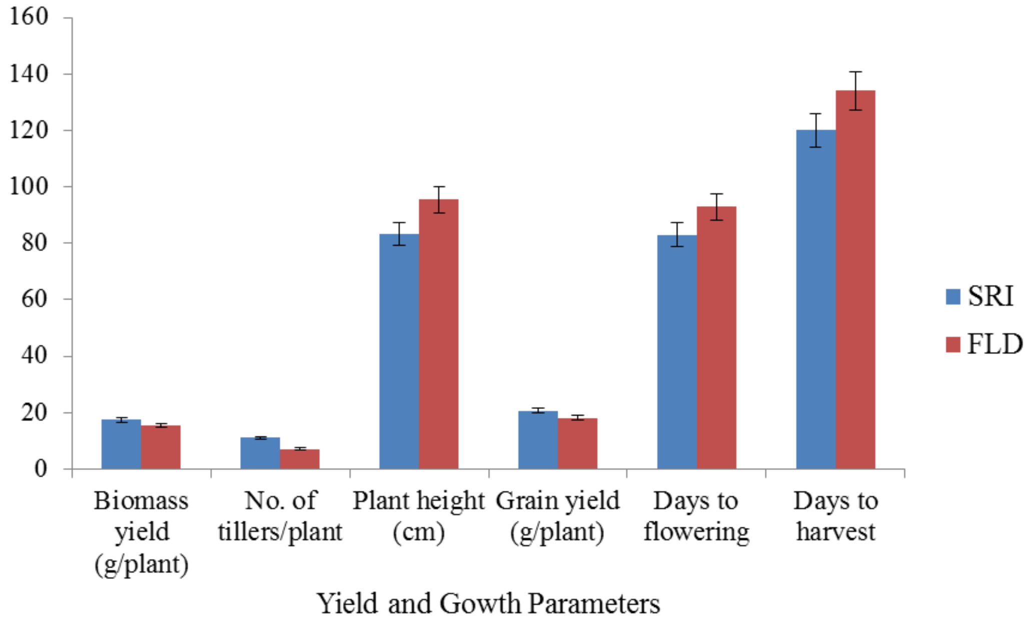

Figure 4: Effect of water management systems on growth and yield of rice

4.5.2 Nutrient content of rice shoot

The concentrations of nutrients (N, P, K and S) in rice shoot as influenced by water management systems are presented in Fig. 5 and App. 3. It is observed that N, P and K were higher in flooded than in SRI plants whereas S was higher in SRI plants than in flooded plants. Nitrogen concentration in SRI plants was 1.7% while in flooded plants was 2.02% (App. 3). High Nitrogen content observed in flooded plants could be due to mineralization of N which led to accumulation of NH_4^+ after few days of flooding (Dobermann and Fairhurts, 2000). Also Zhao *et al*. (2010) reported higher Ammonium volatilization in SRI than in Traditional Flooding, which implies more intensive N loss under SRI. Early results by Baque *et al.* (2006) also indicated reduction of N uptake by plant under water stress. On the other hand potassium concentration was 0.86% and 0.89% in plants receiving SRI and flooding water treatments respectively. Higher K content in flooded plants could be due to the increased release of exchangeable K into the soil solution and enhanced K diffusion to rice root following the reduction of Fe^{3+} and Mn^{4+} which displaces K^+ from CEC sites (Dobermann and Fairhurts, 2000).

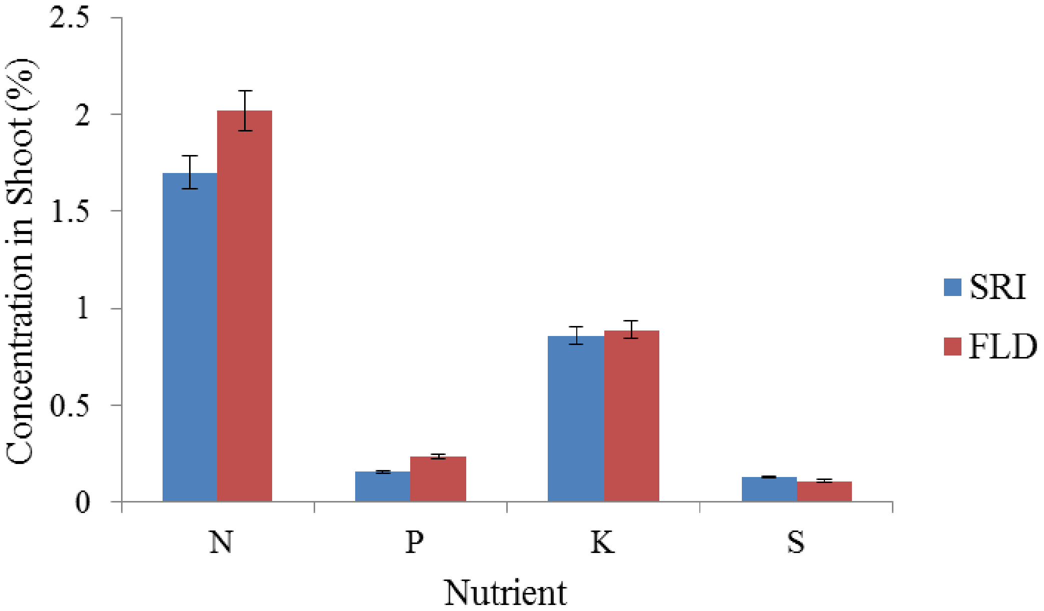

Figure 5: Effect of water management systems on rice shoot nutrient content

Phosphorus was higher in flooded plants (0.24%) than in SRI (0.16%) plants. Higher phosphorus in flooded plants could have been influenced by release of sorbed and co-precipitated P following the reduction of Fe^{2+} compounds which increases concentration of P in the soil solution (Dobermann and Fairhurts, 2000). Also flooding enhances diffusion which is the main mechanism of P supply to root (Dobermann and Fairhurts, 2000). These results are in line with the previous findings of Huguenin *et al.* (2003) who found that in the flooded soil the uptake of P was three times that in the moist soil and there was a sharp decline in P uptake in alternate wet and dry soil because in dried soil P became immobilized in the soil. Sulphur was the only nutrient that was observed to be higher in SRI plants (0.13%) than in flooding (0.11%). lower S in flooded plants could be due to reduction of SO_4^{2+} to elemental S and the formation of sulphides following Fe reduction in flooded soils. This reduction leads to S deficiency in flooded soils (Dobermann and Fairhurts, 2000).

4.6 Interaction Effect of Fertilizer Combinations and Water Management Systems on Growth, Yield and Nutrient Content of Rice Shoot

4.6.1 Growth and yield of rice

The interaction effect of different combinations of fertilizer and water management systems on growth and yield of rice is shown in Table 14. The straw biomass yield, plant height, number of tiller and grain yield was significantly different ($P < 0.05$).

The highest biomass yield of rice straw (25.23 g plant^{-1}) was recorded in treatment combination SRI + $N_{400}P_{80}K_{50}S_0$ which was statistically similar to FLD + $N_{400}P_{80}K_{50}S_{40}$ (24.19 g plant^{-1}), on the other hand the lowest biomass yield (3.07 g plant^{-1}) was recorded in SRI+ $N_0P_0K_0S_0$ which was statistically similar to FLD + $N_0P_0K_0S_0$ and FLD + $N_{400}P_0K_0S_0$ treatment combinations. In case of the plant height, the highest plant height (109 cm) was recorded in treatment combinations FLD + $N_{400}P_{80}K_{50}S_{40}$ and the lowest (63.44 cm) was recorded in SRI + $N_0P_0K_0S_0$ treatment combinations. The order of increase in plant height due to interaction effect of nutrients and water management systems was as follows:

SRI + $N_0P_0K_0S_0$ < FLD + $N_0P_0K_0S_0$ < SRI + $N_{400}P_{80}K_{50}S_0$ < SRI + $N_{400}P_0K_0S_0$ < SRI + $N_{400}P_{80}K_0S_0$ < SRI + $N_{400}P_{80}K_{50}S_{40}$ < FLD + $N_{400}P_0K_0S_0$ < FLD + $N_{400}P_{80}K_{50}S_0$ < FLD + $N_{400}P_{80}K_0S_0$ < FLD + $N_{400}P_{80}K_{50}S_{40}$

On the other hand the highest number of tiller (14.56) was recorded in treatment combination SRI + $N_{400}P_{80}K_{50}S_{40}$ which was not statistically different to SRI + $N_{400}P_{80}K_{50}S_0$ treatment combinations and the lowest number of tillers (3.78) was recorded in FLD + $N_0P_0K_0S_0$ treatment combinations. Grain yield which is the main concern to farmers were significantly higher (27.37 g plant^{-1}) in treatment combinations SRI + $N_{400}P_{80}K_{50}S_{40}$ and low (4.71 g plant^{-1}) in FLD + $N_0P_0K_0S_0$ treatment combinations, a six fold increase.

4.6.2 Nutrient content of rice shoot

The combined effect of nutrient combinations and water management systems on nutrient content of rice shoot was significantly different ($P < 0.05$) (Table 13).

The highest nitrogen concentration (2.80%) was recorded in the treatment combination FLDT + $N_{400}P_0K_0S_0$ which were followed by FLDT + $N_{400}P_{80}K_0S_0$ (2.25%). On the other hand, the lowest nitrogen concentration (1.12%) was observed in the treatment combination FLD + $N_0P_0K_0S_0$ which were not significantly different from SRI + $N_0P_0K_0S_0$.

Table 14: Interaction effect of fertilizer combinations and water management systems on growth, yield and nutrient content of rice

Treatments	N	P	K	S	No. of tillers per plant	Biomass yield (g plant^{-1})	Plant height (cm)	Grain yield (g plant^{-1})
			%					
FLD + $N_0P_0K_0S_0$	1.12a	0.12a	0.48a	0.11a	3.78a	4.05a	76 b	4.71a
FLD + $N_{400}P_0K_0S_0$	2.80d	0.21b	0.97bc	0.09a	5.78bc	9.17a	93.72 de	15.65b
FLD + $N_{400}P_{80}K_0S_0$	2.25c	0.30d	0.77b	0.09a	7.33cd	17.76b	100.17f	20.64bc
FLD + $N_{400}P_{80}K_{50}S_0$	1.90bc	0.26c	1.15c	0.12ab	8.11d	21.71c	98.33ef	22.35bc
FLD + $N_{400}P_{80}K_{50}S_{40}$	2.02bc	0.32d	1.08bc	0.13ab	10.33e	24.19bc	109g	25.15bc
SRI + $N_0P_0K_0S_0$	1.24a	0.11a	0.28a	0.15bc	4.11ab	3.07a	63.44a	5.11a
SRI + $N_{400}P_0K_0S_0$	1.86bc	0.13a	1.02bc	0.09a	10.78ef	17.25b	88.17cd	24.90bc
SRI + $N_{400}P_{80}K_0S_0$	1.82bc	0.20b	0.91bc	0.12ab	12.33fg	18.36b	88.56cd	24.40bc
SRI + $N_{400}P_{80}K_{50}S_0$	1.76b	0.18b	0.99bc	0.12ab	13.22gh	25.23bc	87.56c	24.12bc
SRI + $N_{400}P_{80}K_{50}S_{40}$	1.84bc	0.21b	1.07bc	0.17c	14.56h	22.96c	88.61cd	27.37c
CV %	12.3	10.9	18.5	16.4	11.3	22.8	3.5	27.3
s.e	0.23	0.02	0.16	0.02	1.02	3.73	3.15	5.31

Means in the same column bearing the same letter(s) are not significantly different at (P=0.05); CV = Coefficient of variations; s.e = standard error.
Treatment abbreviations with subscript numbers indicate the nutrient rates applied in mg kg^{-1} soil.

The concentration of phosphorus in rice shoot differed significantly among the treatment combinations. The highest phosphorus concentration in rice shoot (0.32%) was obtained with the treatment combination FLD + $N_{400}P_{80}K_{40}S_{40}$ which were not significantly different from 0.30% in FLD + $N_{400}P_{80}K_0S_0$. On the other hand, the lowest phosphorus concentration (0.11%) was observed in the treatment combination SRI + $N_0P_0K_0S_0$ which were statistically similar with FLD + $N_0P_0K_0S_0$ and SRI + $N_{400}P_0K_0S_0$.

The highest K concentration in rice shoot (1.15%) was obtained in FLD + $N_{400}P_{80}K_{40}S_0$ treatment combination followed by 1.08% in treatment combination FLD + $N_{400}P_{80}K_{50}S_{40}$. The lowest K concentration (0.28%) was recorded in treatment combination SRI + $N_0P_0K_0S_0$ which were significantly similar to 0.48% in FLD + $N_0P_0K_0S_0$. The highest concentration of sulphur in rice shoot (0.17%) was found in treatment combination SRI + $N_{400}P_{80}K_{50}S_{40}$ followed by 0.15% in SRI + $N_0P_0K_0S_0$. The lowest concentration (0.09%) was obtained from FLD + $N_{400}P_0K_0S_0$ which were statistically similar to FLD + $N_0P_0K_0S_0$ and SRI + $N_{400}P_0K_0S_0$.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions were made from the results that were obtained from this study:

i. The studied soils were classified as ***Ustic Endoaquerts*** and ***Haplic Vertisols*** in USDA Soil Taxonomy and WRB respectively. These soil types have characteristics which favour the growth and productivity of rice.

ii. Important nutrients for rice growth and productivity i.e. Nitrogen, Phosphorus and Potassium were deficient in all sampled fields. Micronutrients were adequate except for Zinc which was seen to be low. Sites inside the scheme had higher soil pH and exchangeable bases than sites outside the scheme whereas P, Zn, N and organic carbon were higher in sites outside the scheme than inside the scheme.

iii. Nitrogen, Phosphorus, Potassium and Sulphur were the major nutrient limiting growth and yield of rice of the studied soil as application of these nutrients together led to better growth and a six fold increase in rice yield.

iv. System of Rice Intensification (SRI) was best in promoting the growth and yield of rice while the traditional flooding method of rice farming had positive effects on nutrient availability and uptake. Adoption of SRI together with application of all four nutrients in combination results in higher yield in the studied soil.

5.2 Recommendations

From the results that were obtained in this study the following are recommended:

i. Nitrogen, Phosphorus, Potassium, Sulphur and Zinc that were found to be deficient in the studied area need to be applied so as to improve rice productivity in Mvumi.

ii. Since this study was conducted in a pot experiment under controlled environment, further research needs to be done under field conditions so as to understand clearly the response of rice plants to studied water management systems with nutrient combinations when grown under field condition.

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APPENDICES

Appendix 1: Weather data (collected from Ilonga weather station)

a) Rainfall data

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
2007	164.1	67.6	124.3	175.6	63.6	22.0	19.4	47.5	0.0	10.1	63.0	153.4	910.6
2008	108.2	271.6	125.2	M	72.4	11.0	0.0	11.0	1.8	18.6	144.6	93.1	857.5
2009	36.0	217.8	90.1	184.0	98.8	38.8	0.0	28.2	0.0	24.3	59.0	92.2	869.2
2010	2.4	114.7	133.9	316.5	54.7	2.4	0.0	1.9	1.3	10.2	5.9	106.9	750.8
2011	169.8	144.3	344.2	403.8	134.9	5.3	0.9	M	53.6	m	54.7	225.3	1536.8
2012	81.2	17.0	96.6	134.2	29.5	0.0	0.0	2.8	0.0	0.0	65.7	105.4	532.4
2013	161.9	79.6	292.1	130.4	83.1	1.0	9.0	7.5	16.1	107.0	66.0	66.3	1020.0
2014	126.5	147.4	339.8	264.1	53.8	16.5	0.0	57.0	57.8	26.4	121.8	207.3	1418.4
2015	70.8	159.2	258.7	87.6	49.8	13.8	59.3	7.1	2.3	5.4	173.9	40.7	928.6
MEAN	**102.3**	**135.5**	**200.5**	**212.0**	**71.2**	**12.3**	**9.8**	**20.4**	**14.8**	**25.3**	**83.8**	**121.2**	**980.5**

m = missing value

b) Mean Maximum Temperature

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
2007	31.0	32.1	31.5	30.6	28.8	27.5	27.3	27.9	30.1	31.7	M	m	29.9
2008	32.2	29.8	31.3	M	M	M	M	M	30.8	32.4	M	32.3	31.3
2009	34.3	31.6	32.7	29.8	29.0	M	27.9	28.7	30.9	32.4	33.0	34.1	31.0
2010	31.5	32.2	32.9	30.3	29.3	28.7	M	29.2	30.6	33.2	34.2	32.9	31.2
2011	32.5	31.3	31.2	30.0	28.3	28.3	27.8	28.5	30.5	31.3	32.7	32.1	30.2
2012	31.1	M	31.5	30.3	M	M	29.0	29.8	31.5	32.8	33.0	m	31.1
2013	33.3	22.2	32.4	M	29.2	28.2	28.5	28.7	31.1	20.4	64.4	64.8	31.8
2014	33.6	31.2	31.0	M	28.2	28.0	27.9	28.6	18.9	32.0	33.1	32.9	29.2
2015	31.6	35.1	31.3	30.8	28.8	20.4	28.4	29.3	31.3	33.0	32.9	33.7	30.3
MEAN	**32.3**	**30.7**	**31.8**	**30.3**	**28.8**	**26.8**	**28.1**	**28.8**	**29.5**	**31.0**	**37.6**	**37.5**	**30.7**

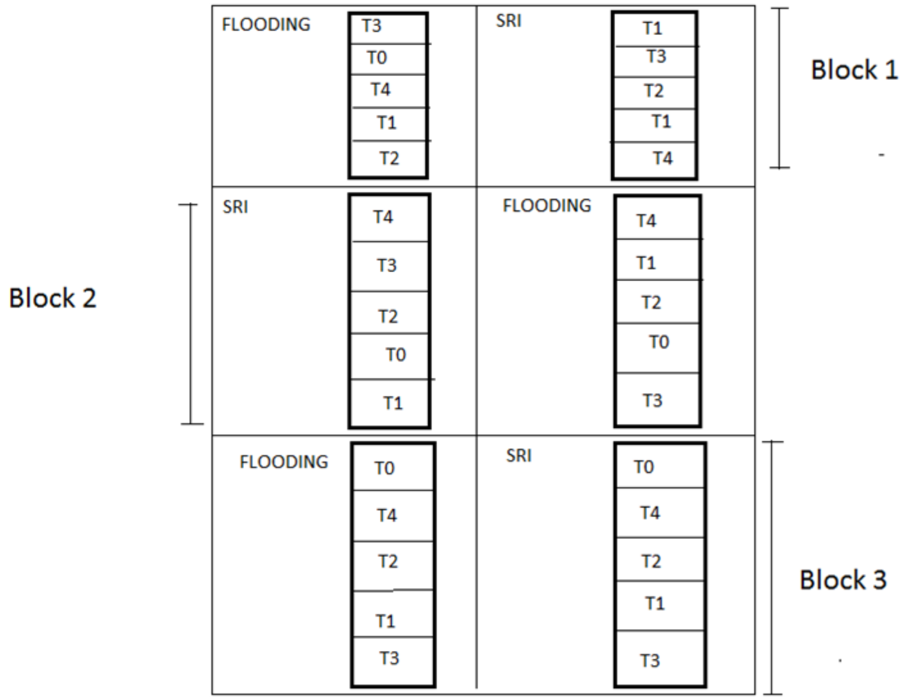
m = missing value

c) Mean Minimum Temperature

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
2007	22.4	22.2	22.0	21.4	20.6	16.8	17.1	18.0	19.0	20.9	M	m	20.0
2008	22.1	20.9	21.9	M	M	M	M	M	18.6	21.2	M	22.2	21.2
2009	22.5	21.7	22.3	21.3	19.4	M	16.8	19.0	20.0	21.7	22.5	23.0	20.9
2010	22.5	22.9	23.1	22.4	20.8	18.6	17.3	17.8	19.4	20.9	22.4	22.7	20.9
2011	22.0	22.1	22.0	21.9	20.5	18.4	16.4	17.2	19.5	20.4	22.2	22.0	20.4
2012	21.6	M	21.9	21.1	M	M	16.5	18.6	20.4	20.8	21.9	m	20.4
2013	23.0	22.2	22.6	M	20.2	17.0	16.5	18.4	19.5	20.4	43.2	43.3	24.2
2014	23.0	22.2	22.2	M	20.0	17.7	17.1	18.5	18.9	21.0	21.8	32.9	21.4
2015	22.3	23.4	22.2	22.0	20.4	28.4	17.0	18.7	19.6	19.6	22.3	22.0	21.5
MEAN	**22.4**	**22.2**	**22.2**	**21.7**	**20.3**	**19.5**	**16.8**	**18.3**	**19.4**	**20.8**	**25.2**	**26.9**	**21.2**

m = missing value

Appendix 2: Layout of the experiment



Appendix 3: Effect of water management systems on growth, yield and nutrient contents of rice shoot

a) Nutrient content

Water management system	N	P	K	S
	%			
SRI	1.70	0.16	0.85	0.13
FLD	2.02	0.24	0.89	0.11

b) Growth and yield of rice

Water management system	Biomass yield (g plant^{-1})	No. of tillers per plant	Plant height (cm)	Grain yield (g plant^{-1})	Days to flowering	Days to harvest
SRI	17.37	11	83.27	20.74	83	120
FLD	15.38	7.07	95.47	18.14	93	134