EFFECT OF UREA AND COWPEA RESIDUES ON GROWTH AND YIELD OF RICE VARIETY MAKASSANE IN ZAMBÉZIA, MOÇAMBIQUE

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ABSTRACT

A field experiment was conducted to assess the effectiveness of cowpea residues (CR), and combination of urea as source of nitrogen on growth and yield of rice variety Makassane. A randomized complete block design (RCBD) was used with six treatments and three replications. The six treatments were control plot, 0% urea + 100% CR, 25% urea + 75% CR, 50% urea + 50% CR, 75% urea + 25% CR and 100% urea + 0 % CR. Soil and organic material analysis revealed that the soil was deficient in N. Data recorded were number of tillers, plant height, leaf area, days to 50% flowering, 1000 grain weight, days to physiological maturity, total dry matter, panicles per plant, spikelets per panicle and grain yield. The recorded data were analyzed by the analysis of variance and stepwise multi-regression techniques. The result showed that sole cowpea residues, urea and different combinations of organic and inorganic fertilizers significantly produced comparable higher rice grain yields over the control plot. Overall, the study results indicated that combination of organic and inorganic source of nitrogen at the rate of 50% urea + 50% CR could be the best combination strategy in improving rice grain yield. Furthermore, it is concluded that cowpea residues instead of urea could be used as a source of nitrogen for improving rice production.

DECLARATION

I, Virgílio Agostinho Gabriel Dinheiro, 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 institution.

16/11/2012

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The above declaration is confirmed

16/11/2012

Prof. Tarimo, A. J. P **Date**

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DEDICATION

I dedicate this work to my father Gabriel Dinheiro "in memory" my beloved mother "Holy Maria" who always prays for me, to my daughter Lubna Nery Dinheiro.

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LIST OF ABBREVIATIONS AND SYMBOLS

AS	Ammonium sulphate
B	Boron
C	Carbon
Ca	Calcium
CEC	Cation exchange capacity
CR	Cowpea residues
CV	Coefficient of variation
DAP	Di-ammonium phosphate
Fe	Iron
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistical database
GY	Grain yield
HI	Harvest Index
HYV	High-yielding variety
IIAM	Instituto de Investigação Agraria de Moçambique
IRRI	International Rice Research Institute
K	Potassium
K_2O	Potassium oxide
Ln	Natural Logarithms
LSD	Least significant difference
MINAG	Ministerio de Agricultura
Mg	Magnesium
Mn	Manganese

Mo	Molybdenum
MOP	Muriate of potash (potassium chloride)
N	Nitrogen
NPT	New plant type
P	Phosphorus
P_2O_5	Phosphorus pentoxide (phosphate)
PC	Protein Content
pH	Negative logarithm of hydrogen ion concentration
PIS	Panicle initiation stage
PR	Phosphate rock
r	Regression coefficient
R^2	Coefficient of determination
S	Sulphur
SOM	Soil organic matter
SSA	Sub-Saharan Africa
SSP	Single superphosphate
USDA	United States Department of Agriculture
YCA	Yield components analysis
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than half of the global human population. As much as 678 million tonnes of rice were produced globally in 2009 - the second highest cereal grain production worldwide after wheat (FAOSTAT, 2010). Rice is a rapidly growing food source in Africa with increasingly significant importance to food security in most food-deficit countries of Sub-Saharan Africa (SSA). Rice belongs to the Poaceae family, with better quality dietary protein than wheat, maize, finger millet and sorghum with relatively non-allergic properties (Chandler, 1979). Increased urbanisation in SSA has spiked consumer preference for rice; as a result of the convenience of preparing a rice meal relative to traditional staples such as cassava, millet, sorghum, and maize, rice demand has been increasing rapidly (Hossain, 2006).

Rice is also becoming increasingly popular in Africa with about 16 million metric tons annual consumption and 14 million tons of production, creating a deficit of 2 million metric tons, which is filled by imports. For instance, the total value of rice imports by Southern African countries is estimated at more than 1 000 000 tons (FAO, 2010).

Rice production within the SSA region (Mozambique inclusive) is, however, lagging behind in meeting the rapidly increasing demand. Many factors are contributing to the low rice grain yield but poor soil fertility status is the major limitation (Roy *et al.*

2006), associated with an inadequate and inefficient use of both inorganic and organic fertilizers- such as manure and legumes (Tilahun, 2009). Roy *et al.* (2006) reported that the widespread loss of organic matter in the region due to soil erosion further exacerbated the already poor soil conditions through depletion or inactivation of nutrients, reduced biological activity and reduced nutrient retention. As long as soil fertility continues to decline, small scale farmers will derive only partial benefits from the new rice varieties. Therefore, harnessing higher rice productivity gains will require an integrated nutrient management approach involving the combination of available nutrient management technologies which would facilitate achieving the required productivity and sustainability by efficient use of soil and applied plant nutrients.

Poor plant nutrition is particularly important in sub-Sahara Africa where the soils generally receive no or little mineral fertilizer. Heavy rains can lead to leaching of plant nutrients and the irregular climate often leads to periodic moisture stress as well. In areas with high demographic pressure on the land, the ensuing continual cultivation compounds the nutrient depletion scenario in the region, resulting in low yields (Bekunda *et al.*, 1997). Soil nutrient balance studies in Africa show evidence of widespread negative nutrient balances (Stoovogel and Smaling, 1990). According to Bekunda *et al.* (1997), this has led to severe nutrient deficiencies, particularly of nitrogen (N) and phosphorus (P). Thus, to increase rice production without necessarily increasing land size calls for methods of increasing soil productivity in areas under rice production. It is now widely recognised that appropriate nutrient application is an essential component of sustainable land management.

Makassane is the first rice variety bred by the International Rice Research Institute (IRRI) that has been designed especially for Mozambique consumers and farmers to ensure it suits local market needs and production conditions. Makassane has an attractive long grain, a nice texture when eaten, and has disease resistance, which is very important to local farmers.

Makassane (IR80482-64-3-3) is of a new plant type (NPT), with distinct morphological characters, such as thick and sturdy stems, dark green thick erect leaves, low number of tillers, large panicles with large numbers of grains, high harvest index (0.6) and short stature (90-100 cm), and has been developed to increase the yield potential of rice by 20-25%.

Several studies have indicated the presence of negative nutrient balances in Mozambican farming systems due to a combination of higher nutrient removal through crop harvests and no or very limited addition of nutrients through inorganic or organic sources (MINAG, 2010). According to Bekunda *et al.* (1997), use of inorganic fertilizers is the meaningful approach for building up nutrients in the soil because of shortage of farmyard manure in required quantities and non-inclusion of leguminous crops in the cropping systems. As fertilizers are expensive and beyond the reach of most smallholder and marginal farmers, it is essential to use integrated nutrient management technologies. Considering the limited native supply of the nutrients and limited use of organic /biological sources of nutrients in conjunction with inorganic fertilizers, adopting proper time of application and adopting techniques to increase nutrient use efficiencies are imperative. The combination of organic sources of nutrients in the form of green manure with inorganic fertilizers may optimize plant nutrition, without leading to excessive losses of nutrients due to leaching and volatilization. Addition of green manure will not only add organic matter and nutrients to the soil but also will not have any negative environmental impacts.

Studies conducted in Mozambique have shown that farmers use both organic and inorganic sources of nutrients in combination on rice to reduce cost of production (MINAG, 2007) and improve soil fertility status. Rice can be easily sold and, as elsewhere in Africa, its market is on the increase due to a growing demand from burgeoning urban centres and institutions of learning. With the government of Mozambique encouraging a shift from subsistence farming to commercial agricultural production (MINAG, 2010), and given the attractive prices for rice, more and more farmers are shifting to rice production. However, there is lack of knowledge on limiting nutrients and their optimum application rates. According to Colwel (1994), the optimal rate of fertilizer application to a crop is that rate which produces maximum economic returns. The optimal rates determined on the economic basis of this definition are smaller than those required to produce maximum crop yields.

The overall objective of the study was to determine the best combinations of urea and cowpea residues as sources of nitrogen for optimization of rice yields. The specific objectives were (i) to assess effectiveness of cowpea residues and urea as source of nitrogen for rice; (ii) to determine the optimal combination of urea and cowpea residues in order to increase rice yields.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice in Mozambique

Mozambique's hot to warm moist climate is potentially suitable to allow for multi-crop rice cultivation in its unique agricultural ecosystems with vast land and water resources waiting to be exploited (MINAG, 2010). Rainfall varies from less than 300 mm to more than 1500 mm. The combination of different altitudes and latitudes (from 10° S to 27°S) provide the country with variable climatic conditions for a diversity of environments where many crops can be grown successfully (MINAG, 2010). Lowland areas in Mozambique are especially dominated by rice, leguminous crops and intensive vegetable cultivation while the upland areas produce maize, cassava and sorghum.

In 1990, rice was the least consumed cereal in Mozambique, among the major cereals maize, rice, wheat and sorghum. However, after the 1992 Mozambique Peace Agreement, rice became the third largest consumed cereal closely followed by wheat. Between the year 1993 and 1998, rice production grew at an annual rate of 12.1 % and the fastest rice consumption growth rate of 18.4 % per annum was registered in the same period (Zandamela, 2008). In the last 15 years, rice production has remained stagnant, with current average rice yield of only 1.06 t ha^{-1} compared with the potential yields of 13 – 15 t ha^{-1} for direct seeded, irrigated rice crop for lowland tropics (Dingkuhn *et al.*, 1991). This yield trend has largely been influenced by the frequency of use of traditional rice varieties like Chupa, Mamima, Nené, or old improved varieties developed in the 1960s or 1970s like C4 -63, ITA 312 and Limpopo (Kajisa and Payongyong, 2008).

2.2 Factors Affecting Rice Production

The area under rice production in Mozambique has increased from 130 000 ha in 1994 to 190 000 ha in 1999 (Zandamela, 2004) and to 226 593 ha in 2009 (MINAG, 2011). Although there was an increase in the rice quantity produced annually from 1991 to 2002, the yield per hectare in rice growing countries in tropical Africa has generally remained low (FAO, 2003). The quantity of rice produced between 1993 and 2002 increased by 30.3%, due to an increase in the total area under rice cultivation by 35%. Hence, the increase in quantity can only be attributed to an increase in area cultivated during that period (FAO, 2003; Zandamela, 2008; MINAG, 2011).

According to MINAG (2010), the main factors which have contributed to low rice yields on farmers' fields are low soil fertility, drought, low yielding varieties, weeds, low quality of planting material, and lack of access and use of harvest and post-harvest equipment. Low soil fertility and lack of sufficient water are the two most important abiotic stresses that cause low yields (Adesanwo *et al.*, 2009).

2.3 Soil Depletion

Soil degradation is widespread in many parts of the world. The basic causes of soil degradation are the result of human activities such as deforestation, overgrazing and poor soil management. Factors that cause soil degradation are interrelated. About 1

200 million ha worldwide are considered to be affected by soil degradation, mostly by erosion (Roy *et al.*, 2006). It has been estimated that human-induced soil degradation has affected 46 million ha in Africa and 15 million ha in Asia (FAO, 2000). Out of these, 25 percent of such soils in Africa and 67 percent in Asia are moderately to be severely affected.

Soil fertility is not a stable property but a dynamic one. There are widespread problems of soil fertility degradation under many cropping systems even on soils with good initial soil fertility. The result of such a decline is a reduced nutrient supply, which reduces crop yields.

From plant nutrition considerations, chemical degradation of the soil, particularly its fertility status, is of greatest concern. Losses of nutrients from soil can be caused by soil erosion, leaching, crop removal or in the form of gases (as in case of N and to a lesser extent S). Nutrient removal by crop products compared with external nutrient inputs can be similar, higher or lower. Negative nutrient balances result where nutrient removals exceed nutrient additions. These are a cause of soil fertility depletion or nutrient mining (Roy *et al.*, 2006).

Nutrient depletion is a widespread problem in low- and medium input agriculture. This is a major threat to productive sustainable farming. It is accelerated by imbalanced fertilization. Nutrient mining can cause the exhaustion of any nutrient required in moderate to large amounts. It can be particularly severe in the case of N, P, K and S depending on soil nutrient reserves and the amounts replenished. A negative balance can be acceptable for a short period, but, where prolonged, it will lead to soil deterioration. It is expensive to improve depleted soils.

2.4 Soil Properties and Rice Crop Requirements

Rice plant need anchorage, water and nutrients from the soil but is sensitive to excesses of growth-impeding substances in the soil. The supply and uptake of nutrients from the soil requires a suitable combination of various soil properties, such as physical, chemical and biological properties. These provide the most favorable environment for the roots to grow, proliferate and absorb nutrients (Roy *et al.*, 2006).

2. 4. 1 Soil texture

Soil texture influences to a large extent several components of soil fertility such as the amount of nutrient reserves and their proportion of the available nutrient fraction. For instance, sandy soils are generally poor in nutrient reserves while clay soils are often rich in nutrient reserves, though they may not necessarily be in plant available form. Loamy soils (like sandy or silt loam) have intermediate properties and are generally most suitable for cropping (Roy *et al.*, 2006). However, rice is grown on a wide variety of soils but performs best on clay soils due to their high water holding capacity.

2. 4. 2 Soil pH and cation exchange capacity (CEC)

The soil pH influences nutrient availability for crop uptake whereas CEC constitutes nutrient reserves through its ability to attract and retain nutrients (Bot and Benites, 2005). According Roy *et al.* (2006) and FAO (2006), most nutrients are available between soil pH of 5.5 and 7.0. Roy *et al.* (2006) reported that cation-exchange capacity (CEC) and base saturation of soils are usually used to assess the potential fertility of soil and possible response to fertilizer application. Roy *et al.* (2006) categorized CEC as follow: very high (> 40 cmolc (+) /Kg of soil), high (25 - 40 cmolc (+)/Kg of soil), medium (12 – 25 cmolc (+) /Kg of soil), low (6 – 12 cmolc (+)/Kg of soil) and very low (< 6 cmolc (+) /Kg of soil). Moreover, CEC is sometimes used to determine the types of minerals present and nutrient reserves in the soil. Clay soils as well as soils rich in organic matter have been reported to have higher CEC and high degree of base saturation and are considered as the most fertile ones (Roy *et al.*, 2006; Landon, 1991).

2. 5 Nutrient Requirement for Rice Crop

Different varieties of rice need different amounts of nutrients. Furthermore, the quantity of nutrients needed depends largely on the crop yield obtained or expected and their response to fertilizer. A local rice variety will not respond so well to fertilizer as an improved variety.

For lowland rice in the Philippines, recommended rates of nutrients are 80 to 100kg N ha^{-1}, 13 to 22 kg P ha^{-1} and 25 kg K ha^{-1}(Motsara and Roy, 2008). Lowland rice, high yielding, improved varieties in India used 125 kg N ha^{-1}, 13 kg P ha^{-1} and 25 kg K ha^{-1}. The nitrogen fertilizer should be applied in two, or, even better, three split applications: ⅓ basal, ⅓ at tillering and ⅓ at panicle initiation. In Mozambique, recommended rates of nutrients are 60 kg ha^{-1} N, 20 kg P ha^{-1} and 25 kg K ha^{-1} (MINAG, 2007; Motsara and Roy, 2008).

Nitrogen being “the motor plant growth nutrient” will usually show its efficiency shortly after application: the plants develop a dark green colour and grow more vigorously (Joubert and Wouda, 2007; Tilahum, 2009). Nitrogen (N) is essential for the normal growth of plants. All vital biological processes are related to the existence of functional plasma, of which N is a basic constituent (proteins, nucleic acids). Nitrogen is also a basic constituent of many other compounds of primary physiological importance to plant metabolism, such as chlorophyll, nucleotides, proteins, alkaloids, enzymes, hormones and vitamins (Buresh and Witt, 2008). Nitrogen promotes rapid growth and increases leaf size and spikelet number per panicle. It affects all parameters that contribute to yield. Leaf color, an indicator of crop N status, is closely related with the rate of leaf photosynthesis and crop production.

Nitrogen is a nutrient required by plants in comparatively larger amounts than are other soil borne elements; endogenous application to crops often results in yield improvement. Many legumes and certain other species can obtain N from the atmosphere, but most species obtain it only from the soil. In agricultural systems, N is obtained from the soil through mineralization of soil organic matter and from external sources, both organic and inorganic (Vanlauwe, 2002).

Nitrogen deficiency is caused by low soil N-supplying power, insufficient use of mineral N fertilizer, and low N fertilizer-use efficiency (losses from volatilization, denitrification, incorrect timing and placement, leaching, or runoff). The soil N supply is commonly not sufficient to support higher yields of modern varieties so that N deficiency is common in all major rice-growing areas. Significant yield responses to fertilizer N are obtained in nearly all lowland rice soils. Nitrogen deficiency in plants results in a marked reduction in growth rate (Roy *et al.*, 2006), and N - deficient plants have a short and spindly appearance. Tillering is poor, and leaf area is small. As N is a constituent of chlorophyll, its deficiency results in a yellowing or chlorosis of the leaves.

Nitrogen is typically the nutrient most limiting rice yields and the nutrient needed in the largest quantity from fertilizer. In Asia's irrigated rice systems, the naturally occurring (i.e., indigenous) supply of N from soil is typically sufficient to achieve a grain yield of 3 to 5 t ha^{-1} without application of fertilizer N (Dobermann, 2002), and even higher yields of 5 to 7 t ha^{-1} without fertilizer N can be achieved in irrigated areas of China (Peng *et al.*, 1996). But across Asia, yields of irrigated rice in the absence of fertilizer N are consistently insufficient to meet food needs and achieve highest profit for farmers. Fertilizer N is clearly needed, but the optimal management of fertilizer N to match crop needs and achieve high profit is season and location specific, varying even among adjacent fields within the same season.

2. 6 Climate Requirement for Rice Crop

Rice is widely distributed throughout the tropical, subtropical, and temperate zone of all continents. Temperature, solar radiation and rainfall are the important climatic components which affect rice growth and yield (Yoshida, 1981). Rice needs adequate moisture and is grown over a wide range environmental condition but the best range during the rice-growing period is between 900 and 2250 mm day^{-1} (water requirement of irrigated rice). Rice is very sensitive to water deficits at any stage of growth and the damage depends on the growth stage of crop at the time of stress, the severity and the duration of stress.

Solar radiation is an important climatic factor that affects temperature, evapotranspiration, and photosynthesis in rice. Solar radiation requirements of rice differ from one growth stage to another (Yoshida and Parao, 1976). Yield is significantly reduced if sufficient solar radiation is not received during reproductive (panicle initiation to flowering) and ripening (flowering to maturity) growth stages. During the reproductive growth, insufficient solar radiation reduces the number of spikelets and consequently grain yield. Similarly, during ripening, the percentage of filled spikelets is also reduced. Inadequate light during the vegetative growth stage affects yield and yield components only slightly (Yoshida and Parao, 1976). Solar radiation of 300 cal cm^{-2} day^{-1}during the reproductive stage allows yields of 5 t ha^{-1} (Yoshida and Parao, 1976).

2. 7 Nutrient Uptake and Concentration

Nutrient uptake and removal by rice is influenced strongly by the variety, season, nature and composition of the soil and the yield level. In order to produce 1 t of paddy (rough rice), the rice crop absorbs on average, 20 kg N, 5 kg P, 25 kg K, 3 kg S, 7 kg Ca, 3 kg Mg, 675 g Mn, 150 g Fe, 40 g Zn, 18 g Cu, 15 g B, 2 g Mo and 52 kg Si. Out of the total uptake, about 50 percent of N, 55 percent of K and 65 percent of P are absorbed at early panicle-initiation stage. About 80 percent of N, 60 percent of K and 95 percent of P uptake is completed by the heading stage (Mohd *et al.*, 2007). The partitioning of uptake in the case of N and P is higher in grain than in straw (3:1), whereas greater proportion of K, Ca, Mg, Si, Fe, Mn and B remains in the straw. The S, Zn and Cu taken up are distributed about equally in straw and grain (Yoshida, 1981; Roy *et al.*, 2006).

There is a close association between the amount of N fertilizer applied to rice and the yield level. Yield responses of 20 kg or more of paddy or rough rice per kilogram of N are frequently obtained. The amount of N that can be applied to traditional, tall rice varieties is limited because of their susceptibility to lodging and low yield potential. However, the improved short HYVs that are resistant to lodging can benefit from a higher level of N supply. While traditional varieties could justify rates of up to 50 kg N ha^{-1}, 160 kg N ha^{-1} or more is recommended for HYVs under good management with assured water supply (Roy *et al.*, 2006; Lactaoen *et al.*, 2010).
The season of planting also influences the N requirement of rice. During the dry season, when abundant sunshine is available, the irrigated HYVs can justify 30 – 40 kg N ha^{-1} more than in the lower-yielding rainy season. Incorporation of a good green manure crop raised before planting rice can add 50 – 60 kg N ha^{-1} as well as a substantial amount of organic matter.

The timing of N applications is very important for improving the efficiency of N use by rice. The crop may require none or only a modest basal application, and up to three top-dressings in the standing crop in order to maintain the N supply throughout its growth. Split applications are especially important where total N requirement is high in order to avoid leaching losses (particularly on permeable soils).

The method of N application is also important for reducing N losses and improving the nitrogen use efficiency by the crop, which is often below 50 percent. The basal application should be worked into the flooded soil. The applications of ammonium or urea N should, where possible, made into the reduced soil horizon. This is because broadcasting them into the floodwater is likely to result in high N losses. Placement of urea in the reduced zone can be facilitated by using urea supergranules (Roy *et al.*, 2006; Fageria *et al.*, 2011).

Total N should be split between a basal and a top-dressing. Owing to high leaching losses. While the availability of soil P is improved by flooding, many old rice soils have a low P content because of crop removal over the years. This, together with the greater demand for P by improved varieties, makes adequate use of P fertilizer important. Optimal rates vary with local conditions, but 9 – 18 kg P ha^{-1} is usually enough for traditional varieties and 33 – 66 kg P ha^{-1} for improved varieties (Roy *et al.*, 2006).

Water-soluble P or a combination of water- and citrate-soluble P is normally most efficient for rice production (Roy *et al.*, 2006). Many upland rice soils are low in available P, and moderate P applications are usually required (Roy *et al.*, 2006).

The crop uptake of K is quite high but much of it remains in the straw. In traditional rice varieties, responses to K have usually been small. However, improved varieties usually respond to K, especially where given adequate N and P.Responses to K are generally greater on sandy soils. While 17 – 33 kg K ha^{-1} may be sufficient for traditional varieties, improved varieties can justify the application of 50 kg K ha^{-1}

particularly on soils that are poor in K (Roy *et al.*, 2006). On most soils, K fertilizer should be applied as a basal dressing. Potash fertilization should also keep in view the fact that, where K is cheaper than N and P, it can be equally profitable even at lower response rates (Roy *et al.*, 2006)

Sulphur deficiency is becoming more widespread in rice (Roy *et al.*, 2006). This is because of higher yields and, thus, greater S removals, the reduced use of organic manures, possible leaching of S and the widespread dominance of S-free fertilizers (urea, DAP and MOP) in the product pattern. Where either AS or SSP is a part of the fertilization schedule, the required S is often supplied through these sources.

2. 8 Nutrient Interaction

Nutrients have their individual specific functions, some common functions as well as interactions. Nutrient interactions can be positive or negative. Where a nutrient interaction is synergetic, their combined impact on plant production is greater than the sum of individual effects where used singly. Positive interaction between P and N for crop production has been revealed by several researchers (Roy *et al.*, 2006).

2. 9 Cowpea Residues as Green Manure

Cowpea [*Vigna unguiculata* (L.) Walp.] can grow under rainfed conditions and can tolerate some drought conditions. Various cowpea varieties compete well with weeds. A high nitrogen producer, cowpea yields about 3 300 to 4 400 kg ha^{-1} of dry biomass containing 3 to 4% nitrogen (Pornparn and Somjai, 2001). Maximum biomass is achieved at 60 to 90 days of crop growth (Pornparn and Somjai, 2001;

Treadwell *et al.*, 2009). Though, Africa grows the largest hectare age at 8.9 of the 9.1 million ha worldwide (FAOSTAT, 2007), cultivation is mainly under traditional systems and it therefore has the lowest average yield.

There is renewed interest in using legumes as green manure to maintain soil fertility especially in areas where chemical fertilizers are costly or not readily available. Green manure refers to fresh plant matter which is added to the soil largely for supplying the nutrients contained in its biomass. Such biomass can either be grown *in situ* and incorporated or grown elsewhere and brought in for incorporation in the field to be manured. Just any plant cannot be used as a green manure in practical farming. Green manure may be plants of grain legumes such as pigeon pea, green gram, cowpea, soybean, or groundnut.

Leguminous plants are largely used as green manure due to their symbiotic N fixing capacity. An ideal green manure should possess the following traits (FAO, 1997; IRRI, 1988; John *et al.*, 1992) show early establishment and high seedling vigor; be tolerant to drought, shade, flood and adverse temperature; possess early onset of N fixation and its efficient sustenance; have an ability to accumulate large biomass and N in 4 - 6 weeks; is easy to incorporate; is quickly decomposable; is tolerant to pests and diseases.

Leguminous Green Manure: These differ widely in nitrogen concentration and yield. Among 86 species used in India as green manure for rice, their N contents ranged from 2.0 to 4.9% N (Weon *et al.*, 2011). Earlier results on the performance of some important green manure crops in lowland rice showed N-fixation of 74-134 kg ha^{-1} and about 200% increase on a paddy yield over unmanured plots (Sanyasi, 1952; Pornparn and Somjai, 2001; Harish and Devasenapathy, 2010).

The nutrient status of rice soils can be improved by applying green manure a week to ten weeks before sowing. Where adequate water is available, green manuring with a fast-growing leguminous plant is often recommended. A good green manure crop of cowpea can add 50 – 60 kg N ha^{-1} where incorporated into the soil before planting rice (Kulkarni and Pandey, 1988). The practice of cowpea residue incorporation after pod harvest is feasible and economical, where a period of 45 to 60 days is available before planting of rice and this can contribute about 50 to 80 kg N ha^{-1} to succeeding rice crop (Kulkarni and Pandey, 1988; Kumari and Reddy, 2009; Kumari *et al.*, 2010). Research efforts aim to maximize the productivity and economic returns of the rice by developing appropriate and viable nitrogen management practices without any discount of soil health requirement (Kumari and Reddy, 2009; Kumari *et al.*, 2010).

The effectiveness of green manure as a source of N depends upon good synchronization of N release with N uptake by the main crop. Studies on kinetics of N mineralization from decomposing cowpea tissue are scarce (Kashem *et al.*, 2007). An important management decision in the practice of green manuring is choosing the growth stage of the plant at the time at which a green manure crop is incorporated into the soil. For field-grown cowpeas, the rate of N accumulation was constant between 4 and 6 weeks after sowing, then decreased between 6 and 7 weeks after sowing (Kashem *et al.*, 2007). Awonaike *et al.* (1991) found that soil supplied 80% of the total N assimilated in the above-ground plant parts of cowpea during the first 6 weeks of growth, while more than 80% of the N assimilated during the remaining period of growth was derived from fixation. The rate of N mineralization during decomposition of cowpea, however, may decrease with increasing age of plant tissue, (Miller and Sundman, 1988; Sanati *et al.*, 2011).

2. 10 Benefits and Constraints of Organic Sources of Nutrients

Organic materials are derived from plants and animals. They include crop residues, plant biomass, green manures, farmyard manures, composts, household wastes, industrial and urban wastes, and commercial products produced from plant and/or animal materials. Organic fertilizers refer to a specific group of organic materials produced from decomposed plant or animal materials and used as a source of nutrients for crops. The increased prices of manufactured fertilizers in recent years have led some countries to promote and subsidize organic fertilizers as an alternative to synthetic manufactured fertilizers.

Organic materials are often promoted for improving the physical, biological, and chemical properties of soils. The improvements in soil physical properties include, better soil structure and aggregation, improved water holding capacity, and better drainage. Such changes in physical properties of well-drained, aerobic soil can improve the medium for plant growth. But such changes are usually not relevant for submerged rice soils in Asia, which during land preparation are typically flooded before plowing or rotovation and then tilled at soil saturation, through a process referred to as puddling, which deliberately destroys soil structure (Deshpande and Devasenapathy, 2010; Okonji *et al.*, 2011).

Incorporated or surface-applied organic materials could potentially improve physical properties of rice soils in the cases where the soil is prepared without puddling such as with direct dry seeding. In such cases, the potential effects on soil physical properties would depend upon tillage practices and the decomposition rate of the added organic material.

Organic materials are often claimed to improve soil biological and microbial activity, but microbial populations and the effects of organic materials on biological activity can differ between submerged rice soils and well-drained, aerobic soils on which other crops are grown. Aerobic soils typically have a diversity of microorganisms surviving on the oxygen contained in soil air. But submerged soils because of the absence of soil oxygen are populated with different organisms, which are predominantly anaerobic bacteria. Added organic materials are generally more likely to stimulate the activity of aerobes in well-drained soils than anaerobes in submerged soil. The stimulation of biological activity is most likely for sandy soil low in SOM (Roy *et al.*, 2006; Batiano, 2008)

Aerobic organisms in microbial amendments are adapted for growth in well-drained, aerobic soils on which crops other than rice are grown, but they are not adapted for growth in the absence of oxygen. Aerobic organisms such as the ***Azospirillum***, a bacterium promoted as an amendment to stimulate biological nitrogen (N_2) fixation, and *Trichoderma*, a fungus promoted to hasten decomposition of organic materials, could potentially grow on the aerobic surface layer of submerged soils, in the aerated root zone of rice, and in the rice nursery. They will not thrive in the anaerobic environment predominant in submerged soils.

Purported benefits of organic materials on soil chemical properties include higher nutrient-holding capacity, such as through increased cation exchange capacity, and increased ability to resist changes in soil pH. Such benefits are more likely to occur in aerobic soils than submerged soils, and for submerged soils the benefits are more likely for sandy than for loamy or clayey soils. The submergence of soil tends to buffer pH near neutrality and reduces the decomposition of native soil organic matter as compared with aerobic soils (Deshpande and Devasenapathy, 2010). In addition, the puddling of rice soils reduces downward movement of water thereby reducing the need for greater nutrient-holding capacity of soil to reduce loss of nutrients by leaching.

The most probable benefit of organic materials for rice on submerged soil is as a source of essential nutrients. Slow-decomposing organic materials because of their long residence time in soil are preferred for improving physical properties of soils. But organic materials resistant to decomposition, such as materials with a high carbon-to-nitrogen (C: N) ratio or high content of recalcitrant components like lignin, would be less desirable as sources of nutrients for crops. The organic materials most effective as a source of nutrients for crops would have high concentrations of essential nutrients and relatively rapid rates of decomposition leading to release of plant-available nutrients synchronized with the needs of the crop for the nutrients.

2. 11 Factors Affecting Decomposition of Organic Materials

Decomposition of green material and nutrient release patterns are largely a biological process that occurs naturally. Its speed is determined by three major factors: soil organisms, physical environment and the quality of organic matter (Bot and Benits, 2005; Okereke *et al.*, 2006).

Adequate soil moisture, soil temperature, soil pH and aeration are needed for good organic materials decomposition. Extreme acidity or alkalinity slows down organic material decomposition. Temperature is a key factor controlling the rate of decomposition of the plant residues according to Bot and Benites (2005) where rates doubled for each increase of 8-9°C in the mean annual air temperature. This explains the higher decomposition of residues observed in the tropics than in temperate area. On the other hand, soil biological activity requires air and moisture. According Bot and Benites (2005), optimal microbial activity occurs at near "field capacity" which is equivalent to 60% water-filled pore space.

2. 12 Integrated Nutrient Management

Crops require an instant flow of nutrient at special growing stage, which cannot be supplied by natural weathering of mineral and organic materials, to ensure high yields. Organic source of plant nutrients release these slowly (Ayoola and Makinde, 2007) and limit their sole utilization. Therefore, plant nutrient losses through leaching could be limited by organic fertilizer applications which also minimize fixation of some nutrients by soil (Roy *et al.* 2006). On the other hand, inorganic fertilizer exerts strong influence on plant growth, development and yield (Kolawole and Joyce, 2009). Complementary use of organic manure and mineral fertilizer has been proved to be a sound soil fertility management strategy in many countries of the world (Roy *et al.*, 2006).

2. 13 Fertilizer Recommendations

The rice crop like most other crops requires nutrients such as nitrogen (N), phosphorus (P) and potassium (K) in large amounts to produce high and stable yields. It has been reported that N is one of the essential macronutrients required in largest amounts for rice growth and productivity. The quantity of nutrients taken up by the crop is a good index of its fertilizer needs. According to a study by FAO (2000) on fertilizer use, paddy which yields 6000 kg ha^{-1} removes 100 kg N, 22 kg P, 133 kg K, 19 kg Ca, 12 kg Mg and 10 kg S ha^{-1}.

2. 14 Methods and Time of Fertilizer Application

FAO (1984) recommended that the application of organic manures, fertilizers and liming materials should be timed when these are most effective. Organic manures and liming materials should be applied several weeks before sowing. The same holds true for materials that need to be converted into soluble and plant available forms in the soil before they can contribute to crop nutrition. However, leguminous green manures grown before rice can be incorporated into the puddled soil a few days before transplanting rice as their rate of decomposition is quite fast.

Fertilizers can be applied both at or before planting and during crop growth. The decision about when and how much to apply depends on: crop duration; total amount of a nutrient to be applied; nature of the nutrient, especially with regard to its transformation and mobility; availability of water; and anticipated outbreak of pests and diseases (Kazemi posht mosari *et al.*, 2007; Islam *et al.*, 2008).

In general, the total amount of N is applied in 2 – 4 installments starting from a basal dressing. Where the crop is raised largely on stored soil moisture, the entire N is to be applied pre-planting, preferably below the soil surface. In the case of N-deficiency symptoms in the standing crops, immediate N application via leaves or soils is suggested. Phosphate and potash fertilizers are mixed into the top layer in moderately fertile soils, especially in narrow-row crops. They are placed strategically or drilled below the seed in wide-row crops, especially in low fertility soils and soils with high P-fixing capacity (Roy *et al.*, 2006; Roberts *et al.*, 2011).

2. 15 Application of Green Manure

Green manure can be either grown *in situ* and incorporated in the main field or grown elsewhere and brought in for incorporation in the field to be manured (Polthanee *et.al.*, 2008; Weon *et al.*, 2011).

2. 16 Nitrogen Use Efficiency

Nitrogen fertilizer requirement, N-use efficiency, and grain yield (GY) were reported to be highly dependent on crop growth and nutrition status of rice before N application (Hussain *et al.*, 2000; Miyama 1998; Singh *et al.*, 2002; Yang *et al.*, 2003; Nguyn *et al.*, 2008; Ghoneim, 2008; Möller, 2009). The variation in growth and nutrition status at various growth stages of cereal crops was caused by spatial and temporal variation in soil properties (Casanova *et al.*, 1999; Dobermann, 1994; Nguyen *et al.*, 2008) and crop population and management (Casanova *et al.*, 2002; Dobermann, 1994). As a result, uniform N application for rice without consideration of crop growth and N nutrition status in a field may result in over application of fertilizer in some locations but nutrient deficiency in others. Excessive N fertilization has been reported as a cause of environmental pollution while N deficiency restricted crop growth and yield.

Spatial variation in soil properties has been studied and considered for prescribing N topdressing amount in upland crops, and lowland rice crop (Miyama, 1998). However, some authors indicated that soil properties, even some stable properties such as soil organic matter, texture, bulk density, and CEC varied considerably from season to season of a year, and from year to year (Dobermann, 1994). In similar perspective, climate conditions and crop management techniques (Casanova *et al.*, 2002; Dobermann, 1994) significantly affecting crop growth and nutrition varied unavoidably from year to year in the same field. Therefore, crop growth and nutrition status could be an ideal indicator for the fertilizer prescription reflecting both spatial and temporal variation in soil, climate, and management techniques (Dobermann *et. al.*, 2002; Peng *et al.*, 1996).

Recently, the real-time prescription of N requirement based on crop growth and N status have received a great deal of attention in rice production (Dobermann *et al.*, 2002; Peng *et al.*, 1996; Singh *et. al.*, 2002; Yang *et al.*, 2003). They found that the higher rice yield and N recovery efficiency were obtained in the plant-based N prescription treatment by chlorophyll meter (SPAD meter) than in the fixed N rate treatment (Dobermann *et al.*, 2002; Hussain *et al.*, 2000; Singh *et al.*, 2002). However, characterizing crop N status by chlorophyll meter was a simple but time-consuming method and difficult to extend to a large scale.

So far various crop variables related to crop physiology and biochemistry such as LAI, plant N concentration, N uptake, and chlorophyll content have been reliably predicted by remote sensing techniques (Casanova *et al.*, 1998). These techniques have provided a fast, nondestructive and relatively inexpensive characterization of crop status and have had a high benefit when applied at regional levels. Therefore, over the past several decades, remote sensing techniques have been used increasingly for crop monitoring and yield prediction. Studying hyperspectral remote sensing technique with hand-held equipment for crop characterization at field scale would lend support for extending to a large-scale application by using satellite or aerial remote sensing image (Casanova *et al.*, 1998).

The N balances were determined by adding N inputs and N outputs at the farm scale (farm gate balance), respective of the scale of the farm compartments arable land and grassland (field N balance).

Field N balances were calculated by adding all N flows at the field boundary including applied mobile manures, seeds and assessed N inputs via BNF, subtracting N removed via harvested biomass and gaseous ammonia-N losses from added mobile manures. Gaseous N losses by ammonia volatilization were assessed according to the results of Möller and Stinner, 2009).

2. 17 Rice Yield and Yield Component Analysis

Several approaches have been developed for the quantitative analysis of plant growth and yield. Studies have refined many of the main concepts and have provided improved procedures for understanding and analyzing experiments related to crop productivity. Major contributions in this general subject area include publications on plant growth analysis (Causton and Venus, 1981; Evans, 1972; Tarimo, 1997), yield components analysis (Jolliffe *et al.*, 1982 and Jahan *et al.*, 2011). Yield component models may be analyzed in several ways including simple or multiple regressions of the components in relation to yield. Other analytical procedures involve the use of ordered stepwise multiple regressions (Eaton and Kyte, 1978).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3. 1 Soil and organic material sampling and preparation

3. 1. 1 Soil sampling

Twenty soil sub - samples were randomly collected from the experimental field at 0 – 30 cm depth and thoroughly mixed to constitute a composite sample, as described by Motsara and Roy (2008). A sample of approximately one kilogram (kg) was taken from the composite sample, air dried and ground to pass through a 2 mm sieve for physical and chemical analysis.

3. 1. 2 Soil analysis

Soil analysis was done in the Department of Soil Science Laboratory, Instituto de Investigação Agraria de Moçambique (IIAM), Maputo, Mozambique (Mozambique Agriculture Research Institute). The soil sample was analyzed for particle size distribution (soil texture), soil pH, cation exchange capacity (CEC), exchangeable bases (Ca, Mg and K), organic carbon, exchangeable Zn, total N, extractable P and sulfate – S.

Particle size distribution was determined by the hydrometer method after dispersing the soil sample with sodium hexametaphosphate solution (Day, 1965). The textural class was determined using the USDA textural triangle (FAO, 1984). Soil pH was determined in water at a soil: water ratio of 1:2.5 using a pH meter, as described by Motsara and Roy (2008). Cation exchange capacity (CEC) was determined by the [illegible] ammonium acetate (pH7), exchangeable bases Ca and Mg were determined from ammonium acetate leachate by an atomic absorption spectrometer while exchangeable K was determined by using a flame spectrometer.

Organic carbon content in the soil was determined by the wet oxidation method of Walkley and Black as described by Nelson and Sommers (1982). Total N was determined by micro – Kjeldahl digestion followed by the distillation and titration as described by Bremmer and Mulvaney (1982). P was extracted by Bray – I method, and P concentration in the soil was determined using the method described Motsara and Roy (2008). Exchangeable Zn was determined by extraction with 0.005M DTPA (diethylenetriamine penta-acetic acid) and quantified using an atomic absorption spectrophotometer, as described by Motsara and Roy (2008). The sulfur content in soil was determined by colorimetric method using a spectrophotometer at 535nm, also as described by Motsara and Roy (2008).

3. 1. 3 Cowpea residues preparation

Fresh material of cowpea residues (CR) were collected from a farmer's field in the Mucelo area of Zambézia Province and brought directly to experimental field for application. Five weeks before rice seeding, a sample of cowpea residues was collected from the field and taken to the laboratory for water content determination and chemical analysis.

After weighing, the cowpea residues sample was oven dried at 60-70^{0}C to constant weight. Dry weight and water content of cowpea residues were then determined using the following formula:

$$\text{Dry weight (\%)} = [\text{Oven dry weight / Fresh weight}] * 100 \tag{1}$$

$$\text{Water content (\%)} = [\text{Fresh weight - oven dry weight / Fresh weight}] * 100 \tag{2}$$

The dried sample was then cut into small pieces and ground to pass through a 0.5 mm sieve for analysis. Chemical analysis involved determination of organic carbon, total N, P, K, Mg, Ca, Zn, total S, and total N.

3. 1. 4 Rice plant analysis

Ear leaf samples were oven dried at 60- 70°C to constant weight. The dried samples were cut into small pieces and ground to pass through a 0.5mm sieve and analysis for total N, P, K and S. The micro – Kjeldahl method was used for N determination in cowpea residues and the rice plant. The HNO_3-H_2O_2 wet digestion was used for extraction of those nutrients.

3. 2 Location

The field experiment was carried out for 160 days, from 20th November 2011 to 30th May 2012 at Mucelo, situated at latitude 15°50’37’’S 39°36’37’’E and 16 m above sea level. The experimental site was situated at 40 km from Quelimane City.

3. 3 Land Preparation

Ploughing and harrowing was done by a tractor (one plowing and 2 harrowings), and the leveling was done manually using hand hoes. Direct seeding of lowland rice was done at a spacing of 20 cm by 20 cm, two seeds were sown per hole on 30th December 2011 and thinning was done two weeks after emergence in order to keep only one seedling per hill.

3. 4 Experiment Design, Treatments and Treatment Application

3. 4. 1 Experiment design

Randomized complete block design (RCBD) was used in the experiment with 6 treatments and three replications. The plot size was 3 m x 1 m, with inter – block and inter – plot spacing of 1 and 0.5 m, respectively. A wide pathway of 1.5 m width was maintained around the entire experimental area.

3. 4. 2 Treatments

The treatments used in this study are shown in Table 1.

3. 4. 3 Treatment application

A uniform dose of 20 kg ha^{-1} P and 24 kg ha^{-1} K were applied as basal fertilizers in each treatment before sowing. Urea was applied two times, half of recommended rate during vegetative stage and the other half during the reproductive stage.

Table 1: Types and names of treatments

S/N°	Treatment	Treatment description
1	T1	Control
2	T2	0 kg Urea (0% of recommended dose) + 3 t (100% N through cowpea residues)
2	T3	25 kg Urea (25% of recommended dose) + 2.25 t (75% N through cowpea residues)
3	T4	50 kg Urea (50% of recommended dose) + 1.5 t (50% N through cowpea residues)
4	T5	75 kg Urea (75% of recommended dose) + 0.75 t (25% N through cowpea residues)
5	T6	100 kg Urea (100% of recommended dose) + 0 t (0% N through cowpea residues)

Fresh cowpea residues were reduced into small pieces before being applied in order to facilitate incorporation into the soil. The total amount of cowpea residues to be applied was calculated on the basis of water and N contents for sole application treatment. After incorporating cowpea residues, the experimental plots were daily watered in order to increase decomposition. The time of application of cowpea residues was 5 weeks before planting the rice crop. For treatments which received combination of inorganic and organic fertilizers, the amount of inorganic fertilizer added was based on N content in the organic material.

3. 5 Cultural Practices

Bird and weed damage to seedlings and established crop were kept to minimum throughout the growing season. Frequent weeding was done to keep the experimental plots weed free during the entire cropping period.

3. 6 Plant Sampling and Sample Preparation

3. 6. 1 Sampling for nutrient content determination

Plants for nutrient content analysis were sampled after flowering as recommended by Roy *et al.* (2006). Three ear leaves per row from each of the inner four out of five rows, giving a total of twelve leaves per plot were sampled from twelve plants. Plants were randomly selected using random numbers. The samples were cut with a knife, put in separate envelops and taken to the laboratory, oven dried at 70°C and analyzed for nutrient content.

3. 6. 2 Sampling for plant growth data

Plant height (cm): five plants per row were selected randomly; the measurement was from soil surface to the tip of the tallest panicle (awns excluded).

Leaf area index: At silking stage, five plants per plot were selected randomly for leaf area (LA) determination. The width (W) and the length (L) of each leaf per plant were measured using a ruler. The area per leaf was determined by the non-destructive L x W technique, using the relationship: leaf area = 0.75(L x W), where 0.75 is a constant (Watson, 1952; Yoshida, 1981). The average leaf area per plot was determined and then the leaf area index (LAI) was calculated using the following relationship: LA (cm^2)/ground area (cm^2) as described by Subedi and Ma (2005).

Crop maturity (Mat) was determined by the number of days from seedling emergence to physiological maturity (85% of grains on panicle are mature):

Total dry matter: At harvest time, ten plants were randomly selected from inner plots and the above ground biomass was determined. Total dry matter (TDM) was determined as described by Roy *et al.* (2006). Plants after sampling were sun - dried. The total plant dry weight was taken using an electronic balance. The total weight was divided by the number of 10 plants to obtain dry weight per plant.

3. 7 Crop Harvest and Yield Determination

Rice panicles were harvested at physiological maturity (i.e. at 125 days after sowing) when the grain moisture content was 18 – 20 %. A guard row was left around each plot so that only the inner rows were harvested. Panicles were sun dried until grain reached 14% moisture content as determined using a moisture meter.

Grain yield (kg ha^{-1}) – this was obtained from the harvested area (2 m^2/ plot) which excluded border rows.

3. 8 Yield Components

The variation is grain yield was determined using the following important yield components of rice are explained below:

Harvest index (HI): the harvest index was calculated using the following relationship: HI = seed weight/ total plant biomass; (3)

Number of spikelet's/panicle = (number of filled spikelet's/panicle) + (number of unfilled spikelet's/panicle); (4)

Percent filled spikelet's = {(number of filled spikelet's/panicle)/ (number of filled + unfilled spikelets)}x 100; (5)

1000 – grain weight (g) – this was determined by counting and weighing 1000 grains per plot.

3. 9 Data Analysis

3. 9. 1 Analysis of variance

The data collected for each variable were analyzed by the analysis of variance techniques (ANOVA) to evaluate the effects of the treatments on all observations, using the following statistical model as described by Gomez and Gomez (1984):

$Y_{ij} = \mu + T_i + \beta_j + E_{ij}$ for $i = 1, 2, 3, \ldots b$ and $j = 1, 2, 3, \ldots t$ (6)

Where

Y_{ij}: observation for each of the treatments, μ: Overall mean, T_i: effect due to the treatment, β_j: effect due to the blocks and E_{ij}: variation within treatment and blocks (i.e., error term)

3. 9. 2 Yield component analysis model

Yield component analysis used the model explained by Jolliffe *et al.* (1982) and Tarimo (1997). In this order, yield components can provide key physiological information to be used during the selection of some modern high-yielding rice cultivars. Plant growth analysis and yield component analysis both use simple plant characteristics:

$GY = N/A * N_{pa}/N * N_{sp}/N_{pa} * N_{spf}/N_{sp} * W_g/N_{spf} = W_g/A$ (7)

Where:

GY: Grain Yield

N: Number of plants/m^2;

A: area (m^2);

N_{pa}: number of panicle / plant;

N_{sp}: number of spikelets / plant;

N_g: number of grain / plant;

W_g: grain yield / plant

The geometric model above was transformed into an additive model by taking natural logarithms (Eaton *et al.*, 1986). Successive terms in this series are indices of plant presence (N/A) and grain yield per plant (GY). A logarithmically transformed data of such a geometric series into an arithmetic series prepares the yield component sequence for subsequent regression analysis as reported by Eaton *et al.* (1986):

$$\mathrm{Ln}\ (GY) = \ln (N/A) + \ln (N_{pa}/N) + \ln(N_{sp}/N_{pa}) + \ln (N_{spf}/N_{sp}) + \ln (W_g/N_{spf}) = \ln (W_g/A) \qquad (8)$$

In stepwise (or statistical) multiple regression, the independent variables are entered according to their chronological contribution in explaining the variance in the dependent variable. The additive model was then analyzed using stepwise multiple regression procedure (SAS statistical package) to attribute yield variation into treatments and yield components.

CHAPTER FOUR

4.0 RESULTS

The results are presented in four main parts; soil physical and chemical properties, chemical properties of cowpea residues and the rice variety used in the study, summarized in Section (4.1), growth characteristics (Section 4.2), reproductive growth characteristics (Section 4.3), and yield components analysis (Section 4.4).

4. 1 Soil Characteristics and Chemical Properties of Cowpea Residues and the Rice Plant

4. 1. 1 Soil characteristics

Analysis of the physical properties of the soil at the experimental site indicated that the texture was clay loam (Table 2). The Chemical property showed that the soil had a pH of 6.20 and was rated as slightly acidic. Total nitrogen (N) was 0.20%, which was rated as low. The CEC was 28.76 $cmol_c$ (+) Kg^{-1}. The exchangeable bases at the experimental site were 24.10 $cmol_c$ (+) Kg^{-1} for Ca^{2+}, 4.30 $cmol_c$ (+) $Kg^{-1}$for Mg^{2+} and 0.30 $cmol_c$ (+) Kg^{-1} for K^+ (Table 2).

Table 2: Some physic-chemical properties of the top soil (0-30cm) of the experimental site

Characteristics	Unit	Value	Rating	Reference
Particle size				
Distribution				
Clay	%	41		
Silt	%	23		
Sand	%	36		
Texture class		Clay loam		FAO (1984)
pH in water(1:2.5)		6.2	Medium acidic	Landon (1991)
Total N	%	0.20	Low	Landon (1991)
Organic Carbon	%	1.73	Low	Landon (1991)
Available P (Olsen)	mg kg^{-1}	7.07	Medium	Msanya *et al.* (2001)
CEC	$cmol_c(+)\ Kg^{-1}$	28.76	High	Msanya *et al.* (2001)
Exchangeable bases	$cmol_c(+)\ Kg^{-1}$			
Ca^{2+}		24.10	Very high	Roy *et al.* (2006)
Mg^{2+}		4.30	High	Roy *et al.* (2006)
K^+		0.30	Low	Roy *et al.* (2006)
Extractable S	mg kg^{-1}	21.28	Adequate	Landon (1991)

4. 1. 2 Chemical properties of cowpea residues and the rice plant

Chemical properties of cowpea residues and the rice plant used in the current study are shown in Table (3 and 4). Total N content in cowpea residues was 2.55%. Organic carbon content was 44.72%, while the C: N ratio was 17.54 (Table 3). The laboratory analytical results for the rice plant samples taken 75 days after planting (booting stage) from the study area and the tissue percentage P was 0.47%, N was 4.17% and K was 1.06% (Table 4).

4. 1. 3 Climate and weather

4. 1. 3. 1 Rainfall amount and distribution

Cumulative weekly rainfall received during the experimental period is illustrated in Appendix 1. The cropping period was marked by high rainfall which was poorly distributed. The experiment started in the last week of November by incorporation of cowpea residues on 24th November 2011. The rainfall received during the three weeks before sowing was 14.8 mm. Rice was sown on 30th December 2011 and after three weeks the area received a lot of water and was flooded for 10 days (Appendix 1). The amount of rainfall recorded during the three weeks period following sowing was 326.8 mm. In the month of January 2012, 492.8 mm of rainfall were received when the rice crop was still in the vegetative grown stage. From 20th March to 20th April the rainfall was only 53.3 mm.

Table 3: Some chemical properties of cowpea residues used in the study

Characteristic	Value
Total N (%)	2.55
Organic carbon (%)	44.72
C/N ratio	17.54
Total P (%)	0.11
Total Ca (%)	1.77
Total Mg (%)	0.25
Total K (%)	1.24
Total S (mg /Kg)	0.10
DTPA extractable Zn (mg /Kg)	13.39
Water content (%)	79.00
Dry weight (%)	21.00

Table 4: Nutrient uptake of rice plant used in the study

Characteristic	Value
Total Nitrogen (%)	4.17
Total Phosphorous (%)	0.47
Total Potassium (%)	1.06

The total rainfall obtained during the whole cropping season was 716.8 mm. This quantity of water was not evenly distributed, 68.75% was received only in January and another 31.25% occurred in the subsequent four months (February, March, April and May). However, due to inadequate rainfall during the cropping period, the experimental plots were given supplementary irrigation in order to supply the amount required by the crop.

4. 1. 3. 2 Temperature

The temperature during the cropping period did not vary significantly (Appendix 2). The mean temperature ranged from 29.7 to 32.9°C from November 2011 to December 2011. January was the hottest, averaging 34.3°C while March recorded the lowest (24.5°C) temperature.

4. 1. 3. 3 Solar radiation

The data collected from Instituto Nacional de Meteorologia de Moçambique (Mozambique National Meteorology Institute) is presented as Appendix 3. The observations showed that solar radiation did not differ significantly during the period from November to February i.e. 6 677.96, 6 578.29, 6 578.29, and 6 272.27 Jm^{-2} per day, respectively, but differed during the three months of March, April and May, i.e. 5 880.59, 5 481.91 and 4 186.18 Jm^{-2} per day during the experimental period. However, high solar radiation was recorded in November (6 677.96 Jm^{-2} per day) and lowest was recorded in May (4 186.18 Jm^{-2} per day).

4. 2 Growth Characteristics

Growth is defined as the advancement towards attainment of full size or maturity. In general the rice plant usually takes 3 – 8 months to reach maturity depending on variety and environmental conditions in which it is grown. The current variety took 135 days.

Growth characteristics considered in this section were total dry matter (TDM) number of tillers per plant, plant height, leaf area index (LAI), days to 50% flowering and days to physiological maturity (PM) (Table 5).

4. 2. 1 Total dry matter

The results (Table 5) indicated that total dry matter (TDM) per m^2 was significantly affected by the source of nitrogen among treatments. Highest TDM per m^2 (1325g) was observed from the treatment with 100% urea + 0% CR. This had high number of tiller, higher plant height and high LAI. This positive relationship as increased the TDM it was then followed by those with 50% urea + 50% CR (988.9g), 75% urea + 25% CR (946.8g) sole cowpea residues (587.7 g), 25% urea + 75% CR (499.7 g) and the lowest was from control (463.8g).

Table 5: Growth characteristics

Treatments	TDM (g m^{-2})	T	P(cm)	LAI	DAF	DPM
Control	463.8e	168.3b	44.5f	1.3e	99.0c	110c
0% urea + 100% CR	587.7d	191.0b	53.5e	1.6d	104.0a	120a
25% urea + 75% CR	499.7d	215.0ab	62.1d	2.0c	102.7b	119.bc
50% urea + 50% CR	988.9b	259.0a	67.7c	2.6b	103.0bc	118bc
75% urea + 25% CR	946.8c	246.0a	71.4b	2.6.b	104.7a	117bc
100% urea + 0% CR	1325.7a	260.0a	74.5a	3.5a	103.7ab	115b
Mean	802.1	223.2	62.3	2.3	102.3	116
LSD (5%)	35.9	48.8	1.96	0.2	1.3	3.7
CV (%)	2.5	12	4.3	12.3	0.7	1.8

The means followed by same letter in columns are not significantly differently at 5% level according to Ducan's New Multiple Range Test.

T – number of tillers per m^2, P - plant height (cm), LAI – Leaf area index, DAF – days to 50% flowering, DPM – days to physiological maturity, TDM – total dry matter g per m^2

However, the treatment with 25% urea + 75 CR was not statistically different from the control, although it gave 7.7% more TDM than the control.

The treatments which received 100% urea + 0% CR, 50% urea + 50% CR, 75% urea + 25% CR and sole cowpea residues (0% urea + 100% CR) produced TDM per m^2 which were statistically higher than that from the other treatments (Table 5). Thus, these TDM production differences among treatments must have influenced the reproductive development in the rice variety, Makassane.

4. 2. 2 Number of tillers

Highest number of tillers per m^2 was observed in plots with 100% urea + 0% CR (260), then followed by 50% urea + 50% CR (259), 75% urea + 25% CR (246), 25 urea + 75% CR (215) sole cowpea residues i.e. 0% urea + 100% CR alone (191) and finally, the control (168.3).

In terms of combination of organic and inorganic fertilizers, plots treated with 50% urea + 50% CR had the highest number of tillers when compared with the other treatment combinations. Increasing urea and reducing cowpea residue (75% urea + 25% CR), the number of tillers per plant was not significantly affected when compared with 50% urea + 50% CR.

These results on tillering (Table 5) indicate that different combinations of organic and inorganic fertilizer resulted in greater tillering ability when compared with the control treatment. The highest rate of urea (100 kg ha $^{-1}$) produced more tillers when compared with that of highest sole cowpea residues (100%) (Table 5).

4. 2. 3 Plant height (cm)

Significant variation in plant height (P) was observed among treatments (Table 5). Overall, plant heights of 74.53cm, 71.40 cm, 67.73 cm, 62.07 cm and 53.47 cm were observed in treatments with urea, 100% Urea + 0% CR, 75% urea + 25% CR, 50% urea + 50% CR, 25% urea + 75% CR and 0% urea + 100% CR, respectively. The control treatment had shortest plants (44.47cm) (Table 5).

From this study it was observed that plant height of the rice variety Makassane was significantly affected by the different combinations of nutrient sources, e.g sole cowpea residues regardless of the crop duration. The rate of increase in plant height was greater between 70 and 90 DAS, which coincided with the maximum vegetative growth stage in the variety Makassane. At 120 DAS plants were about to mature, and hence, the increase in plant height was lowest (Table 5).

4. 2. 4 Leaf area index

Organic and inorganic fertilizer treatments significantly increased LAI when compared with the control. The LAI varied from 1.28 (control) to 3.52 in plots with combinations of organic and inorganic fertilizer, respectively (Table 5).

The highest LAI was 3.5, and then followed by 2.6, 2.59, 2.03 and 1.61 in the treatments with 100% Urea + 0% CR, 50% urea + 50% CR, 75% urea + 25% CR, 25% urea + 75% CR and 0% urea + 100% CR, and the control (1.28), respectively.

4. 2. 5 Days to 50% flowering

The rice variety Makassane took between 99 and 104.67 days to reach 50% flowering and an average of 102.33 days to attain the end of the reproductive stage. The results showed that all treatments were significantly different from control. The treatments with 0% urea + 100% CR, 50% urea + 50% CR, 75% urea + 25% CR and 100% urea + 0% CR were not significantly different. The treatments with 25% urea + 75% CR, 50% urea + 50% CR and 100% urea + 0% CR were also not statistically different (Table 5).

Among treatments, highest number of days to 50% flowering was 104.67 followed by 104.33, 103.67, 103, 102.67 for treatment with 75% urea + 25% CR, 0% urea + 100% CR, 100% urea + 0% CR, 50% urea + 50% CR and 25% urea + 75% CR, respectively.

4. 2. 6 Days to physiological maturity

Days to physiological maturity ranged from 109.67 to 120. The highest number of days to physiological maturity was recorded in the treatment with 0% urea + 100% CR which was 120 days, followed by treatments with 25% urea + 75% CR (119 days), 50% urea + 50% CR (118 days), 75% urea + 25% CR (116.67 days) and 100% urea + 0% CR (115 days). These differences were statistically significant (Table 5).

From the results (Table 5), the treatment with urea alone (100% urea + 0% CR) attained physiological maturity earlier (115 days) than all the other treatments. The longest period to physiological maturity was 120 days in plots which received 100% CR.

The organic and inorganic fertilizer combinations significantly influenced days to physiological maturity when compared with the control. Treatments with 100% urea + 0% CR, 75% urea + 25 % CR, 50% urea + 50% CR and 25% urea + 75% CR did not differ significantly in terms of days to physiological maturity but those with 100% urea + 0% CR differed significantly from that with sole cowpea residues i.e. 0% urea + 100% CR (Table 5).

4. 3 Reproductive Growth Characteristics

4. 3. 1 Reproductive structures

The reproductive growth characteristics studied included number of panicles per m^2, number of spikelets per m^2 and number of grains per m^2. These were recorded at harvest and are summarized in Table 6.

4. 3. 1. 1 Number of Panicles per m^2

The data (Table 6) show that there were significant differences among treatments on the number of panicles per m^2, except in the treatments with sole cowpea residues and the control. The highest number of panicles per m^2 was observed in the treatment with 100% urea + 0% CR (252.3). The other treatments produced significantly less

Table 6: Reproductive growth characteristics of rice variety Makassane

Treatments	Panicle per m^2	Spikelet per m^2	Grain number per m^2
Control	156.300c	10301.00d	6605.38d
0% urea + 100% CR	163.70bc	18538.00c	15032.00c
25% urea + 75% CR	185.00abc	19425.33c	17776.60c
50% urea + 50% CR	222.70ab	35548.33ab	29838.31ab
75% urea + 25% CR	224.00ab	34829.33b	27974.00b
100% urea + 0% CR	242.30a	42582.00a	37656.00a
Mean	196.70	26870.67	22480.38
LSD $_{(0.05)}$	60.91	530.20	741.60
CV (%)	16.83	13.20	20.00

The means followed by same letter in columns are not significantly differently at 5% level according to Ducan's New Multiple Range Test.

number of panicles per m^2. The minimum number of panicles per m^2 was recorded from the treatment with sole cowpea residues (0% urea + 100% CR (163.7). This response, however, was not statistically significant when compared with the control plot. Despite the insignificant difference, it produced 35.3% more panicles than the control indicating that the crop benefitted from the cowpea residues (Table 6).

Other treatments produced 234.3, 224, and 185 panicles m^{-2} with 50% urea + 50% CR, 75% urea + 25% CR and 25% urea + 75% CR, respectively. When urea was increased from 0% to 50% and reduced cowpea residues from 100% to 50%, as sources of nitrogen, the number of panicles per m^2 was increased but increasing urea from 0 to 75% and reducing cowpea residues to 25%, the number of panicles was reduced. When 100% urea was used without additional cowpea residues, the number of panicles per m^2 increased (Table 6).

4. 3. 1. 2 Number of spikelet per m^2

The results (Table 6) showed that the number of spikelet per m^2 were significantly different among treatments. A higher number of spikelets per m^2 were observed in the treatment with 100% urea + 0% CR (42 582). Treatments with 25% urea + 75% CR and 0% urea + 100% CR were not statistically different (i.e. 19 425.33 and 18 538, respectively). Treatments with 50% urea + 50% CR and 75% urea + 25% CR were not statistically different (i.e.35 548.33 and 34 829.33, respectively) (Table 6). The organic and inorganic fertilizer sources of nitrogen had not significant effect on the overall performance of the rice variety Makassane in terms of number of spikelets per m^2.

4. 3. 1. 3 Number of grain per m^2

The highest number of grains per m^2 (37 656) was observed from the treatment with 100% urea + 0% CR ($p<0.05$). The lowest value in this parameter (6 605.38) was recorded from the control treatment. The other treatments had the following number of grains per m^2 29 838.31 (50% urea + 50% CR), followed by 75% urea + 25 CR (27 974), 25% urea + 75% CR (17 776) and sole cowpea residues (15 032). Note that the treatment with sole cowpea residues differed statistically from the control on number of grains per m^2. Thus application of cowpea residues would increase grain yield through increased grain size m^{-2}.

4. 3. 2 Grain yield and yield components

4. 3. 2. 1 Grain yield per m^2

The results indicate that grain yield per m^2 was significantly affected by the source of nitrogen among treatments (Table 7). The highest grain yield per m^2 (633.52 g) was observed from the treatment with 100% urea + 0% CR, followed by treatment with 50% urea + 50% CR (469.68 g). The treatments with 75% urea + 25% CR yielded 463.91g per m^2 while that with sole cowpea residues yielded 280.90g and that with 25% urea + 75% CR gave 265.88 g. The lowest grain yield per m^2 was observed from the control (143.14 g).

The treatments which received either 25% urea + 75 CR; 0% urea + 100 CR or 75% urea + 25 CR were not statistically different in grain yield per m^2. The treatment with sole cowpea residues gave 11.63% less grain yield per m^2 than that with 25% urea + 75 CR. The plots that received 75% urea + 25% CR gave 49.62% more grain yield per m^2 when compared with 25% urea + 75 CR. The treatment with sole cowpea residues gave less grain yield per m^2 (34.03%) than 75% urea + 25% CR. Thus urea in combination with cowpea residues increases grain yield in the variety Makassane.

Table 7: Effect of fertilizer source on grain yield in the rice variety, Makassane

Treatments	Grain yield ($g\ m^{-2}$)	1000 grain weight (g)	Harvest Index (%)
Control	143.14d	21.67c	30.9b
0% urea + 100% CR	280.90c	28.00b	47.8a
25% urea + 75% CR	265.88c	24.67c	53.2a
50% urea + 50% CR	469.68b	26.33b	47.5a
75% urea + 25% CR	463.91b	27.33b	49.0a
100% urea + 0% CR	633.52a	30.67a	47.8a
Mean	376.16	26.44	46
LSD (5%)	20.69	1.616	9.139
CV (%)	20.20	3.40	10.90

The means followed by same letter in columns are not significantly differently at 5% level according to Ducan's New Multiple Range Test.

The highest grain yield in treatment 100% urea + 0% CR were associated with different parameters such high number of panicle per m^2, number of spikelets per plant, number of filled spikelets per plant, weight of filled plant, 1000 grain weight and harvest index contributed to increase grain yield.

4. 3. 2. 2 1000-grain weight

The 1000-grain weight varied significantly among treatments (Table 7). The highest 1000-grain weight (30.6 g) was obtained in the treatment with 100% urea + 0% CR. Variation in this parameter depended on the source of nitrogen. The lowest 1000 - grain weight was recorded from the control (21.67). The other treatments gave respectively, 28 g (sole cowpea residues), followed by 75% urea + 25% CR

(27.33g), 50% urea + 50% CR (26.33g), and 25% urea + 75% CR (24.67g). Overall, application of urea in the place of cowpea residues significantly increased 1000 - grain weight in the rice variety Makassane.

4. 3. 2. 3 Harvest index

The highest HI (53.2%) was achieved in the treatments with 25% urea + 75% CR and the lowest was observed from the control (30.9%). The treatment that received 75% urea + 25% CR gave HI of 49%, followed by sole cowpea residues and 100% urea + 0% CR both with 47.8%, and 50% urea + 50% CR which had HI of 47.5% (Table 7).

The effect of nitrogen on HI was remarkably noted among treatments (Table 7). The results have shown that the highest HI was from the treatment with 25% urea + 75% CR. Overall, treatments applied with fertilizers were statistically similar with regard to this yield parameter (Table 7).

4. 4 Yield Components of the Rice Variety, Makassane

Yield component analysis was based on the primary values collected from the experimental plots (Table 8). To examine the relative importance of each yield components for yield in rice, the percentage of contribution was computed and calculated regression coefficients and coefficients of determination based on the geometric transformation of those data (Table 9) and the logarithmic transformation of same (Table 10).

Analysis of variance (ANOVA) and stepwise multiple regression analysis techniques were used to evaluate the contribution of each yield components to the overall variation in yield in the rice variety, Makassane among the treatments. The results show that all components varied significantly among treatments (Table 8 – 10).

Table 8: Primary yield components of the rice variety Makassane

Treatments	**Grain yield per m^2 (gm^{-2})**	**Number of plant per area**	**Number Panicle per plant**	**Number of spikelet per panicle**	**Number of filled spikelet per panicle**	**weight of filled spikelet per m^2 (g)**
Control	143.14d	9.60e	1	66.00e	43.00e	5.74f
0% urea + 100% CR	280.90c	11.67de	1	126.00cd	95.30d	11.20d
25% urea + 75% CR	265.88c	13.00cd	1	105.00d	87.30d	10.66e
50% urea + 50% CR	469.68b	20.33b	1	164.10ab	136.30b	18.70b
75% urea + 25% CR	463.91b	15.67c	1	149.30bc	112.50c	18.49c
100% urea + 0% CR	633.52a	27.67a	1	191.30a	160.50a	25.46a
Grand mean	376.16	16.33	1	133.72	105.8	15.04
LSD	20.69	3.31		27.81	15.18	0.15
CV (%)	20.2	11.1		11.4	7.9	9.4

The means followed by same letter in columns are not significantly differently at 5% level according to Ducan's New Multiple Range Test.

Table 9: Yield components (geometric scale) of the rice variety Makassane

Treatments	**N/A**	**N_{pa}/N**	**N_{sp}/N_{pa}**	**N_{spf}/N_{sp}**	**W_g/N_{spf}**	**W_g m^{-2}**
Control	240.600e	0.106a	67.600e	0.635ns	0.1309b	143.14d
0% urea + 100% CR	293.500de	0.086b	137.200c	0.697ns	0.1164c	280.90c
25% urea + 75% CR	325.000d	0.078bc	116.000d	0.753ns	0.1214bc	265.88c
50% urea + 50% CR	508.400b	0.049de	178.700b	0.764ns	0.1381abc	469.68b
75% urea + 25% CR	391.700c	0.064cd	167.900b	0.673ns	0.1638a	463.91b
100% urea + 0% CR	691.700a	0.036e	216.700a	0.742ns	0.1582ab	633.52a
Grand mean	408.50	0.070	147.300	0.711	0.0092	376.16
LSd	59.70	0.019	14.720	0.179	0.005	20.69
CV (%)	8.00	14.60	5.500	13.900	28.700	20.2

The means followed by same letter in columns are not significantly differently at 5% level according to Ducan's New Multiple Range Test.

N: Number of plants/m^2; A: are (m^2); N_{pa}: number of panicle / plant; N_{sp}: number of spikelets / panicle; N_{spf}: number of filled spikelets/ panicle; W_g: grain yield / plant.

Table 10: Yield components (logarithmic scale) of the rice variety Makassane

Treatment	**N/A**	**N_{pa}/N**	**N_{sp}/N_{pa}**	**N_{spf}/N_{sp}**	**W_g/N_{spf}**	**W_g/A**
Control	5.475e	-2.256a	4.211e	-0.476ns	-2.033abc	4.921f
0% urea + 100% CR	5.678d	-2.459b	4.920c	-0.365ns	-2.151c	5.623d
25% urea + 75% CR	5.776cd	-2.557bc	4.753d	-0.284ns	-2.109bc	5.579e
50% urea + 50% CR	6.231b	-3.012d	5.185b	-0.270ns	-1.980abc	6.154b
75% urea + 25% CR	5.970c	-2.751c	5.122b	-0.401ns	-1.809a	6.131c
100% urea + 0% CR	6.538a	-3.319e	5.378a	-0.301ns	-1.844ab	6.452a
Grand mean	5.945	-2.726	4.928	-0.350	-1.976	5.821
LSD	0.200	0.2	0.104	0.261	0.251	0.168
CV (%)	1.800	4.0	1.2	4.1	7.0	3

The means followed by same letter in columns are not significantly differently at 5% level according to Ducan's New Multiple Range Test.

N: Number of plants/m^2; A: are (m^2); N_{pa}: number of panicle / plant; N_{sp}: number of spikelets / panicle; N_{spf}: number of filled spikelets/ panicle; W_g: grain yield / plant.

The yield components which showed positive relationship with yield were number of plants per area (r = 0.849), number of panicles per plant (r = 0.491), number of spikelets per panicle (r = 0.802), number of filled spikelets per number of spikelet (r = 0.655) and weight per grain (r = 0.946) (Table 11). Among these yield components, N/A, Npa/N, Nsp/Npa, Nspf/Nsp and Wg/Nspf were significantly correlated with grain yield per m^2 (Table 11).

Coefficients of determination among yield and yield components (Table 11) indicate that the N/A contributed significantly to the variation yield in (R^2 = 20.42). Similarly, the other components significantly accounted for the yield variation e.g. number of panicles per plant (R^2 = 17.35), number of spikelet per panicle (R^2 = 32.11) number of filled spikelets per spikelet (R^2 = 16.9) and weight per grain (R^2 = 13.23).

The highest contribution to yield was achieved in the spikelets per panicle with 32.11 and the lowest was observed from the grain weight with 13.23%.

Table 11: Regression coefficient and coefficient of determination of yield components

Dependent Variable	Independent variable					
	constant	**N/A**	**Npa/N**	**Nsp/Npa**	**Nspf/Nsp**	**Wg/Nspf**
			Regression coefficient			
N_{pa}/N	-1.072	0.091***				
N_{sp}/N_{pa}	6.738	-0.668***	-0.688**			
N_{spf}/N_{sp}	7.614	0.459**	0.389***	-0.732***		
Wg/N_{spf}	4.173	0.832ns	0.563***	-0.909***	0.612***	
W_g/A	-0.036	0.849***	0.491***	0.802***	0.655***	0.946***
			Coefficients of determination (%)			
	Total					
N_{pa}/N	89.48	89.48***				
N_{sp}/N_{pa}	94.82	65.69***	29.13**			
N_{spf}/N_{sp}	97.5	14.07**	48.52***	34.91***		
Wg/N_{spf}	98.12	-22.53ns	17.85***	75.69***	27.11***	
W_g/A	100	20.42***	17.35***	32.11***	16.9***	13.23***

** Significant at 1% level; *** Significant at 0.1% and ns none significant

CHAPTER FIVE

5.0 DISCUSSION

5. 1 Growth Characteristics

The rice variety Makassane is high yielding. The treatments with urea had higher number of tillers (260) than those with increasing amounts of cowpea residues (< 255). Similar observation was reported by Gomez (1972) in which the range was 200 to 280 tillers m^{-2}. This variety, together with suitable agronomic practices, such as method of planting and fertilizer application play an important role in tillering ability. Tillering in rice is an important factor in the overall productivity (Kupkanchanakul, 2007).

Tillering is an important trait for grain production in rice and is also an important characteristic in aspect of growth, i.e. dry matter production although productivity greatly depends on the number of productive tillers (tillers which bear panicles) rather than the total tiller numbers (Zhang *et al.*, 2009; Rahman *et al.*, 2007; Hasanuzzaman *et al.*, 2010).

Greater number of tillers in the rice variety Makassane was due to the fertilizer combinations used in the study. For example, more number of tillers per square meter might have resulted from increased availability of nitrogen, which plays a vital role in rice growth and development. Organic sources of nitrogen offer more balanced nutrition to plants, especially micro – nutrients, which positively influence the number of tiller per plant. Similar observations have been reported by Miller (2007); Mirza *et al.* (2010) and Morteza *et al.* (2011).

Plant height at 50% flowering was significantly different among treatments as result cowpea residues and urea application which improved plant growth and vigor. Urea and cowpea residues had high nutrient releasing ability, especially N. Similar observations have been reported by Joubert and Wouda (2007) and Onasanya *et al.* (2007). The variation in plant height due to nutrient sources was considered to be associated with variation in the availability of the nutrients. Chemical fertilizer offers nutrients which are readily soluble in soil solution and thereby instantaneously being made available to plants. Similar observations have been reported by Morteza *et al.* (2011).

With regard to organic fertilizers, nutrient release is slower than that from inorganic once, hence plants appeared to be comparatively short, especially where the organic fertilizer was applied singly. Similar observations were made in some other studies, e.g. Ayoola and Makinde (2007) and Hasanuzzaman *et al.* (2010). While not similar plant height with inorganic fertilizer and complemented with organic ones were greater than those from sole cowpea residues (Hasanuzzaman *et al.*, 2010 and Morteza *et al.*, 2011).

Differences in LAI, which is used to describe the capacity of the assimilatory (i.e. photosynthetic) apparatus of a plant stand (Watson, 1952 and Ishii *et. al.*, 1977) and which serves as a key index for interpreting variation in yield and plant growth at different stand densities were noted in the current study. The variation appears to be related to plant vigor. It was noted in the current study LAI did not reach the physiological optimum for increased crop yield. For example, the maximum LAI was only 3.5 but the necessary LAI to achieve maximum crop photosynthesis during the reproductive stage varies from 5 to 6 (Kupkanchanakul, 2007). It is essential to maintain high level of leaf nitrogen required for high photosynthetic activity through application of N fertilizers (Kupkanchanakul, 2007; Yoshida, 1972 and Ishii *et al.*, 1977).

Greater LAI results into greater rates of crop growth and dry matter production. In this study, greater rates of dry matter was recorded with proper combination of cowpea residues and urea as sources of nitrogen. Such plants resulted into luxurious growth as well as higher number of tillers per plant. Total dry matter production therefore increased due to nitrogen availability during active tillering and panicle initiation stages. This observation was also reported by Zhang *et al.* (2009) and Rahman *et al.* (2007). It is also linked to the benefits from organic materials as described by Bot and Benit (2005); Roy *et al.* (2006) and Makinde *et al.* (2010). Organic matter in soil improves soil structure, thus allowing for greater crop access to nutrients and water.

Nitrogen, for instance, has been reported to contribute highly to dry matter production (Joubert and Wouda, 2007). According to Onasanya *et al.* (2007) and Dordas (2009) N makes up 1 to 4% of dry matter of plants and performs better when it is in balance with other nutrients.

5. 2 Reproductive Growth Characteristics

Rice physiologists believe that if total filled grains in panicle was greater than 85%, sink would be limiting while if less than 80%, source would be limiting. Between 80 and 85% grain filling there would be a good balance between source and sink (Kupkanchanakul, 2007).

The source of nitrogen could have a marked effect on the performance of reproductive structures of this rice variety. Grain number per plant increased with increased levels of urea and reduced levels of cowpea residues in different combinations up to the combination with 50% urea + 50% CR. Grain number per plant decreased with further increases of urea above 50% urea + 50% CR or 75% urea + 25% CR. This could mainly be attributed to the increase in the number of panicles per plant and total number of spikelets per panicle (Table 7).

On the other hand, increasing panicles per plant increased grain number per plant indirectly by increasing the number of spikelets per panicle. Kumar and Rao (1992); Gebrekidan and Seyoum (2006) also reported similar findings, indicating improvements in grain number per plant, which was attributed to increments in yield components. Increases in yield components were associated with better nutrition, plant growth and increased nutrient uptake (Kumar and Rao, 1992; Gebrekidan and Seyoum, 2006).

Reduction in number of grains per plant with increments of applied urea and reduced cowpea residues was mainly caused by successive reductions in the number of filled spikelet per panicle and 1000-grain weight. Singh *et al.* (1995) reported a decrease in grain yield in rice with high doses of N fertilizers. Reinke *et al.* (1994) noted that where the grain number per plant response is negative, yield reduction is primarily caused by a reduction in the proportion of the number of filled spikelets per panicle.

5. 2. 2 Grain yield

The best combinations of urea and cowpea residue as sources of nitrogen for optimization of rice yield were the main focus of this study. The combination of sources of nitrogen used in this study ranged from 0% (control plot, i.e without using urea or cowpea residues source of nitrogen) to 100% (46 kg N ha^{-1}) which is the average amount of urea currently recommended for rice variety Makassane in the locality. The experiment has provided information on growth and yield of the rice variety Makassane.

Harvestable yield per hectare has always been the basis of agronomic recommendations (Kupkanchanakul, 2007; Yoshida, 1981). The yield per ha increased with increase of the source of nitrogen. However, the flood problem caused fertilizer losses and reduction in the yield of the crop in this study. Problems of irrigation water control also disadvantaged productivity of this rice variety during the course of the experiment.

Crop yield ranged from 1.41 to 6.33 t ha^{-1} i.e. from without fertilizer, to the highest amount of the N source, respectively. The intermediate source of nitrogen (50% Urea + 50% Cowpea residues) yielded 4.70 t ha^{-1}, which is only slightly less than that obtained when using the highest doses of individual fertilizer sources. This study has shown the response of rice variety Makassane to combinations of incorporated cowpea residues and varying rates of urea and cowpea residues. The use of these sources of nitrogen has been shown to result in high levels of rice production. Nitrogen, perhaps, is the most critical nutrient essential for growth and development of the rice plant because it is easily leached and washed away with runoff water. The contribution of nitrogen has been known to account for 67% of the total fertilizer applied to rice as reported by Okonji *et al.* (2011) and Tayebeh *et al.* (2010).

Incorporation cowpea residues before sowing of rice had the best advantage by increasing 1000 - grain weight. The results showed that sole cowpea residues had heavier grains than other treatments with different combinations of source of nitrogen. Similar observations on cowpea residues effects on rice yield were reported by Okonji *et al.* (2010). Grain size is rigidly controlled by hull size. Under most conditions, 1000 – grain weight in rice is a very stable varietal character, the CV for the 1000 - grain weight varies from 2.2 to 4.4% and in the current study the CV was 3.4 which was in agreement with those reported for this character (Matsushima, 1970; Yoshida, 1981).

Comparable rice yield from both complementary application of organic and inorganic fertilizers and from sole cowpea residues is a further indication that the nutrients supplied from the complementary application were as effective as those supplied by sole cowpea residues.

Grain yield is a function of interaction among various yield components that are affected differentially by crop management practices. The yield per plant increases when urea is increased. The increase in biological and grain yield could be due to the increase in yield related attributes (plant height, number of productive tillers, panicles, and 1000-grain weight) concurrently (Ebaid *et al.*, 2007). A significant difference in 1000-grain weight of rice as affected by variation in fertilizer packages was also observed by Mirza *et al.* (2010).

The increase in grain yield components can be due to the fact that available more water enhanced nutrient availability which improved nitrogen and other macro- and micro-elements absorption as well as enhancing the production and translocation of the dry matter content from source to sink. (Ebaid *et al.*, 2007).

5. 3 Yield Components

Yield component analysis (YCA) provided additional information on the growth and yield response of the rice variety Makassane to different combinations of cowpea residues and urea fertilizer. A major strength of the approach is the statistical allocation of quantitative relationships among components of yield (R^2). Due to involvement of many morphological characteristics in YCA, Jolliffe *et al.* (1982) proposed use of snort yield components series to simplify interpretation and lessen the complications which might arise from major shifts in plant development. Some of the components (N/A and Ng/Nsp) do not make a significant contribution to yield but those components are important components in model. The number of panicle per plant is a good indicator of contribution of the component to Yield.

The contribution of N/A and Nsp/Npa was strongly and positively correlated, and both contributed greater than 50% of the total yield. The individual yield components were positively correlated to the yield and did not compensate to individual yield component, however since strong positive correlation between terms have been identified in other studies (Eaton and Kyte, 1978).

Yield components of special importance are identified by the statistical significance of their relationship with yield. The signs of regression coefficients show the direction of the relationship between variation in yield components and variation in yield. Hasanuzzaman *et al.* (2010) reported the importance of number of panicles per plant in determination of rice yield.

The key yield components were N/A, Npa/N, Nsp/ Npa, Nspf/Nsp and Wg /Nspf and contributed significantly to the variation yield. Since yield is the strict product of the yield component series, all of the variability in yield must be attributable to the variation in the yield components as reported by Aris *et al.* (2010).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

From the results obtained in this study, the following conclusions and recommendations have been made:

6. 1 Conclusions

(i) Of all the six treatments, 100% urea + 0% CR gave the highest grain yield (6.3 t ha^{-1}).

(ii) Organic fertilizers had significant influence on growth and productivity of the rice variety. Hence organic fertilizers can be a better supplement of inorganic fertilizers to improve growth and yield in rice.

(iii) The combination of 50% urea + 50% CR, supplied suficient nutrients for growth and yield of the rice variety, Makassane. Cowpea residues used in the current study were found to be of high quality and provided sufficient amounts of N that increased yield.

(iv) Dependence on urea diminished as the amount of cowpea residues increased. Hence treatments with 100% CR out yielded those with 25% urea + 75 CR.

6. 2 Recommendations

(i) Effectiveness of cowpea residues as source of nutrients for rice production has been observed in this and previous studies. It should therefore be recommended so that (cowpea residues) can be used as a source of nitrogen instead of inorganic fertilizers alone.

(ii) Where feasible, a combination of organic and inorganic fertilizers at the rate of 50% urea + 50% CR is recommended in order to reduce the quantity (and expenses) of inorganic fertilizer in rice production.

(iii) The Zambézia Region of Mozambique has areas where there is high production of the cowpea crop. These should be used as a source of N for rice production.

(iv) This study was conducted for only one season and at one location (Mucelo Farm). It is recommended that more such studies be conducted at different locations in order to confirm the current results.

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APPENDICES

Appendix 1: Rainfall distribution during the experiment period

Month	Week 1	Week 2	Week 3	Week 4	Total
October	0.0	0.0	0.0	14.8	14.8
November	0.0	0.0	0.0	0.0	0.0
December	0.0	0.0	0.0	0.0	0.0
January	0.0	0.0	326.8	166.0	492.8
February	0.0	0.0	0.0	0.0	0.0
March	0.0	0.0	0.0	22.0	22.0
April	9.0	0.0	22.3	0.0	31.3
May	78.0	0.0	33.0	44.9	155.9

Appendix 2: Mean monthly temperature during the experimental period

Temperature	Nov	Dec	Jan	Feb	Mar	Ap	May
Mean Max temperature	33.8	39.3	30.1	32.7	28.8	33.7	28.4
Mean min temperature	25.6	26.4	23.2	22.9	20.1	24.7	22.3
Mean temperature	29.7	32.9	26.7	27.8	24.5	29.2	25.4

Appendix 3: Data of solar radiation (J m^{-2})

Month	**Solar radiation (J m^{-2})**
November	6 677.96
December	6 578.29
January	6 578.29
February	6 272.27
March	5 880.59
April	5 481.91
May	4 186.18