UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECTS OF PLANT SPACING AND WATER CONTROL ON THE YIELD OF RICE (*ORYZA SATIVA L.*) IN THE SYSTEM OF RICE INTENSIFICATION

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EFFECTS OF PLANT SPACING AND WATER CONTROL ON THE YIELD OF RICE (*ORYZA SATIVA L.*) IN THE SYSTEM OF RICE INTENSIFICATION (SRI)

BY

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AUGUST, 2015

DECLARATION

Student

I hereby declare that this dissertation/thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere:

Candidate's Signature: …..................…........…… Date: ……..............………

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I hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of dissertation/thesis laid down by the University for Development Studies.

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ABSTRACT

Yield of rice obtained by farmers in rain-fed situation is about 1200 kg/ha which is far below 2710 kg/ha obtained elsewhere. There is need for improved cultural method other than fertilizer application to increase output. System of rice intensification (SRI) has helped to improve rice yield. The objectives of the study were to determine how spacing and water control affect yield of rice. The study was conducted at Golinga under irrigation scheme and also at Yendi under rain fed situation in 2014 cropping season. The rice variety used was Jasamine 85 locally called "*Gbewa Rice*" with maturity period of 120 days. Two water control systems, continuous and intermittent flooding served as main plots in a split plot design. Four plant spacing (20 x 20 cm, 25 x 25 cm, 30 x 30 cm and 40 x 40 cm) were used as subplot treatments. Organic matter at 10000 kg/ha was incorporated without the application of NPK fertilizer. Data on root dry matter, plant height and tillering were taken at 15 days interval till harvest at 105 days. Data on yield parameters were also taken. Results showed that increased plant spacing and intermittent flooding did not lead to higher yield. Shorter plant spacing of 20 x 20 cm and continuous flooding that gave higher yield of 5230 kg/ha. Continuous flooding favoured narrow spacing (20 x 20 cm) in the productive tillers proliferation while intermittent flooding favoured longer spacing. Plants spaced at 25 x 25 cm produced significantly higher number of panicles (154.3 panicles / $m^{2)}$ under continuous flooding than all treatments. The highest root dry matter was obtained at 40 x 40 cm with intermittent flooding and that could not translate into superior grain yield. The use of continuous flooding and shorter plant spacing was superior to the practices of SRI i.e. longer plant spacing and intermittent flooding. Shorter plant spacing and continuous flooding is therefore recommended to farmers.

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DEDICATION

This Research is dedicated to my Wife Arahamatu Shani, my daughter Aqilah, and my son Muslim for their love and support.

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LIST OF ABBREVIATIONS

CEO: Chief Executive Officer

CF: Continuous Flooding

CV: Coefficient of Variation

DAP: Days After Planting

DAT: Days After Transplanting

FAO: Food and Agricultural Organization of the United Nation

GE: Genotype and Environment

GH: Ghana

HI: Harvest Index

IF: Intermittent Flooding

JICA: Japan International Cooperation Agency

LSD: Lest Significant Difference

METSS: Monitoring, Evaluation and Technical Support Service

MoFA: Ministry of Food and Agriculture

NRDS: National Rice Development Strategy

PH: Plant Height

QTL: Quantitative Trait Loci

RCBD: Randomize Complete Block Design

RDM: Root Dry Matter

SRI: System of Rice Intensification

US: United State

WUE: Water Use Efficiency

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CHAPTER ONE

1.0 INTRODUCTION

Rice (*Oryza sativa L.*) is an important staple in the world and in Ghana it is the second most important cereal. About 90% of the world's rice crop is grown in Asia. Rice consumption in Ghana is increasing steadily as a result of increase in urbanization which demands for a staple food crop that can be cooked and stored easily. Per capita consumption of rice in Ghana increased from 17.5 kg per annum between 1999 and 2001 to 22.6 kg per annum between 2002 and 2004. By 2011, it had reached 38 kg per annum and projected to reach 63 kg per annum by 2015. About 70% of rice consumed in Ghana was purchased from abroad in 2013. According to the US Department of Agriculture in 2014, Ghana can produce around 275,000 tonnes of rice for human consumption, compared to an estimated 600,000 tonnes that it purchased from international sources in 2013.

The ministry of food and agriculture says that foreign rice purchases cost an estimated $450 million each year. It is expensive relative to local rice. As of December 2012, the cost of imported rice was GH₵2.36 ($1.20) per kg, compared to GH₵0.97 ($0.49) for domestic varieties (Vincent, 2012).

Demand for rice outstrips supply and there is the need to improve production and processing in Ghana. System of rice intensification (SRI) is a method for upscaling rice yield. The SRI makes three main changes in irrigated rice cultivation: transplanting younger seedlings, preferably 8-15 days old before the plants enter their fourth phyllochron of growth, planting the seedlings singly rather than in clumps of 3-6 plants, and keeping the paddy soil moist but not continuously saturated during the plants' vegetative growth phase. Yield performance of rice in SRI method suggests that average rice yields can be doubled over the present world average without requiring a change in cultivar's or the use of purchased input (Wang *et al.*, 2002).

Stoop *et al.* (2002) and Uphoff *et al.* (2002) provide a detailed overview of the rationale and key components of SRI and they also discuss its scope for adoption. SRI is understood as a set of principles and a set of mostly biophysical mechanisms. It should be noted, however, that SRI is not a ‘‘standard package’’ of specific practices, but rather represents empirical practices that may vary to reflect local conditions (Uphoff, 2002). Variants of SRI have also been tested in which only some of the basic components were practiced.

It has become difficult to increase production from traditional rice farming. Rice production needs extra labour and a lot of capital. Farming with modern methods is also expensive since outside inputs are needed. With conventional methods, it is only by using expensive chemical fertilisers, pesticides and hybrid seed that farmers can increase their production (FAO, 2010). It is becoming increasingly difficult for ordinary farmers to afford all these inputs. It is also known that using chemicals can be harmful to the environment (Katherine and Hendrik, 2010). Though average yield has improved country-wide to about 2200 kg/ha as of 2000 and the amount of land dedicated to rice production increased by 70% over the past decade, Ghana is unable to meet local demand (Vincent, 2012).

Under the 2009 national rice development strategy (NRDS), the ministry of food and agriculture (MoFA) planned to double rice production by 2018. Among other goals, the NRDS seeks to improve land and water management practices. The adoption of SRI will help MoFA to achieve this objective. The overall objective in this study is therefore to examine the effects of System of Rice Intensification on the yield of rice in Ghana.

The specific Objectives are to:

1. establish the best rice seedling spacing that will maximise yield of rice under the SRI in Ghana
2. establish an efficient water control mechanism that will be suitable for maximum yield of rice in the SRI in Ghana

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

It is reported that the rice yields obtained in the SRI method is similar to the yields obtained under conventional system although it requires 50 percent less water. This is the most important feature, since the water table depletion has become a global phenomenon, which is sending alarming signals to rice growing countries. As the rice crop is being traditionally cultivated under continuous submerged conditions, some alternate methods have to be researched into to minimize the water requirement of rice a crop. In this aspect, SRI cultivation method offers a wonderful approach to minimize water consumption for rice cultivation and to increase the productivity (Laulanie, 1993). Seedling age is known to influence the seed yield (Singh *et al.*, 2004).

A study involving simultaneous evaluation of root characteristics and grain yield, concluded that genotypes with a deep rooting habit had an advantage in stress conditions and that those genotypes that had produced deep roots prior to the onset of stress showed improved productivity compared with a genotype that did not have the capacity to produce roots prior to the onset of stress (Wang *et al.*, 2006). The study also suggested, based on quantitative trait loci (QTL) mapping, that the loci for productivity traits were not congruent with those related to root morphology, except at one locus. Subsequently, Toorchi *et al.* (2006) and Kanbar *et al.* (2009), based on canonical correlation studies conducted under contrasting moisture regimes, suggested that maximum root depth, root–shoot ratio, and root dry weight conferred an advantage to grain yield under water stress rice cultivation. Two major land management systems, commonly referred to as upland and lowland are used in rice cultivation. These two systems differ greatly in their yield potentials because of soil characteristics that affect root growth and plant response to drought.

2.2 Rice plant morphology

The growth of rice roots in terms of total dry matter, maximum root depth, and root length and density, increases until flowering stage**,** thereafter it decreases sharply at maturity (Yoshida and Hasegawa, 1982). Kawata and Soejima (1974) indicated that roots produced after flowering may play an important role during the grain-filling period. The shape of the root system differs greatly with soil texture, soil water status, and soil compaction (Hoshikawa, 1989). Rice is characterized by a shallow root system compared with other cereal crops (Angus *et al*., 1983), having limited water extraction below 60 cm (Fukai and Inthapan, 1988). The form of the rice root system also varies with cultivation methods (Yoshida and Hasegawa, 1982; Tuong *et al*., 2002). In upland conditions with direct sowing, the root system generally develops deeper than in transplanted rice in lowland conditions.

The rice root system, a fibrous root system, can be divided into different classes: seminal roots, mesocotyl roots, and nodal roots. Lateral roots emerge from each of these classes. These three classes differ in origin, anatomy, and function. When the seed germinates, the coleorhiza emerges first and then, within a short time, the first seminal root (radical) breaks through the covering. The emergence of the root is the first sign of seed germination. The seed contains a relatively large reserve of storage carbohydrate and nutrients (Marschner, 1998), which allows the embryonic root to grow rapidly.

It grows 3–5 cm long in 2–3 days after germination. Root to shoot ratio is a measure of the allocation of resources between different plant components. The allocation of resources toward the root is high at early vegetative stages but decreases markedly at flowering and is almost negligible after anthesis (Gregory *et al.*, 1996). Asch *et al.* (2004) reported that the proportion of total dry matter allocated to root or shoot parts depended on the rate of soil drydown, with root–shoot ratios averaging 0.05–0.1 at flowering. Genetic variation in root–shoot ratio among Oryza species was also reported, and was seen among subspecies groups (Kondo *et al.*, 2003).

Rice root anatomy characteristically exhibits cortical aerenchyma, which are associated with gas transport to roots growing in anaerobic conditions. The effects of soil moisture on aerenchyma formation have been documented, and these reports point to aerenchyma formation as prevalent in rice roots from all types of root growth media.

Colmer (2003) studied 12 rice varieties, including upland, paddy, and deepwater types, and all produced aerenchyma in both drained and flooded soil conditions, as well as in aerated and stagnant solution culture. Greater aerenchyma formation was observed in the flooded treatments, but no difference in aerenchyma formation among cultural types was reported.

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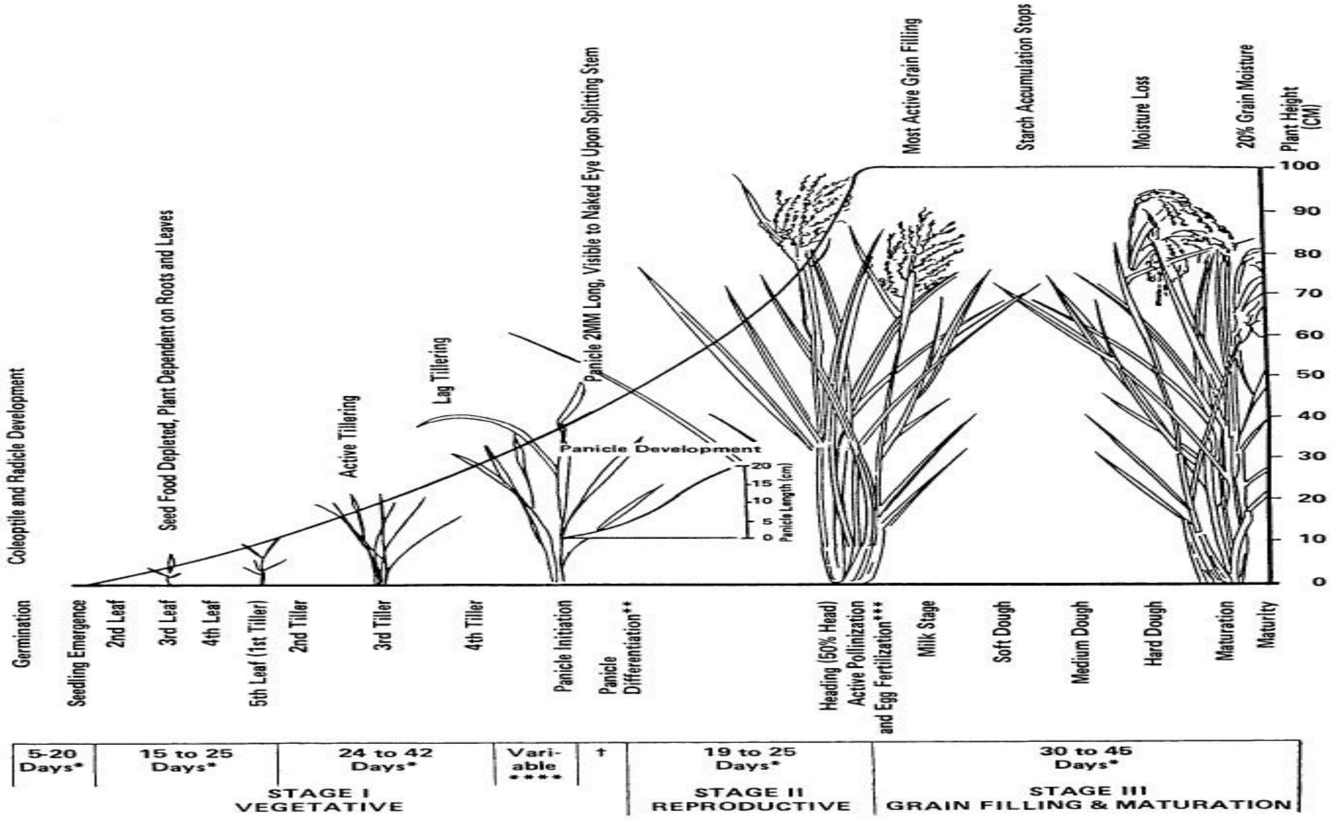

†3 to 5 days.

*Under warm conditions use the lower number of days and for cool conditions use the larger number of days.

**The reproductive stage begins with panicle initiation.

***Stage III begins when 50% of the florets are pollinated.

****Variable time – 0 to 25 days (dependent upon variety).

Figure 1: Development stages of rice plant (Karen and Nathan, 2013)

Aerenchyma formation has been observed under drought conditions in both aerobic and lowland genotypes, although to a lesser extent than under flooded conditions (Suralta and Yamauchi, 2008). Internal gas space may not reflect aerenchyma formation; rice roots have a root porosity of approximately 9% at 20–25 mm behind the root tips even aerenchyma (Armstrong, 1971). Parreno-de Guzman and Zamora (2008) observed that a greater number of aerenchyma lacunae were formed under intermittent and upland water regimes than in flooded conditions.

The authors reported genotypic differences when the roots were observed at tillering, but not at panicle initiation, which suggests genetic differences in the onset of aerenchyma formation. Although drought has been observed to affect aerenchyma formation, it is unknown whether aerenchyma formation affects water uptake in rice.

Rice roots adaptation to growth in flooded conditions display a unique formation of apoplastic barriers compared with other crop plants. The role of suberin and the Casparian band in limiting water uptake has received mixed reports. In drought-stressed lowland rice, the implications of apoplastic root barrier formation are complex since the soil at the start of the season is flooded, then fluctuates or steadily decreases based on rainfall patterns.

Hose *et al.* (2001) concluded that the extent and rate of Casparian band and suberin lamella formation depend on environmental conditions (drought, hypoxia, salt, heavy metal, and nutrient availability). Typically, a greater degree of Casparian band and suberin lamella development resulted in less water permeability of the root. Formation of an exodermis in rice was induced by growth in stagnant solution, and resulted in an effective barrier to radial oxygen loss in rice (Colmer *et al.*, 1998). Root water uptake ability and hydraulic conductance have been evaluated according to root pressure, determined by root system xylem sap flux through cut stems. Xylem sap flux of lowland variety Koshihikari decreased with decreasing water availability in a water-saving trial, but did not change in two upland varieties (Matsuo and Mochizuki, 2009b). Chang *et al.* (1972) compared root traits of several upland and lowland varieties and found that drought resistance was associated with coarse, long roots, a dense root system, and a high root to shoot ratio. Yoshida and Hasegawa (1982) also reported genetic variation in root depth, with a tendency for upland rice cultivars to have deeper roots than lowland rice cultivars. Ingram *et al.* (1994) used cultivars belonging to different types of rice for root studies and found tropical japonica types to have larger root systems than indica types. In another study, Lafitte *et al.* (2001) investigated the genotypic variation for root traits in different types of rice and reported that indica rice types had fine, highly branched superficial roots with narrow xylem vessels and low root to shoot ratio, whereas japonica types had coarse roots with wider vessels, less branched long roots, and a large root to shoot ratio.

So far, ten genes have been identified in rice relating to root growth, out of which mutants of six genes, rm1 and rm2 (Ichii and Ishikawa, 1997), rrl1 and rrl2 (Inukai *et al.*, 2001a), srt5 (Yao *et al.*, 2002), and srt6 (Yao *et al.*, 2003), are involved in a reduction in seminal root elongation. Mutants of two genes, crl1 and crl2 (Inukai *et al.*, 2001b), are involved in a reduction in number of nodal roots, one rm109 (Hao and Ichii, 1999) is involved in blocking lateral root initiation, and one rh2 (Ichii *et al.*, 2000) is involved in reducing root hairs.

Other mutants include crl4 (Kitomi *et al.*, 2008), lrt1 (lateral rootless phenotype; Chhun *et al.*, 2003a), arm1 and arm2 (lateral root number decreases; Chhun *et al.*, 2003b). Most of these genes have not been identified except for crl1 (Inukai *et al.*, 2008).

Positive associations between root length and grain yield have been documented in rice (Mambani and Lal, 1983; Lilley and Fukai, 1994). In contrast, Ingram *et al.* (1994) found no significant association between the two traits. It may be that a simple correlation between root growth and yield could be expected only in well-defined target environments (Mambani and Lal, 1983; Ekanayake *et al.*, 1985).

2.3 Lowland and upland rice land management systems

Rice cultivars adapted exclusively to upland conditions are typically characterized by a deep and coarse root system, tall stature, thicker stems, and fewer tillers (Ling *et al.*, 2002), whereas lowland rice cultivars have shallow and finer roots, a large number of roots, and many tillers (Lang *et al.*, 2003). In upland fields during stress, the major sources of water for growth and development are rain that is retained by the soil and groundwater. A coarse and deep root system, for soil penetration and access to water reserves deep in the soil, is considered valuable for improved drought resistance under upland conditions (O’Toole and Chang, 1979; Ling *et al.*, 2002).

Yoshida and Hasegawa (1982) noticed large variation among upland rice cultivars for root length density below 30 cm and suggested that the effect of drought stress depends on the ability of plants to develop a deep root system. Chang *et al.* (1986) also found that rice with a deep root system avoided drought better than rice with a shallow root system. Advantages conferred by a deep root system depend on three major factors: duration of the drought period, availability of water at depth, and rate of water uptake. If water is not limited in upper layers of the soil, the plant may not benefit from the formation of deep roots. In upland conditions, Puckridge and O'Toole (1981) found that deep-rooted cultivar Kinandang Patong extracted more water at a depth of 40–70 cm than shallow-rooted cultivars (IR20 and IR36).

A range of trends have been reported regarding root growth response to drought stress in upland rice, including both root growth inhibition and root growth promotion in drought stress treatments. Kato *et al.* (2006) has reported the effects of various water regimes on deep root growth and biomass partitioning to roots in upland rice. They concluded that while many studies report an increase in root: shoot ratio and deep root growth in response to drought, conditions as timing of the drought at seedling stage, very severe drought stress, and presence of hardpans have reduced resource partitioning to roots. Conclusions about drought effects on root growth may also differ because root mass and root length can show opposite trends, especially when root diameter decreases because of drought, resulting in greater length but less mass.

Iijima *et al.* (1991) indicated that maize roots were better able to penetrate hard soil than rice roots. In general, roots of dicotyledonous plants have a higher penetration rate than monocot roots (Materechera *et al.*, 1992), and upland rice cultivars have greater penetration ability than lowland cultivars (Yu *et al.*, 1995). Changes in soil conditions can greatly alter root distribution patterns. However, the mechanism by which roots penetrate compacted soil layers is not well understood. It remains to be demonstrated whether the penetrated root mass has any role in the uptake of moisture and increasing grain yield in intermittent flooding.

Root plasticity can be defined as the ability of a genotype to adjust its root growth phenotype according to environmental constraints (O'Toole and Bland, 1987). The timing of root growth in response to the intermittent flooding following a period of drought stress is a vital feature of root growth plasticity (e.g., Banoc *et al.*, 2000a). Genetic variation has been observed in rice for plasticity in several root traits, including the ability of lateral roots to develop in response to rewatering after soil drying (Banoc *et al.*, 2000b), and also in response to soil drying after flooding (Suralta *et al.*, 2010). Genetic differences have also been observed in the ability of seminal roots to continue elongation and form aerenchyma under flooded conditions after drought (Suralta and Yamauchi, 2008; Suralta *et al.*, 2008 a, b, 2010).

Under intermittent flooding (Kato *et al.*, 2006), this type of plasticity may be valuable for improved rice growth under drought by allocating resources to increased root growth only when needed. These abilities are quite important for rainfed lowland rice due to the unique soil environment as mentioned earlier, and thus the desirable roots traits are not as simple as those for upland rice such as deep or coarse roots. Different genotypes have exhibited different responses in plasticity depending on type of water control (Kano *et al.*, 2011).

2.4 Climate and yield potential of rice

The yield potential of SRI is lower at tropical lowland sites, particularly in double- or triple-crop system with short growth duration of rice (Kropff *et al.*, 1994), but also at sea level in Madagascar where the climate is tropical. Climatic differences in yield potential must be emphasized when trying to promote the adoption of SRI elsewhere. For example, the average grain yield reported for conventional irrigated rice management (3900 kg/ha) in the SRI studies (Fernandes and Uphoff, 2002) was significantly less than the current global average irrigated rice yield of about 5300 kg/ha (Dobermann, 2000).

In studies on intermittent flooding irrigation, grain yield of rice was increased (Li, 2001; Tuong *et al.*, 2005; Zhang *et al.*, 2008 a, 2009 a) but reduced in others (Mishra *et al.*, 1990; Tabbal *et al.*, 2002; Yang *et al.*, 2007; Belder *et al.*, 2004) when compared with continuously flooded conditions. The discrepancies between the studies are probably attributed to the variations in soil hydrological conditions and the timing of the irrigation method applied (Belder *et al.*, 2004).

The yield ceilings are less than some of the yield claims made for SRI in on-farm studies in Madagascar (Rafaralahy, 2002), but they are comparable with maximum yields achieved in several research experiments conducted elsewhere. Grain yields of 10–12 Mg ha^{-1} have been achieved in tropical dry season crops, whereas maximum yields in the 13–15 Mg ha^{-1} range have been measured at sites with subtropical or temperate climate in Australia and China (Horie *et al.*, 1997; Kropff *et al.*, 1994; Sheehy, 2000; Ying *et al.*, 1998). The latter are typically sites with high solar radiation and/or cooler night temperatures, often associated with higher elevation, and a growth duration that is typically 30–50 days longer than in the tropics (Horie *et al.*, 1997; Ying *et al.*, 1998). Most of the SRI sites in Madgascar for which super yields have been reported are found on higher elevation (500 to 1500 m).

2.5 Continuous flooding and intermittent flooding in SRI

Oryza glaberrima is evolved as a wild species in seasonally flooded portions of West African river valleys and mostly flourished as deep-water rice in soils were water was abundant, nutrients were available, and there was less competition by other species (Dobermann, 2004). To take advantage of this, it had to develop an aerenchyma and, due to the abundance of water and nutrients, it could easily thrive on a relatively shallow root system (Dobermann, 2004). Root porosity or aerenchyma formation (Armstrong, 1967) is directly related to redox potential, but plants that are adapted to wetland conditions appear to perform best under slightly reducing conditions as compared to strongly reduced or strongly oxidized soil (Kludze and Delaune, 1995; Kludze and Delaune,1996).

A floodwater layer has unique benefits. It acts as a buffer zone that stabilizes many soil processes and has a rich biological life, as summarized by Roger (1996) but biological activity in the floodwater is a major component of the long-term sustainability of rice systems, mainly due to the large C and N inputs associated with it.

Research on rice yield performance under different water management regimes generally suggests that most water saving practices are associated with a slight yield decrease, the level of which depends on the groundwater table depth, the evaporative demand and the drying period in between irrigation events (Bouman and Tuong, 2001).

Kar *et al.* (1974) reported total root number, root dry weight, and shoot dry weight of rice grown under continuous flooded condition were much larger than under unsaturated condition (at which the relative root deterioration was less). In the continuous flooded soil, root degeneration only started to become significant about 50 days after germination, first affecting rootlets. Reddy and Kuladaivelu (1992) also observed that root volume and root-dry weight were higher under continuous submergence or at irrigation to submergence after reaching the soil-saturation point than under drier upland moisture regimes.

Zhang *et al.* (1990) studied nutrient uptake in lowland and upland rice cultivars under hypoxia. They found that the cortex was more developed in the lowland cultivar, which was related to adaptation to water logging. Hypoxia decreased root growth, Ca and P uptake but had no effect on N uptake in either NO^{3-} or NH^{4+} form. The decreases in root growth and P and Ca uptake were greater in the upland cultivar, which was related to their different capacities for oxygen transport to the roots.

On less acid and particularly on neutral rice soils less ferrous iron is produced, there is less need for oxygen excretion by roots, less rhizosphere acidification, faster diffusion of acid away from the root, and roots will likely remain healthier (Kirk and Bajita, 1995; Kirk and Saleque, 1995).

Morita and Yamazaki (1993) summarized the Japanese work on root morphology in response to the management factors that also form the basis of SRI. They suggested that the following practices help develop deep roots and achieve high yields: (1) good drainage, (2) deep plough layers, (3) compost application, (4) moderate, infrequent N application, (5) moderate water percolation, and (6) planting at moderate density. These are all components of SRI too.

Across species, morphological and physiological changes in plant growth due to effects of hardpans on root include a reduction in transpiration rate and leaf area expansion, and ultimately a decrease in dry matter accumulation (Masle and Passioura, 1987; Ludlow *et al.*, 1989; Assaeed *et al.*, 1990; Masle, 1992). These effects may be due to direct consequencse of reduced root access to water and nutrients. The presence of hardpan in shallow soil layers may further promote uneven moisture distribution in the soil profile, so that the root system tends to be partially exposed to dry soil, causing stomates to close while the rest of the system can access water (Siopongco *et al.*, 2008, 2009). Soil cracking can penetrate hardpans, strongly influences rainfall infiltration and water evaporation processes (Tuong *et al.*, 1996).

Tao *et al.* (2002) evaluated effects of SRI methods on physiology and growth of two rice hybrids at a site in southeast China in comparison with a continuous flooding. Although SRI intermittent flooding plants had a much deeper root system and larger root and total plant dry matter per hill than plants grown under continuous flooding, total aboveground dry matter production expressed in kg ha^{-1} was not significantly different in both systems from tillering to maturity.

Thakur *et al.* (2011) reported that plant height was negatively affected by prolonged flooding. Similar to this observation, Thakur *et al.* (2011) stated that rice plants grown under alternate wetting and drying were 22 and 24% taller than rice plants grown under continuous flood. Tillering is the result of continuous root development (through adventitious roots) which under aerated soil moisture regime remained active, whilst under continuous flooding it degenerated significantly and became minimized and hampered (Thankur *et al.*, 2011). The lower number of productive tillers in the continuous flooded rice in the study could be associated with the lack of aeration and degeneration of the roots. In line with this result Thakur *et al.* (2011) reported doubling in the number of tillers under aerated rice field as compared to continuous flooding. Nyamai *et al.* (2012) also reported improved rice tiller growth with alternate flooding and drying as compared to continuous flooding.

Zhang *et al.* (2010) and Thakur *et al.* (2011) reported that the percentage of filled grains significantly increased under alternate wetting and drying condition as compared to under continuous flooding. Zhang *et al.* (2010) reported a 6.6% increase in aboveground biomass yield with alternate wetting and drying compared to continuous flooding. In this study grain yield penalties of 26.3% and 25.9% were observed with two weeks and eight weeks continuous flooding water treatments compared to two weeks and seven weeks continuous flooding water management treatments.

Nyamai *et al.* (2012) reported a 71% yield increase with alternate flooding and drying over continuous flooding. Similarly, Thakur *et al.* (2011) reported rice yield increase of 25 to 50% in a non-continuous flooding water management. Lin *et al.* (2011) also reported a 10.5 to 11.3% grain yield increase under intermittent water application (aerobic irrigation) compared to continuous flooding which they attributed to the increase in the number of grains per panicle with aerobic irrigation. To increase yield further and to break the yield ceiling, breading effects have the yield sink capacity (the maximum size of sink organs to be harvested) mainly by increasing the number of spikelets per panicle (Kato *et al.*, 2007). The degree and rate of grain-filling in rice spikelets differ largely with their positions on a panicle. In general, earlier-flowering superior spikelets, usually located on apical primary branches, fill fast and produce larger and heavier grains. While later-flowering inferior spikelets, usually located on proximal secondary branches, are either sterile or fill slowly and poorly to produce grains unsuitable for human consumption (Mohapatra *et al.*, 1993; Yang *et al.*, 2000). The slow grain-filling rate and low grain weight of inferior spikelets have often been attributed to a limitation in carbohydrate supply (Sikder and Gupta, 1976; Murty and Murty, 1982; Zhu *et al.*, 1988). Grain-filling in cereals depends on carbon from two sources: current assimilates and assimilates redistributed from reserve pools in vegetative tissues either pre- or post-anthesis (Kobata *et al.*, 1992; Schnyder, 1993; Samonte *et al.*, 2001). The contribution of reserved assimilates in culms and leaf sheaths of rice plants are estimated at around 30% of the final yield depending on cultivar and environmental conditions (Gebbing and Schnyder, 1999; Takai *et al.*, 2005). Remobilization and transfer of the stored assimilates in vegetative tissues to the grain in monocarpic plants such as rice and wheat require the initiation of whole-plant senescence. Delayed whole-plant senescence can lead to poorly filled grains and unused carbohydrates in straws. Slow grain-filling can often be associated with a delay in whole-plant senescence (Zhu *et al*., 1997; Mi *et al.*, 2002; Gong *et al.*, 2005).

2.6 Water use efficiency (WUE)

It is well documented that high yield potential and high yield under water-limited conditions (intermittent Flooding) are generally associated with reduced WUE (e.g. Munoz *et al*., 1998) mainly because of high water use. Features linked to low yield potential, such as smaller plants (Martin *et al*., 1999) or short growth duration (Lopezcastaneda and Richards, 1994) ascribe high WUE because they reduced water use (Condon *et al*., 2002).

Water loss avoidance as achieved by enhanced capture of soil moisture by roots has been found to be associated with low WUE in such diverse species as rice (Kobata *et al*., 1996, Zhang *et al*., 1997). On the other hand, reduced transpiration in rice (Kobata *et al*., 1996) and reduced evapotranspiration in sorghum (Tolk and Howell, 2003) were associated with higher WUE.

Intermittent irrigation with shallow or little standing water management during transplanting is desirable, since a large water supply during puddling and after transplanting could increase the loss of fertilizers through percolation, and lead to greater environmental pollution (Lu *et al*., 2000; Won *et al*., 2003).

Sufficient water supply under continuous flooding in rice often leads to excessive vegetative growth which may result in less root activity, unhealthy canopy structure, and Lower harvest index (HI) (Li, 2001, Zhang and Yang, 2004). The HI is the grain yield over total above-ground biomass. The grain yield and water productivity would be improved by either an increase in transpiration efficiency or an increase in HI. However, the ratio of biomass production over transpiration has been shown to be fairly constant for a given species in a given climate (Ehlers and Goss, 2003), and can be selected for in plant breeding (Bouman, 2007). Plant biomass production is linearly coupled with the amount of water transpired, and higher water use efficiency (WUE) is often a trade-off against lower biomass production (Zhang and Yang, 2004). In agriculture, many ways of conserving water have been investigated and techniques such as alternate partial root zone irrigation, deficit irrigation, and drip irrigation, have shown that WUE can be enhanced (Tabbal *et al*., 2002; Kang *et al*., 2000; Li *et al*., 2010). In general, these techniques are a trade-off: a lower yield for a higher WUE (Zhang and Yang, 2004). On the other hand, HI has been shown to be a variable factor in crop production Zhang *et al*., 2008).Variations in harvest index within a crop are mainly attributed to differences in crop management (Guo *et al*., 2004; Peltonen-Sainio *et al*., 2008).

A water and/or nitrogen management system that could increase growth rate during grain filling and/or enhance the remobilization of assimilates from vegetative tissues to grains during the grain-filling period usually leads to a higher HI within a crop (Zhang *et al*., 2008b; Xue *et al*., 2006; Bueno and Lafarge, 2009; Fletcher and Jamieson, 2009; Ju *et al*., 2009). In many situations, HI is closely associated with WUE and grain yield in wheat (Triticum aestivum L.) and rice (Yang *et al*., 2000, 2007; Zhang *et al*., 2008a, c).

Grain filling is the final stage of growth in cereals when fertilized ovaries develop into caryopses and depends on carbon from two resources: current assimilates and assimilates redistributed from reserve pools in vegetative tissues either pre- or post-anthesis (Kobata *et al.*, 1992; Samonte *et al.*, 2001). The contribution of reserved assimilates in culms and a leaf sheath of rice plants is estimated at 10–40% of the final yield, depending on the cultivar and the environmental conditions (Gebbing and Schnyder, 1999; Takai *et al.*, 2005). Remobilization of reserves to the grain is critical for grain yield if the plants are subjected to water stress or if the yield potential is largely based on the high biomass accumulation (Herwaarden, 2003; Plaut *et al.*, 2004). Remobilization and transfer of the stored assimilates in vegetative tissues to the grain in monocarpic plants such as rice and wheat require the initiation of whole plant senescence (Gan and Amasino, 1997; Noode´n *et al.*, 1997).

Delayed whole plant senescence (i.e. plants remain green when grains are due to ripen) results in much non-structural carbohydrate left in the straw and leads to a low HI. Slow grain-filling can often be associated with the delay of whole plant senescence (Mi *et al.*, 2002; Gong *et al.*, 2005). Their senescence is unfavourably delayed because the gain from the extended grain-filling period is less than the loss due to slow grain filling and unused assimilates left in the straw (Yang and Zhang, 2006). The improved leaf architecture would allow more radiations to penetrate the canopy, which is very important to maintain a healthy canopy during grain filling (Fageria, 2007). Harvest index (HI) is a variable factor in crop production. Enhancement in HI would increase WUE without compromising grain yield.

The maximum number of tillers produced by the rice plant is inversely proportional to the length of the phyllochron (Katayama, 1951), which is dependent upon the extent of stresses. Wider spacing, availability of solar radiation, medium temperature, soil aeration, and nutrient supply promote shorter phyllochrons which increase the number of tillers in the rice plant (Quyen *et al*., 2004).

The rate of tiller production in rice is faster from establishment to maximum tillering (35-40 days of age) and slower thereafter, but tiller production continues until flowering (Vergara, 1979). Huang *et al.* (1996) and Quyen *et al.* (2004) observed that the tillers that started late grew at a slower rate, died off due to insufficient supply of assimilates and nutrients and mutual shading. As observed by Wu *et al.* (1999), young tillers in transplanted rice began to die off after 48 days after emergence. These results in the production of tillers at the latter part of the growth of the rice plant and it flowers late. These lately produce panicles ripen late and could not mature along the earlier formed panicles and hence becoming unproductive (Vergara, 1979).

The unfilled grain % might be due to poor nutrient available for grain filling at wider spacing. Zhang *et al.* (2010) and Thakur *et al.* (2011) reported that the percentage of filled grains significantly increased under alternate wetting and drying condition as compared to under continuous flooding. This is consistent with Veeramani (2011) who reported significant higher number of unfilled grains per panicle and lower spikelet sterility percentage at continuous flooding with wider spacing of 40 cm x 40 cm compared with closer pacing of 20 cm x 20 cm. Usually, water stress at grain-filling time induces early senescence and shortens the grain-filling period but increases the remobilization of assimilates from the straw to grains (Palta *et al.*, 1994; Asseng and van Herwaarden, 2003; Plaut *et al.*, 2004). Slow grain-filling can often be associated with the delay of whole plant senescence (Mi *et al.*, 2002; Gong *et al.*, 2005). Their senescence is unfavourably delayed because the gain from the extended grain-filling period is less than the loss due to slow grain filling and unused assimilates left in the straw (Yang and Zhang, 2006).

2.7 Growth hormones and water control

Abscisic acid and Auxin promote lateral root formation, cytokinin suppresses lateral root formation, ethylene has interactions with auxin and may play a role in lateral root formation through cortical cell breakdown, and gibberellic acid acts with ethylene to promote adventitious root growth in continuous flooded rice. Studies of hormone effects on rice root growth report that ethylene mediates aerenchyma formation and adventitious root growth under continuous flooded conditions in rice (Rzewuski and Sauter, 2008), but is not involved in the formation of barriers to radial oxygen loss (Colmer *et al.*, 2006). Use of an antisense transgenic indicated a positive role of cytokinins for rice root development (Liu *et al.*, 2003). Abscisic acid (ABA) was observed to play a role in lateral root formation, tip swelling, root hair formation, and water permeability in roots of some rice varieties (Chen *et al.*, 2006).

2.8 Rice spacing

Rice plants largely depend on temperature, solar radiation, moisture and soil fertility for their growth and nutrition requirements. A dense population of crops may have limitations in the maximum availability of these factors. It is, therefore, necessary to determine the optimum density of plants population per area unit for obtaining maximum yields (Baloch *et al*,. 2002). Optimum plant spacing ensures plants to grow properly both in their aerial and underground parts through different utilization of solar radiation and nutrients. The optimum plant density depends on different factors that most importance of this factors include: plant characteristics, growth period duration, planting time and methods, soil fertility, plant size, available moisture, sunshine, planting pattern and situation of weeds (Shirtliffe *et al*., 2002). Plant spacing is an important production factor in transplanted rice (Gorgy *et al*., 2010). Mohapatra *et al*. reported that plant spacing of 20 × 20 cm was better than those of 25 × 25 or 25 × 20 cm under normal soil for rice productivity (Mohapatra *et al*., 1989). Maske *et al*. (1997) reported that plant height, leaf area index, yield and yield components of rice with plant spacing of 20 × 20 cm were higher than of 25 × 25 cm or 25 × 20 cm. Patel (1999) observed that hill spacing of 20 × 20 cm in compared with 20 × 15 cm and 20 × 10 cm of hill spacing recorded perceptible increase in number of panicles per meter, yield and straw yield. Also, Number of grains per panicle and 100 - grain weight was not affected by hill spacing. Number of seedling per hill is another important factor that can play an important role in boosting yield of rice. Because it influences the tiller formation, solar radiation interception, total sunshine reception, nutrient uptake, rate of photosynthesis and other physiological phenomena and ultimately affects the growth and development of rice plant. In densely populated rice field the inter-specific competition between plants is high in which sometimes results in gradual shading and lodging and thus increase production of straw instead of grain. It is, therefore, necessary to determine the optimum plant spacing and number of seedling per hill for high yield (Ghosh and Singh, 1998; Hossain, *et al.*, 2003). Faruk *et al.* reported that the highest grain yield was recorded from two seedlings per hill and the lowest one was recorded from single seedling per hill (Faruk *et al.*, 2009). Mohammadian *et al.* (2011) with Study of yield and yield components of rice variety *Ali Kazemi* in different Plant Spacing and Number of Seedlings per Hill was reported that the highest grain yield was obtained from plant spacing of 20 × 20 cm with 5582 kg/ha.

System of Rice Intensification (SRI) recommended wider spacing (25 x 25cm to 30 x 30 cm) for higher yield (Batuwitage, 2000) however, Ferraris *et al.*, (1973) mentioned that the plant spacing do not have much effect on final grain yield of rice under high nitrogen application. Peng *et al.* (1998) reported that the final grain yield for hybrid rice depends more on panicle size and panicle number. Matsuo *et al.* (1995) has reported that the yield of rice varieties did not change when the planting distance was maintained below 35 x 35 cm.

2.9 Fertilization in flooding rice fields

Change in early-season water management has direct implications for nitrogen fertility management, but current recommendations were developed for continuously flooded rice. The impacts of an early-season drain on nitrogen fertilizer dynamics, particularly the effect on potential nitrogen losses, are not well understood. Of all nutrients applied as fertilizer, nitrogen is required by rice in higher quantities and is most susceptible to losses (Schnier, 1995).

Fertilizer nitrogen is applied to rice fields in the form of organic matter, ammonium (NH_4) or urea (which rapidly converts to ammonium). When a rice field is flooded, the fertilizer largely remains as ammonium (Linquist *et al.*, 2006) and is taken up as ammonium by the rice plant.

When the field is drained and the soil becomes aerobic, ammonium is oxidized through microbial processes (known as nitrification) into nitrate (NO_3^-). Nitrate is susceptible to losses in rice systems, and it disappears from the rice rooting zone within a week or two of a soil being flooded (Linquist *et al.*, 2006). The rate of nitrate in flooded soils is difficult to determine. Plants, including rice, can take up nitrate before it is lost by other means. The most likely cause of nitrate loss from rice systems is denitrification (Bowman *et al.* 2002). When the field is reflooded and the soil becomes anaerobic, microbes convert a portion of the nitrate into nitrogen gas (denitrification), which is lost to the atmosphere (Buresh and De Datta, 1991). In some rice systems, nitrate leaching can be a significant loss (Yoon *et al.*, 2006).

Linquist *et al.*, (2006) reported that shortly after flooding for planting, most nitrate is lost from the soil plough layer, and most mineral nitrogen is in the form of ammonium. The nitrate present prior to flooding the fields for planting would most likely have been lost via denitrification (Buresh and De Datta, 1991). Over time, however, (Obcema *et al.*, 1984), this nitrogen moves laterally through the soil and subsurface nitrogen levels become less variable.

Nitrate and ammonium can be lost in water runoff from rice fields. These losses are usually small, unless nitrogen fertilizer is applied just before or during a runoff period. Shortly after fertilization, nitrogen levels in rice floodwaters are low. Patrick and Reddy (1976) found that rice floodwater contained only 1.4 pounds nitrogen per acre six (6) days after a surface nitrogen application. In another study, only 0.3% of nitrogen fertilizer was lost via leaching and runoff (Zhao *et al.*, 2009).

2.10 Quantitative trait loci (QTL)

Many studies across crops have indicated considerable genotype and environment (G×E) interactions for root traits, which are expected given the number of environmental factors (i.e., soil physical, chemical, and biological) that affect root growth. In rice, Kondo *et al.* (2003) investigated G × E interactions by using both intermittent flooded and continuous flooded at three sites in the Philippines, where in both site nitrogen treatments contributed to environmental variation. In that study, genotype accounted for the largest proportion of variation for specific root weight, nodal root number, and root to shoot ratio, whereas the environmental effect of nitrogen treatment was relatively high for total dry weight and deep root length ratio.

Root traits are generally controlled by many genes through quantitative trait loci (QTL). Since the study by Champoux *et al.* (1995) to locate genes controlling rice root traits with molecular markers, many QTLs related to root traits have been identified in rice using 12 different mapping populations, with QTLs, identified and analyzed in rice for more than 30 root morphological parameters. The most studied root traits in all QTL mapping studies are maximum root depth, root diameter, and root to shoot ratio.

The most notable contrast among rice root QTL studies is the vast array of growth media and observation methods used. The effects of G × E on root growth is particularly important for rice under intermittent flooded conditions, with continuous flooded soils being a complex layer of soil over a hardpan in dry cracked soils over the same season. Understanding how growth and observation methods affect root QTL studies is key for using our knowledge of QTLs to improve drought resistance in rice. Most of the above QTL studies have measured root traits in containers under controlled conditions, although it is yet to be proven whether these results reflect true genetic differences (Steele *et al*., 2007).

Root traits that result in improved plant water status through a stress-prone growing season could confer non-stage-specific drought resistance. For example, conventional breeding for root-related drought resistance in rice was conducted using farmer-participatory plant breeding approaches. These more productive phenotypes under SRI are characterized by higher number of tillers per plant, increased plant height, longer and wider leaves, longer panicles, more grains per panicle and improved grain quality (Mishra and Salokhe, 2011; Thakur *et al*., 2011).

2.11 Root dry matter

The main physiological principle behind SRI is to provide optimal growing conditions to individual rice plants so that tillering is maximized and phyllochrons are shortened, which is believed to accelerate growth rates (Nemoto *et al.*, 1995). It was also observed that tiller mortality is reduced. Furthermore, intermittent irrigation is believed to improve oxygen supply to rice roots, thereby decreasing aerenchyma formation and causing a stronger, healthier root system with potential advantages for nutrient uptake (Stoop *et al.*, 2002).Genetic variation exists in potential root length, however, when plants are exposed to an intermittent flooded soil, root morphology and growth can change to the extent that the potential root length, whether it is short or long, becomes relevant. In cereals drying, hard topsoil resists the penetration and establishment of adventitious roots while existing roots receive all transient assimilates and grow deeper (Blum and Ritchie 1984; Asseng *et al.*, 1998).

Shoot/root dry matter ratio increases under drought stress, not because of an increase in root mass but due to a relatively greater decrease in shoot mass (Pheloung and Siddique, 1991). Root mass rarely increases under intermittent flooding due to moisture stress. However, root length and depth may increase in a drying soil even at a reduced total root mass (Yang *et al.*, 2001a).

The major exception that constitutes a form of an effective dehydration tolerance mechanism in crop plants is stem reserve utilisation for grain filling under drought stress in intermittent flooding (Blum 1998). This is a harmonised whole-plant process that allows effective grain filling when whole-plant photosynthesis is inhibited by stress during grain filling. It is a tolerance mechanism that allows grain filling in dehydrated or over-heated cereal plants, which can account for up to 90% of total grain weight under stress (Blum *et al.*, 1994; Asseng and van Herwaarden 2003). Stem reserve utilisation has been found to be an effective yield-supporting mechanism under drought stress in intermittent flooding (Hossain *et al*., 1990; Gavuzzi *et al*., 1997; Yang *et al*., 2002; Asseng and van Herwaarden, 2003; Plaut *et al*., 2004) major condition for stem reserves for grain filling is sufficient carbohydrate storage before grain filling.

Although some stem reserve mobilisation may support grain filling under non stress conditions (continuous flooding), reserve mobilisation is noticeably induced by drought stress during grain filling (Blum *et al*., 1994; Palta *et al*., 1994; Plaut *et al*., 2004). The signal for the induction of reserve mobilisation under drought stress is not clear but likely to involve hormones such as gibberellins and abscisic acid (Yang *et al*., 2001 b).

Rahman and Ando (2012) described that continuous flooding caused the soil to become increasingly anaerobic with low redox potential which led to adverse effects on root development and activity, such as reduction in the number and diameter of lateral roots, root respiration, root damage and rots. Kassam *et al.* (2011) also reported that rice plant roots that were grown under hypoxic soil conditions did not fully develop and were abnormal. The roots that grew degenerated prematurely, so that they became less functional and effective, taking up less soil nutrients and water as the roots died back (Kassam *et al*., 2011).

According to Rahman and Ando (2012), at about the time of the 45th. day before heading, the soil in a field under the continuous flooded condition became short of oxygen, causing an abnormal fermentation of organic matter in soil and producing harmful organic acid or hydrogen sulphides, which consequently inflicted damages on roots.

According to Thakur *et al.* (2011), rice soil aerating practice not only induces greater root growth, but also enhances root activity. Root systems in aerated rice enhanced nutrient uptake (Thakur *et al.*, 2011) while continuously submerged paddy fields had impaired root development thus reduced nutrient uptake.

Mishra and Salokhe (2011) and Thakur *et al.* (2011) reported that roots, under continuous flooded conditions, do not develop as well and have a shorter life span. Under flooded conditions, root system activity declines after mid-season, while in the SRI intermittent flooding system, roots remain active longer into the grain filling period. Under continuous flooding, up to three-fourth of the roots degrade by the flowering stage (Kar *et al.*, 1974, cited by Satyanarayana *et al.*, 2007). Under SRI, roots reach deeper and achieve double the volume compared to plants in conventionally planted hills (Thakur *et al.*, 2011). With larger root systems, plants access water at deeper soil horizons, which makes the crop more resilient towards drought stress (Satyanarayana *et al.*, 2007).

2.12 Critique of SRI

Critics of SRI suggest that claims of yield increase in SRI are due to unscientific evaluations. They object that there is a lack of details on the methodology used in trials and a lack of publications in the peer-reviewed literature (McDonald *et al.* 2006; Mcdonald *et al.*, 2008). Some critics have suggested that SRI success is unique to soil conditions in Madagascar (Christopher, 2008).

Uphoff (2013) states that SRI "can raise irrigated rice yields to about double the present world average without relying on external inputs and also offering environmental and equity benefits.

In 2011 a young farmer named Sumant Kumar set a new world record in rice production of 22400 kg/ha using SRI, beating the existing world record held by the Chinese scientist Yuan Longping by 3000 kg. (Vidal and John 2013).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site description

The study was carried out in the Golinga irrigation site in the Tolon district under irrigation from February 2014 to May 2014 and Nyembolni in the Yendi municipality under rain-fed from June 2014 to September 214. Golinga is located 10 km west of Tamale and lies approximately on latitude 0˚56′.678″W and longitude 9˚21′.346″N whiles Nyembolni is about 6 km South of Yendi on latitude 0˚04′.996″E and longitude 9˚26′.678″W.

The parent rocks of the experimental field in Golinga consist of sand and clay-shell which belong to the rocks of the Obosun bed of the lower bottom voltian formation.The soils of the area belong to the kpalsawgu series, which consist of yellow-brown clay and silt mainly developed from local colluviun and the Tolon series which are characterised by moderately drained sandy loam free from concretion. Soils in Yendi are basically formed from sedimentary rocks of predominantly voltarian sandstone, shales and mudstones. The soils derived from the above parent materials range from laterite, ochrosols, sandy soils, alluvial soils and clay. The organic content is low and is increasingly worsened by the extensive bush burning and bad agricultural practices.

The areas have a unimodal rainfall pattern with the rainy season stretching from April to October. The rainfall data from 2013 to 2014 showed that Golinga has a mean annual rainfall of 1079 mm. The temperature distribution is not uniform with mean monthly temperature ranging from 23.4˚C (minimum) and 40.5˚C (maximum). Relative humidity of the area generally varies greatly, rising during the rainy season. The mean monthly values were 54% in 2013 and 67% in 2014.

The study areas are within the interior Guinea savannah zone of Ghana. The dominant indigenous trees are *Azadirachta indica*, *Parkia spp* and *Vitellaria paradoxa*. The common weed species are *Rottboellia cochinensis*, *Heteropogon contortus*, *Cyperus spp* and *Digitaria horizontalis.*

3.2 Treatment structure and experimental design

The experimental factors were water control at two levels and spacing at four levels. The water controls were continuous flooding (CF) and intermittent flooding (IF) whiles the spacing were 20 x 20 cm, 25 x 25 cm, 30 x 30 cm and 40 x 40 cm (Table 1). The treatments were laid in the split plot design with three replications. The cultural practices were the same for all experimental sites. The lands were ploughed and harrowed with tractor after excess water was completely drained.

The rice variety used was Jasmine 85 also called (*Gbewa Rice*) which is an improved variety with a maturity period of 120 days. The yield potential of this variety is estimated to be 10,000 kg/ha. It is the most common variety used by farmers in Ghana. This variety is highly appreciated by consumers.

Table 1: Treatments combination applied at Golinga and Yendi

Factors			Treatment
Plant Spacing (cm)	**Water Control**		
	Continuous Flooding (CF)	**Intermittent Flooded (IF)**	
20 X 20 cm	CF		CF 20 x 20 cm
25 x 25 cm	CF		CF 25 x 25 cm
30 x 30 cm	CF		CF 30 x 30 cm
40 x 40 cm	CF		CF 40 x 40 cm
20 x 20 cm		IF	IF 20 x 20 cm
25 x 25 cm		IF	IF 25 x 25 cm
30 x 30 cm		IF	IF 30 x 30 cm
40 x 40 cm		IF	IF 40 x 40 cm

Each block measured 21 m X 13 m with 1 m between blocks. Each Block had eight (8) plots each measuring 5 m X 4 m.

3.3 Raising rice seedlings in nursery

The seedling bed was carefully prepared before sowing. The plots were hand ploughed using traditional “hoe” and then manually harrowed and levelled. The seedbed was kept moist for two days then seeds were soaked overnight and planted in the nursery. The nursery was kept moist until full germination then regularly irrigated as needed without flooding.

3.4 Transplanting the seedlings

Seedlings were transplanted (one seedling per hill) at the two leaf stage (10 days after germination) after sowing in nursery. Transplanting spacing between hills depended on treatment description (20 x 20 cm, 25 x 25 cm, 30 x 30 cm and 40 x 40 cm).

3.5 Water control

Bunds were made round plots for water control. Water was maintained at 5 cm depth throughout the growing period in the continuously flooded fields. In the intermittent fields, for up to two weeks, as the seedlings are establishing, the paddy was kept wet. After this, water was managed to allow just the right amount of moisture. Once every two weeks the soil was allowed to completely dry out and even cracks. In the rainy season, the rain was enough to satisfy the water needs. If irrigation was needed, the fields were once flooded in the evening, allowed to soak in overnight, then drain off any excess water the following day. When the rice flowered, more water was allowed to flood the field. From 3-4 weeks before harvest, no irrigation was done and the field was drained.

3.6 Cultural practices

The plots were kept weed free throughout the growing period. Weeding was done manually at two weeks interval using the hand hoe making effect to incorporate the weeds into the soil.

Industrial produced organic matter were applied and thoroughly mixed up through the harrowing process at the rate of 10,000 kg/ha.

3.7 Data collection

Data were collected on the following parameters:

1. Plant height (cm)
2. Rice root dry matter (g)
3. Days to 50% flowering
4. Number of productive tillers per hill
5. Tiller number per m^2 at 60 DAT
6. Panicle number per m^2
7. Grain number per panicle
8. Unfilled grain (%)
9. Dry straw yield (kg/ha)
10. Rice paddy yield (kg/ha)
11. Harvest Index

Five (5) plants were tagged on each plot for the measurement of plant height. With the aid of 150 cm measuring tap tiered to a long pole, the height of the rice plant was measured at 15 days interval after transplanting until maturity at 120 days.

Five (5) rice plants were carefully uprooted from each plot at 15 days interval after transplanting. Root systems were separated by washing with running water on a mesh of size 6.4 squares/cm until all the soils disappear from the root mass. Then roots were oven-dried at 70˚ C. until a constant weight reached and root dry weight recorded (Bohm, 1979).

Days to 50% flowering of rice plant was recorded from each plot when 50% of its rice plants had produced flowers. Data on number of productive tillers per plant recorded at maturity from yield plots. Five (5) yield plots of 1 m x 1 m were pegged out on each plot for yield measurement. The number of productive tillers was determined by counting the number of tillers that produced paddy. Tiller number per m^2 at 60 days after transplanting was determined by finding the average of the tillers produce by the five (5) 1 m x 1 m yield plots mentioned above at 60 days after transplanting (Yashida, 1981). The number of panicles produced in the 1 m^2 yields plots was counted and the average of the five (5) was determined. Grain number per panicle was determined from the yield plots by counting the number of grains produced either filled or unfilled together. The percentage of unfilled grain was then calculated from the unfilled. The weight of the filled grains from above was measured and extrapolated to give the paddy yield in kg/ha. The straw produced by the yield plots was measured (kg/ha). The harvest index was then calculated (Donald, 1962).

3.7 Harvesting, threshing and winnowing

Harvesting was done at physiological maturity (120 days) with a sickle, manually threshed and winnowed.

3.8 Rice paddy yield

At maturity, yield plots of 1 m^2 were taken at five different locations (five samples) per plot. Harvested paddy was threshed, winnowed, dried and weighed to estimate yield.

3.9 Statistical analysis

Data from Golinga and Yendi sites were analysed separately using GENSTAT for analysis of variance and the treatment means were separated at least significant difference (LDS) at 5% probability (Steel and Torrie, 1980).

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of plant spacing and water control on rice plant height

Water control and plant spacing did not significantly differ in the main effects and interaction in Golinga. However, at Yendi, plant spacing had significant ($p< 0.001$) effect on plant height. Plant spacing and water control had significant interaction effect ($p< 0.001$) on plant height at Yendi. In Yendi, (Figure 2) plants receiving wider plant spacing treatment (40 x 40 cm) grew taller than those spaced 25 x 25 cm.

Plant height significantly increased with days from 15 days after transplanting to 105 days after transplanting in both continuous flooding and intermittent flooding with spacing in Yendi and Golinga (Table 2 and Table 3).

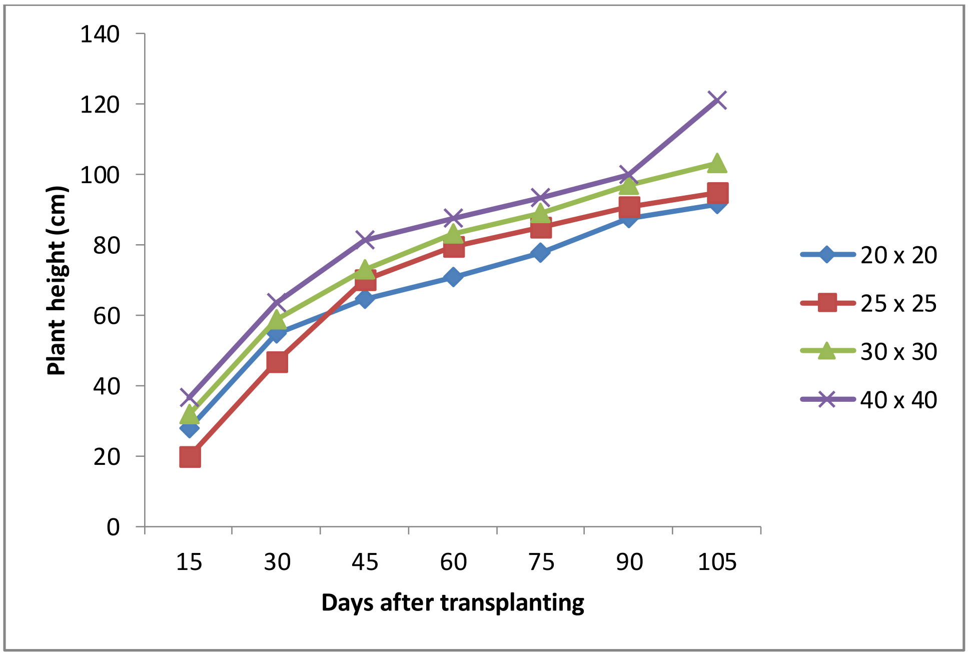

Figure 2: Effects of spacing and water control on plant height of Jasmine 85 rice variety grown at Yendi

Table 2: Effects of plant spacing and water control interaction on plant height in Yendi

Treatments	**Plant height days after transplanting**						
	15	**30**	**45**	**60**	**75**	**90**	**105**
Interaction effects of plant spacing and water control on plant height							
Continuous flooding x Plant spacing							
20 x 20	26.33	53.33	60.00	65.00	73.33	81.83	86.33
25 x 25	13.67	40.67	78.00	89.67	96.00	101.67	106.67
30 x 30	39.33	66.33	70.00	78.00	82.00	87.67	96.57
40 x 40	31.33	58.33	82.67	87.33	91.67	96.67	104.67
Intermittent flooding x Plant spacing							
20 x 20	29.00	56.00	69.33	76.67	82.33	93.33	96.87
25 x 25	26.00	53.00	61.67	69.43	74.00	79.73	83.10
30 x 30	24.00	51.00	75.67	88.17	96.00	106.50	110.00
40 x 40	41.67	68.67	79.67	87.33	94.67	103.17	137.50
LDS (0.05)				5.772			
CV (%)				4.6			

Table 3: Effects of plant spacing and water control interaction on plant height (Golinga)

Treatments	**Plant height days after transplanting**						
	15	**30**	**45**	**60**	**75**	**90**	**105**
Interaction effects of plant spacing and water control on plant height							
Continuous flooding x Plant spacing							
20 x 20	19.53	30.27	45.90	48.67	63.33	68.67	82.77
25 x 25	25.10	33.00	48.33	51.67	71.67	84.40	87.90
30 x 30	23.43	31.00	38.67	51.33	65.00	82.43	92.00
40 x 40	22.37	35.60	50.53	52.67	68.67	85.33	91.53
Intermittent flooding x Plant spacing							
20 x 20	21.50	30.17	37.50	49.67	68.20	74.00	82.50
25 x 25	20.77	28.60	39.70	51.00	63.67	83.67	91.23
30 x 30	26.47	30.50	48.50	50.67	54.33	73.33	82.83
40 x 40	18.90	36.00	47.67	53.33	69.00	74.33	78.60
LDS				11.198			
CV%				7.7			

4.2 Effects of plant spacing and water control on days to 50 % flowering in jasmine 85 rice

Days to 50 % flowering was significantly ($p< 0.001$) influenced by plant spacing at both sites. Days to 50 % flowering increased with increasing plant spacing (**Error! Reference source not found.**). The interaction of plant spacing and water control was significant only at Yendi ($p< 0.001$). Days to 50 % did not record any regular pattern with plant spacing in its interaction with water control (**Error! Reference source not found.**).

Table 4

The shortest number of days to 50 % flowering with plant spacing was recorded at 20 x 20 cm smaller plant spacing and the longest number of days recorded at 40 x 40 cm larger plant spacing. The treatment interaction (Table 4) produced similar results. Although the results looks similar, SRI at Golinga took longer days to reach 50 % flowering (Table 4) compared with SRI at Yendi (**Error! Reference source not found.**).

Table 4: Effects of plant spacing and water control on days to 50 % flowering

Treatments	**Golinga**		**Yendi**	
Plant spacing (cm)	**Intermittent flooding**	**Continuous flooding**	**Intermittent flooding**	**Continuous flooding**
20 x 20	65.00	65.33	62.00	56.67
25 x 25	72.67	72.67	64.67	70.00
30 x 30	76.00	76.00	57.33	69.33
40 x 40	80.67	80.67	61.00	70.00
LSD (0.05)	3.657		4.95	
CV (%)	3.2		4.0	

4.3 Effects of plant spacing and water control on root dry weight

Root dry weight accumulation was significantly influenced by water control ($p< 0.046$) and plant spacing ($p< 0.001$) as well as their interaction ($p< 0.001$).

Root dry weight accumulation increased with increasing plant spacing in the continuous flooding (CF) and intermittent flooding (IF).

Plate 1: Picture showing effects of spacing and water control on root dry matter in Yendi, where; IF mean intermittent flooding and CF continuous flooding.

Root dry weight accumulation in continuous flooding increased at an increasing rate from 15 DAT to 75 DAT (Figure 3) and it declined at 90 DAT and 105 DAT. When water was applied intermittently, root dry weight also increased with increasing plant spacing. Root dry matter declined around 60 and 90 DAT (Figure 3). Plant spacing and water control did not significantly affect root dry matter accumulation at Golinga.

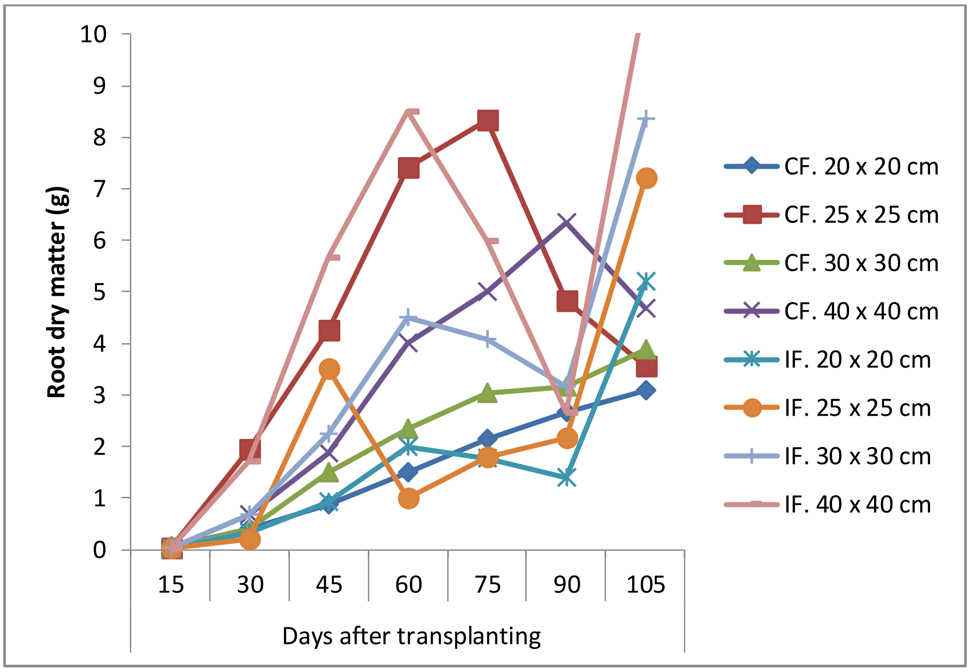

Figure 3: Effects of plant spacing and water control on root dry matter at Yendi

4.4 Effects of plant spacing and water control on tiller and productive tiller number per plant

Water control and plant spacing did not significantly affect the number of tiller per plant in both Golinga and Yendi.

The number of productive tillers per plant was significantly influenced by plant spacing (*p< 0.001*) at Yendi. Number of productive tillers per plant increased with increasing plant spacing (Figure 4).

Water control did not significantly affect reproductive tiller number (*p=0.423*), however spacing and water control had significant interaction effect on productive tillers (*p=0.002*). Continuous flooding and intermittent flooding were both favored by longer spacing (40 x 40 cm) in the productive tillers proliferation (Figure 5). However, intermittent flooding produced slightly higher productive tillers than continuous flooding. Spacing and water control did not have significant effect on productive tiller number at Golinga.

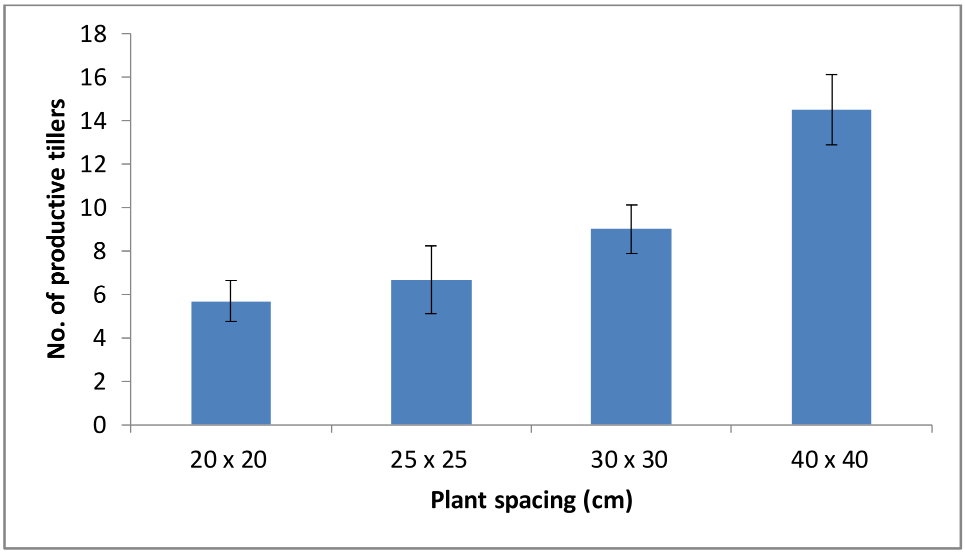

Figure 4: Effect of plant spacing on number of productive tillers at Yendi

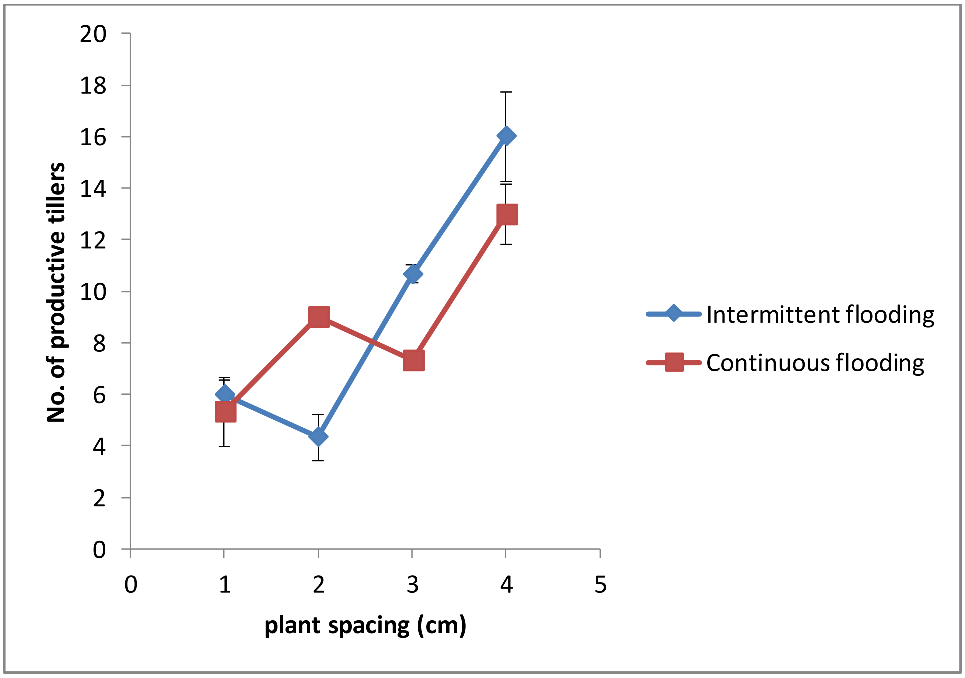

Figure 5: Effect of water control and plant spacing on number of productive tillers at Yendi

4.6 Effects of plant spacing and water control on panicle number per m^2

Plant spacing and water control did not significantly enhanced panicle number in the main effects ($p < 0.523$) and interaction ($p < 0.127$) at Golinga. However, at Yendi the panicle number was significantly influenced by plant spacing ($p < 0.001$) and the interaction between plant spacing and water control ($p < 0.002$). Pancle number increased between 20 x 20 and 25 x 25 cm spacing then it declined and remained insignificantly different between 30 x 30 and 40 x 40 cm spacing (Figure 6).

Plants spaced at 25 x 25 cm produced significantly higher number of panicles under continuous flooding than all treatments (Figure 7). Narrower spacing of 20 x 20 cm under intermittent flooding produced significantly higher number of panicles than other treatments except 25 x 25 cm under continuous flooding.

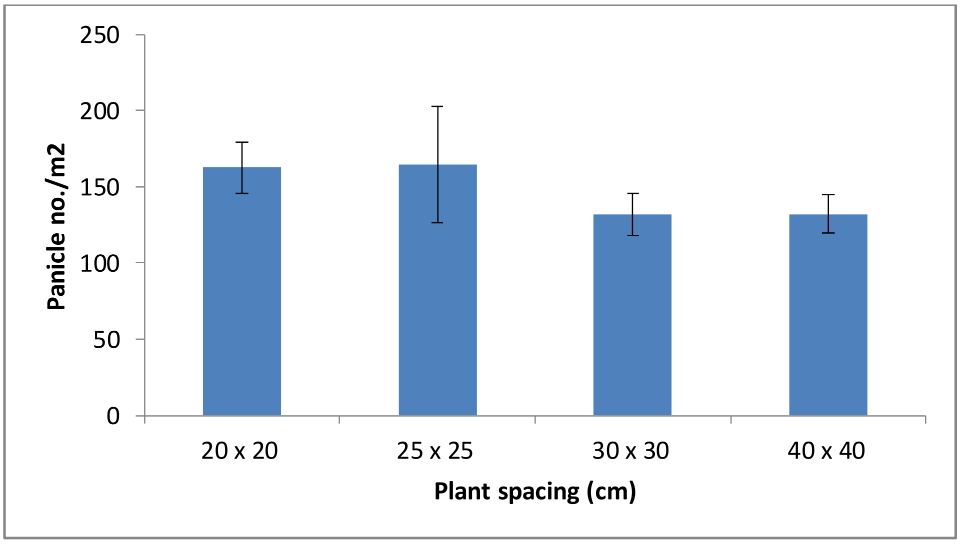

Figure 6: Effect of plant spacing on number of panicle/m^2 at Yendi. Bars represent SEM

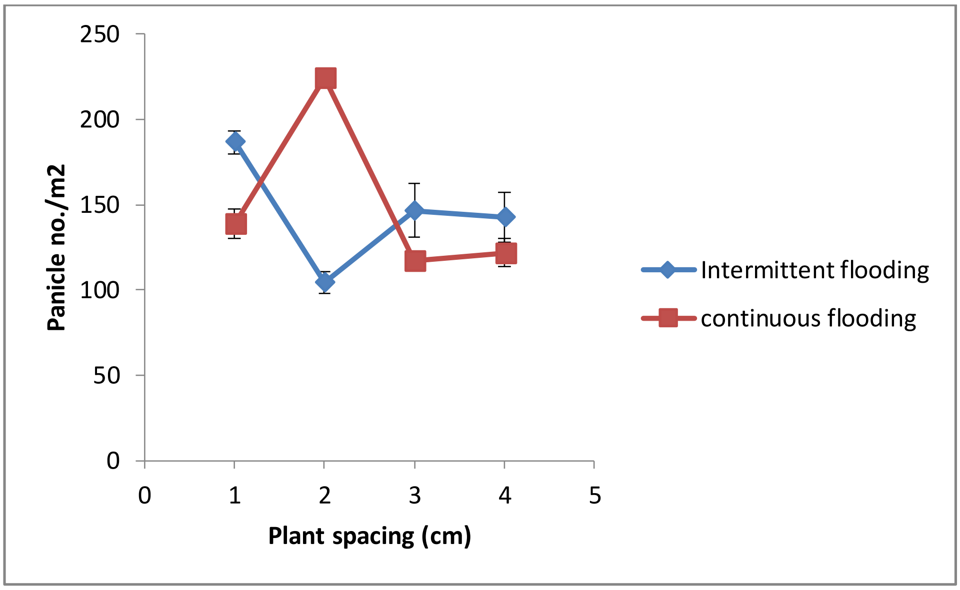

Figure 7: Effect of plant spacing and water control on panicle number/m^2 at Yendi. Bars represent SEM

4.7 Effects of plant spacing and water control on grain number per panicle

Plant spacing and water control did not significantly affect grain number/panicle at Yendi. At Golinga, it was only plant spacing that significantly influenced (*p<0.001*) grain number per panicle (Figure 8). Grain number decreased with increasing plant spacing (Figure 8). There was no significant difference between 30 x 30 cm and 40 x 40 cm in grain number. The interaction of plant spacing and water control however did not record a regular pattern in grain number per panicle.

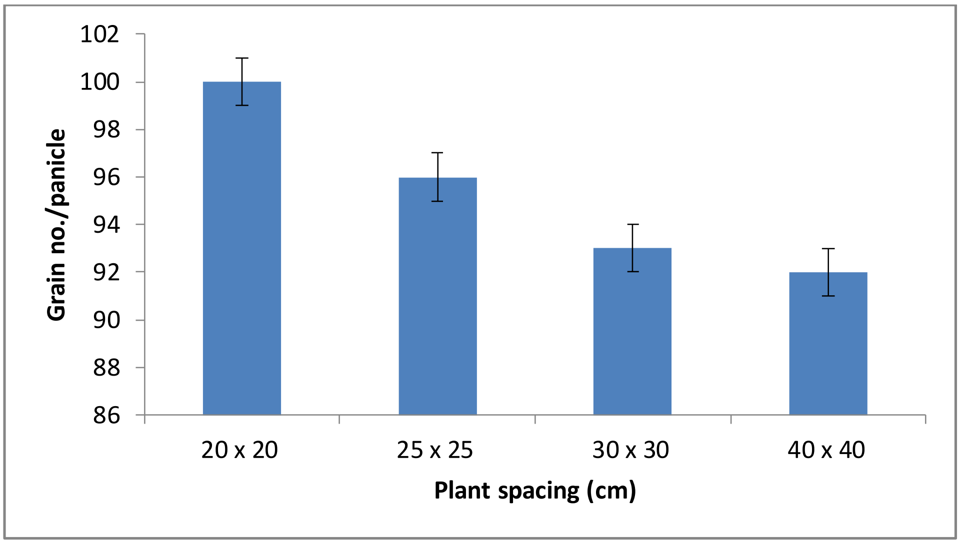

Figure 8: Main Effects of plant spacing on grain number/panicle at Golinga

4.8 Effects of plant spacing and water control on percentage unfilled grain

Plant spacing and water control as well as their interaction did not significantly affect unfilled grain percentage at Golinga. Also at Yendi plant spacing and water control did not show significant effect on percentage of the grain that were unfilled however, their interaction significantly ($p < 0.001$) influenced unfilled grain percentage. Intermittent flooding produced 3.3 % more unfilled grain than continuous flooding. Under continuous flooding the percentage unfilled grain increased with increasing plant spacing from 20 x 20 cm to 30 x 30 cm and insignificantly declined at 40 x 40 cm (Figure 9). There was no regular pattern of increased or decreased in percentage unfilled grain under intermittent flooding. Smaller plant spacing both in continuous flooding and intermittent flooding recorded much lower unfilled filled grain % than wider plant spacing.

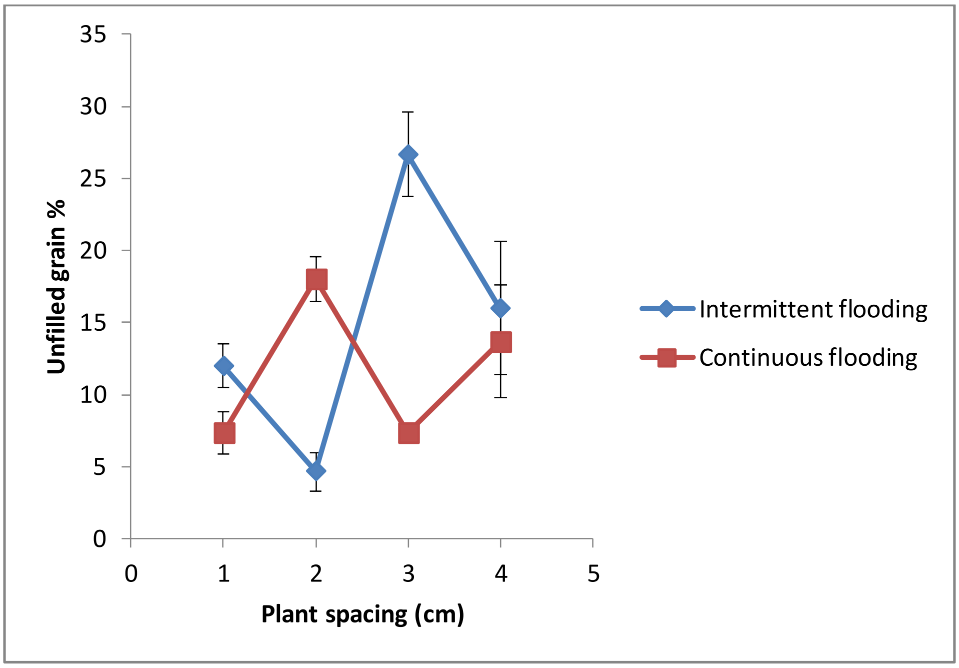

Figure 9: Effect of plant spacing and water control on unfilled grain % at Yendi

4.9 Effects of plant spacing and water control on rice dry straw yield (kg/ha)

Plant spacing, water control and their interaction did not significantly affect rice straw yield at Golinga. At Yendi, the plant spacing and water control did not show significant effect on dry straw yield. However, the interaction of plant spacing and water control significantly (*$p<0.001$*) influenced straw yield. With the exception of plant spacing at 25 x 25 cm straw yield with plant spacing was higher under intermittent flooding than continuous flooding (Figure 10).

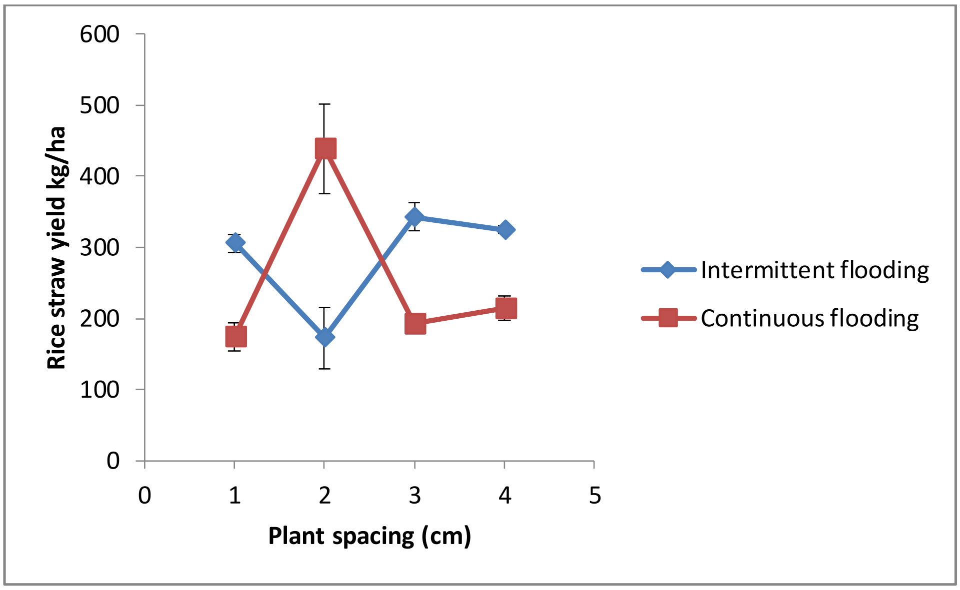

Figure 10: Interaction of plant spacing and water control on rice straw yield at Yendi

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4.10 Effects of plant spacing and water control on rice paddy yield (kg/ha)

At Yendi, plant spacing and water control significantly ($p < 0.001$) influenced rice paddy yield but their interaction was not significant ($p < 0.993$). At Golinga only plant spacing had significant effect on paddy yield. Yield at the two sites were similar.

Though rice paddy yield decreased with increasing plant spacing significant difference was only observed between 20 x 20 cm and 40 x 40 cm at both Golinga and Yendi (Figure 11).

At Yendi, fields under continuous flooding produced significantly higher amount of paddy rice (4776 kg/ha) than those under intermittent flooding (4396 kg/ha).

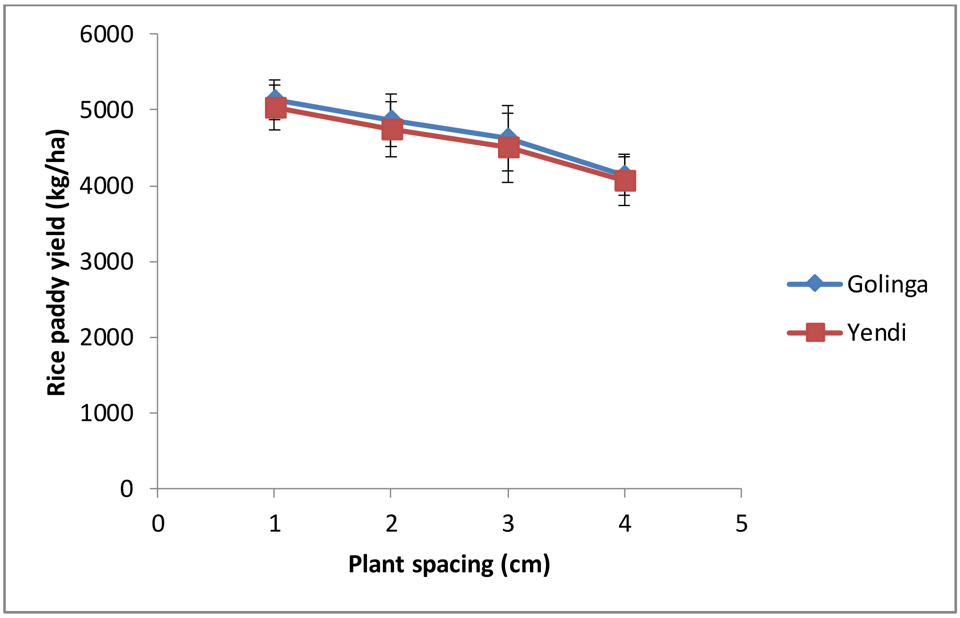

Figure 11 Effect of plant spacing on rice paddy yield at Golinga and Yendi

4.11 Effects of plant spacing and water control on rice harvest index

Plant spacing and water control had significant effect on harvest index at Yendi (*p< 0.003*).

Increase in plant spacing from 20 x 20 cm to 25 x 25 cm under continuous flooding led to a decline in harvest index but the opposite was observed under intermittent flooding (Figure 12). Again, between 25 x 25 cm and 30 x 30 cm harvest index increased under continuous flooding but a decline was observed under intermittent flooding. A further increase in planting distance to 40 x 40 cm saw a decline in harvest index under both water control systems.

At Golinga plant spacing and water control as well as their interaction did not have significant effect on harvest index.

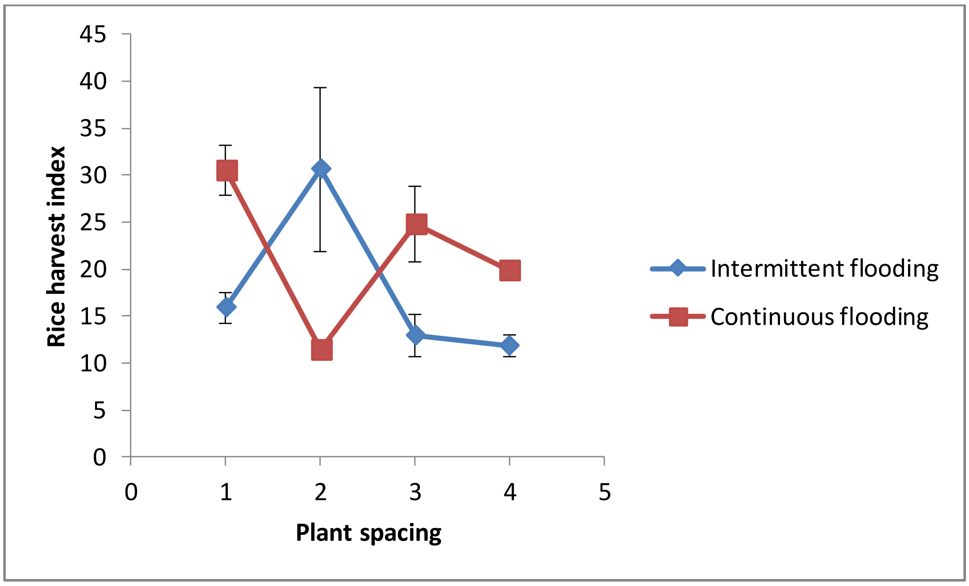

Figure 12: Interaction of water control and plant spacing on harvest index in Yendi

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Effects of plant spacing and water control on rice plant height

Plant height increased with increasing plant spacing (Figure 2) and relatively wider spacing (40 x 40 cm) grew much taller than narrow spacing (20 cm x 20 cm). Taller plants produced by wider spacing may be attributed to adequate spacing for moisture available for rapid vegetative growth. Rapid vegetative growth leads to an increased of shoot under wider spacing of 30 cm x 30 cm and 40 cm x 40 cm in continuous flooding compared to smaller spacing of 20 x 20 cm (Table 2 and Table 3). The plant also gets sufficient space to grow and there will be increased light transmission in the canopy which may leads to increased plant height. This is in accordance with the findings of Shrirame *et al.* (2000) who reported that the number of functional leaves and leaf area (vegetative growth) were higher at wider spacing which increased the photosynthetic rate leading to taller plants. Transplanting younger seedlings at wider spacing under continuously flooded condition make rice plant to have more vigorous root growth and lesser transplant shock because of lesser leaf area during the initial growth stages which stimulate increased cell division causing more stem elongation resulting in increased plant height (Kim *et al.*, 1999).

5.2 Effects of plant spacing and water control on days to 50 % flowering

The result of this study shows that number of days to 50 % flowering increased with increasing plant spacing in both continuous flooding and intermittent flooding (Table 4). Plant spacing and water control (continuous flooding and intermittent flooding) resulted in early flowering (**Error! Reference source not found.**) under closer plant spacing of 20 x 20 cm and 25 x 25 cm than 30 x 30 cm as well as 40 x 40 cm. The differences in days to 50 % flowering may be due to rapid vegetative growth in closer plant spacing resulting in competition for light, nutrient, spacing and then resulting in early switch over to reproductive phase. This result is consistent with this finding of Krupakar (2004) and Udayakumar (2005). They reported that close plant spacing results in quick vegetative growth leading to early switch over to the reproductive phase.

5.3 Effects of plant spacing and water control on root dry weight

The increases in root dry weight (Figure 3) accumulation from 15 DAT to 75 DAT but declining at 90 DAT and 150 DAT under continuous flooding is in responds to anaerobic condition created by prolonged continuous flooding. Even though root dry matter accumulation also declined (Figure 3) at 60 and 90 DAT in the intermittent flooded field, but it again appreciated at 105 DAT. This indicates that the continuous flooded rice needs to be drained at least once every month for aeration. One of the most important principles of draining in intermittent flooding is to allow active aeration of the soil. Rahman and Ando (2012) described that continuous flooding caused the soil to become increasingly anaerobic with low redox potential which led to adverse effects on root development and activity, such as reduction in the number and diameter of lateral roots, root respiration, root damage and rots from 60 DAT 105 DAT in the continuous flooding compared to the intermittent flooding. This might also be due to the fact that under continuous flooded conditions, root system activity declines after mid-season as a result of poor aeration, while in the SRI intermittent flooding system, roots remain active longer into the grain filling period. This is in consistence with the results of Satyanarayana *et al.* (2007) that under continuous flooding, up to three-fourth of the roots degrade by the flowering stage. The findings are also in conformity with research by Mishra and Salokhe (2011) and Thakur *et al.* (2011) that says that, roots under flooded conditions do not develop very well and have a shorter life span. Under intermittent flooding, roots reach deeper and achieve double the volume compared to plants in continuous flooded planted (Thakur *et al.*, 2011).

5.4 Effects of plant spacing and water control on tiller and productive tiller number per plant

Tiller and productive tiller number per plant increased when plant spacing enlarged in both Golinga and Yendi (Figure 5). This could be attributed to greater space available for individual plant to put forth more tillers at wider spacing compared to closer spacing. Shrirame *et al.* (2000) in a study in rice also reported that the total number of tillers per hill were higher at wider spacing as a result of increasing plant spacing and photosynthetic rate.

Number of productive tillers per plant (Figure 4) favoured longer plant spacing in both continuous flooding and intermittent flooding with intermittent flooding producing slightly higher productive tillers than continuous flooding. The slightly lower number of productive tillers in the continuous flooded rice in the current study could be associated with the lack of aeration and degeneration of the roots. Thakur *et al.* (2011) reported doubling in the number of productive tillers under aerated rice field as compared to continuous flooding.

The low productive tillers by smaller spacing may also be due to a major condition of poor stem reserves of sufficient carbohydrate storage before grain filling in. Veeramani (2011) reported significant higher number of productive tillers/plant and lower spikelet sterility percentage at wider row spacing of 30cm x 25cm compared with closer pacing of 25cm x 25cm which is in agreement with the current study.

5.6 Effects of plant spacing and water control on panicle number per m^2

The decreasing panicle number/m^2 with increasing plant spacing (Figure 6 and Figure 7) in both the main effect and interaction may be due to higher tiller number per hill at wider plant spacing leading to greater competition among tillers for nutrients at wider plant spacing as compared to closer plant spacing that produced lesser tiller per hill. This may also be due to increased plant density at narrow plant spacing i.e. 36 plants/m^2 at 20 x 20 cm, 25 plants/m^2 at 25 x 25 cm, compared to lower planting density with wider plant spacing i.e. 16 plants/m^2 at 30 x 30 cm and 9 plants/m^2 at 40 x 40 cm. This contrasts the opinion that panicle number per m^2 and the number of grains per panicle are not affected by hill spacing (Patel, 1999). Consistent with the findings is that just enough stem reserve utilisation at smaller plant spacing has been found to be an effective yield-supporting (panicle number/m^2) mechanism under water control and plant spacing (Hossain *et al.*, 1990; Pheloung and Siddique 1991; Gavuzzi *et al.*, 1997; Yang *et al.*, 2002; Asseng and van Herwaarden 2003; Plaut *et al.*, 2004).

5.7 Effects of plant spacing and water control on grain number per panicle

It was observed that grain number decreased per panicle with increasing plant spacing (Figure 8). This may be due to very high late flowering inferior spikelete than superior spikelets with increasing plant spacing. This increases the differences in spikelet position on a panicle with increasing spacing. Earlier-flowering superior spikelets, usually located on apical primary branches, fill faster and produce larger and heavier grains, whiles later-flowering inferior spikelets, usually located on proximal secondary branches, are either sterile or fill slowly and poorly to produce grains unsuitable for human consumption (Mohapatra *et al.*, 1993; Yang *et al.*, 2000, 2006).

5.8 Effects of plant spacing and water control on unfilled grain percentage (%)

Unfilled grain % was uniform among the treatments at Golinga. Intermittent flooding produced 3.3 % more unfilled grain than continuous flooding. Under continuous flooding the percentage unfilled grain increased with increasing plant spacing (Figure 9) from 20 x 20 cm to 30 x 30 cm and insignificantly declined at 40 x 40 cm. High unfilled grain % recorded by intermittent flooding could have been attributed to a limitation in carbohydrate supply and poor assimilates redistributed from reserve pools in vegetative tissues either pre- or post-anthesis for grain filling in. Consistent with the study, Kobata *et al.* (1992); Schnyder, (1993); Samonte *et al.* (2001) said that grain-filling in cereals depends on carbon from current assimilates and assimilates redistributed from reserve pools in vegetative tissues either pre or post-anthesis for grain filling. The contribution of reserved assimilates in culms and leaf sheaths of rice plants are estimated at around 30% of the final yield of rice depending on cultivar and environmental conditions (Gebbing and Schnyder, 1999; Takai *et al.*, 2005).

5.9 Effects of plant spacing and water control on rice dry straw yield (kg/ha)

Rice straw yield in the main effects of plant spacing and water control were uniform because straw yield is dependent on the combined effects of plant spacing, water control, nutrient and other growth factors. However, intermittent flooding produced more rice dry straw than continuous flooding (Figure 10). This may be due for poor root activities in support rapid vegetative growth under continuous flooding. The findings are in conformity with research by Mishra and Salokhe (2011) and Thakur *et al.* (2011) that says that, roots under continuous flooded conditions do not develop very well and have a shorter life span. The high dry straw produced at 25 x 25 cm continuous flooding may be due to competition among plant with higher tillers but little plant space. In densely populated rice field the inter-specific competition between plants is high resulting in gradual shading and lodging and thus increase production of straw in continuous flooding (Ghosh and Singh, 1998; Hossain,*et al.*, 2003) with smaller spacing.

5.10 Effects of plant spacing and water control on rice paddy yield (kg/ha)

In the two seasons, the rice paddy yields in this study ranged from 4,000 to 5,000 kg/ha in average. Although reports on SRI studies have shown yields range of 6,000 to 22,000 kg/ha. Such yields levels could not be obtained in the present study. Rice paddy yield decreased with increasing plant spacing in continuous flooding and intermittent flooding at both Golinga and Yendi. The interaction of plant spacing and water control produced a slightly higher paddy yield (7.57 %) under continuous flooding than intermittent flooding and this could be attributed to poor stem reserve of sufficient carbohydrate under intermittent flooding before grain filling and, hence produce more unfilled grains (Figure 11). Stem reserve utilisation before grain filling has been found to be an effective yield-supporting mechanism under drought stress in intermittent flooding (Hossain *et al.*, 1990; Gavuzzi *et al.*, 1997; Yang *et al.*, 2002; Asseng and van Herwaarden, 2003; Plaut *et al.*, 2004).

Uneven moisture distribution in intermittent flooding could have resulted in moisture stress and untimely availability of plant nutrient to improve paddy yield. This is consistent with the research findings that intermittent flooded fields makes the soil become aerobic and microbes convert a portion of the nitrate into nitrogen gas (denitrification), which is lost to the atmosphere (Buresh and De Datta, 1991) hence not available for plant during grain filling to improve yield. This is also in agreement with Siopongco *et al.* (2008, 2009) who said that the presence of a hardpan in shallow soil layers promote uneven moisture distribution in the soil profile, so that a root system tends to be partially exposed to dry soil, causing stomates to close while the rest of the root system can access water under intermittent flooding.

Continuous flooding with 20 x 20 cm which produced the highest paddy yield in both Golinga and Yendi could have been due to optimum plant population that produced the highest panicle number/m^2, lower productive tillers per plant and high grain number per panicle but with fewer unfilled grain percentage (Figure 4, Figure 6, Figure 8 and Figure 9). It however produced the lowest root dry matter (Figure 3 and **Error! Reference source not found.**).

Plant spacing 40 x 40 cm which produced the highest root dry matter (Figure 3) also produced the highest tiller number per plant and low productive tillers per unit area but had the lowest grain number per panicle and very high unfilled grain percentage hence produced the lowest paddy yield. Paddy yield is favoured by dense plant density and productive tillers rather than tiller number and root dry matter. This is in agreement with Mohammed *et al.* (2006) who reported that among yield components, productive tillers are very important in the final yield since it is a function of the number of panicle bearing tiller per unit area. The optimum level of plant population coupled with better yield parameters might have resulted in higher paddy yield ha^{-1} with 20 x 20 cm spacing. This result is in conformity with the finding of Ceesay and Uphoff

(2003) and Zhang *et al.* (2004). Mohammadian *et al.* (2011) studied yield and yield components of rice variety in different plant spacing and number of seedlings per hill and reported that the highest grain yield was obtained from plant spacing of 20×20 cm with 5582 kg/ha. In studies on intermittent flooding irrigation, grain yield of rice was increased (Tuong *et al.*, 2005; Yang *et al.*, 2007; Zhang *et al.*, 2008a, 2009a) but reduced in others (Mishra *et al.*, 1990; Tabbal *et al.*, 2002) when compared with continuously flooded conditions. The discrepancies between the studies were attributed to the variations in soil hydrological conditions and the timing of the irrigation method applied (Belder *et al.*, 2004).

5.11 Effects of plant spacing and water control on rice harvest index

In the combined effects of spacing and water control, harvest index was higher in continuous flooding than intermittent flooding. Except 25 x 25 cm intermittent flooding, continuous flooding produced bigger harvest indent. This may be attributed to differences in water management. The results contradict Zhang and Yang, (2004) who reported that sufficient water supply under continuous flooding in rice often leads to excessive vegetative growth which may result in less root activity, unhealthy canopy structure, and lower harvest index (HI). This however agrees with the findings that continuous flooding could increase growth rate during grain filling and or enhance the remobilization of assimilates from vegetative tissues to grains during the grain-filling period leading to a higher HI under continuous flooding (Zhang *et al.*, 2008b; Fletcher and Jamieson, 2009; Ju *et al.*, 2009).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The results indicated significant yield benefit of the continuous flooding on rice yield. Based on the objectives, the following conclusions could be made:

- Close spacing results in higher productive tiller numbers and paddy yield than large spacing.
- Continuous flooding resulted in relatively higher plant performance in vegetative and productive parameters
- Intermittent flooding, an attribute of system of rice intensification only favoured root dry matter accumulation but that could not translate into grain yield. SRI attributes; increased plant spacing and intermittent flooding was not better than close spacing and continuous flooding they nevertheless increased yield over what is traditionally obtained on farmers' field.

6.2 RECOMMENDATIONS

- The application of organic matter and continuous flooding gave higher yield than obtained on farmers fields and is recommended to farmers.
- Shorter plant spacing led to higher yields, and 20 x 20 cm spacing is recommended alongside continuous flooding.

- This work used organic matter at 10 tonnes per hectare; further work should concentrate on how water control, plant spacing and increasing organic matter content will have on yield of rice under SRI.
- Further work on chemical fertilizer in SRI should be investigated.

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APPENDICES

Appendix 1: Analysis of variance of the effects of plant spacing and water control under SRI on days to 50 % flowering in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1621.750	810.875	19461.00	
Rep.Water_Cont stratum					
Water_Cont	1	0.042	0.042	1.00	0.423
Residual	2	0.083	0.042	0.01	
Rep.Water_Cont.Spacing stratum					
Spacing	3	766.125	255.375	45.40	<.001
Water_Cont.Spacing	3	0.125	0.042	0.01	0.999
Residual	12	67.500	5.625		
Total	23	2455.625			

Appendix 2: Analysis of variance of the effects of plant spacing and water control under SRI on days to 50 % flowering in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	16.000	8.000	0.76	
Rep.Water_Cont stratum					
Water_Cont	1	165.375	165.375	15.75	0.058
Residual	2	21.000	10.500	1.62	
Rep.Water_Cont.Spacing stratum					
Spacing	3	213.125	71.042	10.98	<.001
Water_Cont.Spacing	3	257.458	85.819	13.26	<.001
Residual	12	77.667	6.472		
Total	23	750.625			

Appendix 3: Analysis of variance of effects of spacing and water control under SRI on grain number per plant in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1996.30	998.15	436.28	
Rep.Water_Cont stratum					
Water_Cont	1	17.92	17.92	7.83	0.107
Residual	2	4.58	2.29	0.10	
Rep.Water_Cont.Spacing stratum					
Spacing	3	968.63	322.88	14.46	<.001
Water_Cont.Spacing	3	38.78	12.93	0.58	0.640
Residual	12	267.89	22.32		
Total	23	3294.10			

Appendix 4: Analysis of variance of effects of spacing and water control under SRI on grain number per plant in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	984.25	492.12	6.74	
Rep.Water_Cont stratum					
Water_Cont	1	140.17	140.17	1.92	0.300
Residual	2	146.08	73.04	0.80	
Rep.Water_Cont.Spacing stratum					
Spacing	3	37.83	12.61	0.14	0.936
Water_Cont.Spacing	3	447.17	149.06	1.62	0.236
Residual	12	1101.00	91.75		
Total	23	2856.50			

Appendix 5: Analysis of variance of effects of spacing and water control under SRI on harvest index in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	14.769	7.384	5.27	
Rep.Water_Cont stratum					
Water_Cont	1	6.163	6.163	4.39	0.171
Residual	2	2.805	1.402	0.43	
Rep.Water_Cont.Spacing stratum					
Spacing	3	8.062	2.687	0.83	0.502
Water_Cont.Spacing	3	6.569	2.190	0.68	0.583
Residual	12	38.820	3.235		
Total	23	77.187			

Appendix 6: Analysis of variance of effects of spacing and water control under SRI on harvest index in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	38.10	19.05	0.44	
Rep.Water_Cont stratum					
Water_Cont	1	88.53	88.53	2.06	0.287
Residual	2	85.82	42.91	0.97	
Rep.Water_Cont.Spacing stratum					
Spacing	3	175.43	58.48	1.33	0.311
Water_Cont.Spacing	3	1089.49	363.16	8.25	0.003
Residual	12	528.52	44.04		
Total	23	2005.90			

Appendix 7: Analysis of variance of the effects of spacing and water control under SRI on number of tiller per plant in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	7.583	3.792	0.68	
Rep.Water_Cont stratum					
Water_Cont	1	16.667	16.667	3.01	0.225
Residual	2	11.083	5.542	0.76	
Rep.Water_Cont.Spacing stratum					
Spacing	3	33.500	11.167	1.53	0.256
Water_Cont.Spacing	3	7.667	2.556	0.35	0.789
Residual	12	87.333	7.278		
Total	23	163.833			

Appendix 8: Analysis of variance of the effects of spacing and water control under SRI on number of tiller per plant in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.583	1.792	6.14	
Rep.Water_Cont stratum					
Water_Cont	1	0.667	0.667	2.29	0.270
Residual	2	0.583	0.292	0.15	
Rep.Water_Cont.Spacing stratum					
Spacing	3	458.333	152.778	76.92	<.001
Water_Cont.Spacing	3	90.333	30.111	15.16	<.001
Residual	12	23.833	1.986		
Total	23	577.333			

Appendix 9: Analysis of variance on the effects of spacing and water control under SRI on number of productive tiller in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.583	0.292	0.04	
Rep.Water_Cont stratum					
Water_Cont	1	8.167	8.167	1.16	0.394
Residual	2	14.083	7.042	1.39	
Rep.Water_Cont.Spacing stratum					
Spacing	3	9.333	3.111	0.62	0.618
Water_Cont.Spacing	3	12.500	4.167	0.82	0.505
Residual	12	60.667	5.056		
Total 23 105.333					

Appendix 10: Analysis of variance on the effects of spacing and water control under SRI on number of productive tiller in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	14.583	7.292	3.57	
Rep.Water_Cont stratum					
Water_Cont	1	2.042	2.042	1.00	0.423
Residual	2	4.083	2.042	0.94	
Rep.Water_Cont.Spacing stratum					
Spacing	3	280.792	93.597	43.20	<.001
Water_Cont.Spacing	3	61.458	20.486	9.46	0.002
Residual	12	26.000	2.167		
Total 23 388.958					

Appendix 11: Analysis of variance of effects of spacing and water control under SRI on panicle number per m2 in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	9306.	4653.	0.61	
Rep.Water_Cont stratum					
Water_Cont	1	4455.	4455.	0.59	0.523
Residual	2	15136.	7568.	2.99	
Rep.Water_Cont.Spacing stratum					
Spacing	3	17615.	5872.	2.32	0.127
Water_Cont.Spacing	3	4672.	1557.	0.62	0.618
Residual	12	30381.	2532.		
Total	23	81565.			

Appendix 12: Analysis of variance of effects of spacing and water control under SRI panicle number per m2 in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	14.2	7.1	0.69	
Rep.Water_Cont stratum					
Water_Cont	1	170.7	170.7	16.58	0.055
Residual	2	20.6	10.3	0.03	
Rep.Water_Cont.Spacing stratum					
Spacing	3	5962.2	1987.4	5.62	0.012
Water_Cont.Spacing	3	26867.0	8955.7	25.32	<.001
Residual	12	4243.8	353.7		
Total	23	37278.5			

Appendix 13: **Analysis of variance of the effects of spacing and water control under SRI on rice paddy yield (kg/ha) in Golinga**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6530120.	3265060.	23951.22	
Rep.Water_Cont stratum					
Water_Cont	1	126.	126.	0.92	0.438
Residual	2	273.	136.	0.01	
Rep.Water_Cont.Spacing stratum					
Spacing	3	3119315.	1039772.	45.87	<.001
Water_Cont.Spacing	3	565.	188.	0.01	0.999
Residual	12	271996.	22666.		
Total	23	9922394.			

Appendix 14: **Analysis of variance of the effects of spacing and water control under SRI on rice paddy yield (kg/ha) in Yendi**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6822819.	3411410.	723.58	
Rep.Water_Cont stratum					
Water_Cont	1	865260.	865260.	183.53	0.005
Residual	2	9429.	4715.	0.19	
Rep.Water_Cont.Spacing stratum					
Spacing	3	3026864.	1008955.	40.06	<.001
Water_Cont.Spacing	3	2119.	706.	0.03	0.993
Residual	12	302201.	25183.		
Total	23	11028693.			

Appendix 15: Analysis of variance of the effects of spacing and water control under SRI on rice straw yield (Kg/ha) in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	16975144.	8487572.	2.84	
Rep.Water_Cont stratum					
Water_Cont	1	4974062.	4974062.	1.66	0.326
Residual	2	5980839.	2990420.	0.97	
Rep.Water_Cont.Spacing stratum					
Spacing	3	19205853.	6401951.	2.09	0.156
Water_Cont.Spacing	3	1427306.	475769.	0.16	0.924
Residual	12	36817826.	3068152.		
Total	23	85381030.			

Appendix 16: Analysis of variance of the effects of spacing and water control under SRI on rice straw yield (Kg/ha) in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5450.	2725.	0.74	
Rep.Water_Cont stratum					
Water_Cont	1	6112.	6112.	1.66	0.326
Residual	2	7349.	3674.	1.44	
Rep.Water_Cont.Spacing stratum					
Spacing	3	13063.	4354.	1.70	0.219
Water_Cont.Spacing	3	179126.	59709.	23.34	<.001
Residual	12	30701.	2558.		
Total	23	241802.			

Appendix 17: Analysis of variance of the effects of spacing and water control under SRI on tiller number per m2 at 60 days in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4184.	2092.	0.68	
Rep.Water_Cont stratum					
Water_Cont	1	3384.	3384.	1.10	0.404
Residual	2	6147.	3074.	0.29	
Rep.Water_Cont.Spacing stratum					
Spacing	3	80302.	26767.	2.51	0.109
Water_Cont.Spacing	3	30025.	10008.	0.94	0.453
Residual	12	128175.	10681.		
Total	23	252218.			

Appendix 18: Analysis of variance of the effects of spacing and water control under SRI on tiller number per m2 at 60 days in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4343.	2172.	0.19	
Rep.Water_Cont stratum					
Water_Cont	1	6176.	6176.	0.55	0.536
Residual	2	22561.	11280.	1.89	
Rep.Water_Cont.Spacing stratum					
Spacing	3	27709.	9236.	1.54	0.254
Water_Cont.Spacing	3	96132.	32044.	5.36	0.014
Residual	12	71795.	5983.		
Total	23	228717.			

Appendix 19: Analysis of variance on the effects of spacing and water control under SRI on unfilled grain % in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	10.100	5.050	0.62	
Rep.Water_Cont stratum					
Water_Cont	1	7.744	7.744	0.95	0.432
Residual	2	16.222	8.111	0.89	
Rep.Water_Cont.Spacing stratum					
Spacing	3	59.872	19.957	2.19	0.142
Water_Cont.Spacing	3	3.700	1.233	0.14	0.937
Residual	12	109.212	9.101		
Total	23	206.851			

Appendix 20: Analysis of variance on the effects of spacing and water control under SRI on unfilled grain % in Yendi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	39.08	19.54	1.18	
Rep.Water_Cont stratum					
Water_Cont	1	63.38	63.38	3.81	0.190
Residual	2	33.25	16.62	0.78	
Rep.Water_Cont.Spacing stratum					
Spacing	3	198.46	66.15	3.11	0.067
Water_Cont.Spacing	3	804.79	268.26	12.62	<.001
Residual	12	255.00	21.25		
Total	23	1393.96			

Appendix 21: Analysis of variance of the effects of spacing and water control under SRI on plant height in Golinga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	225.28	112.64	1.19	
Rep.Water_Cont stratum					
Water_Cont	1	227.27	227.27	2.40	0.261
Residual	2	189.34	94.67	0.78	
Rep.Water_Cont.Spacing stratum					
Spacing	3	538.66	179.55	1.49	0.268
Water_Cont.Spacing	3	136.75	45.58	0.38	0.771
Residual	12	1450.16	120.85	3.33	
Rep.Water_Cont.Spacing.*Units* stratum					
Days	6	80361.06	13393.51	369.41	<.001
Water_Cont.Days	6	115.60	19.27	0.53	0.783
Spacing.Days	18	853.58	47.42	1.31	0.200
Water_Cont.Spacing.Days	18	1039.63	57.76	1.59	0.077
Residual	96	3480.66	36.26		
Total	167	88617.99			

Appendix 22: Analysis of variance of the effects of spacing and water control under SRI on plant height in Yendi

Variate: Plant_Height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	418.54	209.27	3.51	
Rep.Water_Cont stratum					
Water_Cont	1	258.02	258.02	4.32	0.173
Residual	2	119.32	59.66	0.74	
Rep.Water_Cont.Spacing stratum					
Spacing	3	6276.72	2092.24	25.81	<.001
Water_Cont.Spacing	3	2781.27	927.09	11.44	<.001
Residual	12	972.67	81.06	1.55	
Rep.Water_Cont.Spacing.*Units* stratum					
DAYS	6	90438.40	15073.07	288.53	<.001
Water_Cont.DAYS	6	328.41	54.73	1.05	0.400
Spacing.DAYS	18	1736.98	96.50	1.85	0.030
Water_Cont.Spacing.DAYS	18	5259.06	292.17	5.59	<.001
Residual	96	5015.06	52.24		
Total	167	113604.43			

Appendix 23: Analysis of variance of the effects of spacing and water control under SRI on root dry matter in Golinga

Variate: Root_Dry_Matter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4759.	2379.	1.19	
Rep.Water_Cont stratum					
Water_Cont	1	3201.	3201.	1.61	0.333
Residual	2	3985.	1992.	0.86	
Rep.Water_Cont.Spacing stratum					
Spacing	3	8309.	2770.	1.19	0.355
Water_Cont.Spacing	3	7315.	2438.	1.05	0.407
Residual	12	27901.	2325.	0.99	
Rep.Water_Cont.Spacing.*Units* stratum					
Days	6	16908.	2818.	1.20	0.315
Water_Cont.Days	6	15343.	2557.	1.09	0.376
Spacing.Days	18	43253.	2403.	1.02	0.445
Water_Cont.Spacing.Days	18	42116.	2340.	0.99	0.474
Residual	96	226081.	2355.		
Total	167	399169.			

Appendix 24: Analysis of variance of the effects of spacing and water control under SRI on root dry matter in Yendi

Variate: Root_Dry_Mater

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6.063	3.032	17.90	
Rep.Water_Cont stratum					
Water_Cont	1	3.399	3.399	20.06	0.046
Residual	2	0.339	0.169	0.04	
Rep.Water_Cont.Spacing stratum					
Spacing	3	144.574	48.191	11.90	<.001
Water_Cont.Spacing	3	92.700	30.900	7.63	0.004
Residual	12	48.576	4.048	2.20	
Rep.Water_Cont.Spacing.*Units* stratum					
DAYS	6	571.513	95.252	51.77	<.001
Water_Cont.DAYS	6	133.296	22.216	12.07	<.001
Spacing.DAYS	18	65.252	3.625	1.97	0.019
Water_Cont.Spacing.DAYS	18	112.984	6.277	3.41	<.001
Residual	96	176.634	1.840		
Total	167	1355			