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EVALUATION OF SYSTEM OF RICE INTENSIFICATION (SRI) FOR ENHANCED RICE (*Oryza sativa* L.) PRODUCTION IN THE GUINEA SAVANNAH ZONE OF GHANA

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EVALUATION OF SYSTEM OF RICE INTENSIFICATION (SRI) FOR ENHANCED RICE (*Oryza sativa* L.) PRODUCTION IN THE GUINEA SAVANNAH ZONE OF GHANA

BY
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(UDS/MCS/0011/13)

THESIS SUBMITTED TO THE DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN AGRONOMY

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DECLARATION

I, Yussif Ibrahim Salifu, hereby declare that except for references to other people's work which have been duly acknowledged, this thesis is the result of my original research and that it has neither in whole nor in part been presented elsewhere. That the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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ABSTRACT

Field experiment was conducted in the dry season of 2014 in the Golinga Irrigation farm (Latitude 09°21'N and Longitude 0°56' W) at Golinga, in the Northern Region, Ghana. This was to evaluate the System of Rice Intensification (SRI) for enhanced grain yield, yield components and economic viability of Gbewaa rice variety production under irrigated conditions. The experiment was laid out in Randomized Complete Block Design with three replications. The treatments comprised four SRI and two Farmers' Practice treatments viz: T1- FP 1, T2 - SRI 1, T3 - SRI 2, T4 – SRI 3, T5 - SRI 4 and T6 – FP 2. Under all SRI treatments, seeds were nursed and seedlings were transplanted singly and widely (25 cm × 25 cm), irrigated intermittently and soil earthing up regularly. SRI 1 and FP 2 each received only 13 t/ha compost, SRI 2 and FP 1 each received an amount of 37.5 kg/ha each of N, P_2O_5 and K_2O as basal application and 26.25 kg/ha of N as top dressing while SRI 3 and SRI 4 both received 13 t/ha compost followed by either 18.75 kg/ha each of N, P_2O_5 and K_2O as basal application or 13.13 kg/ha of N as top dressing respectively. SRI 1 plants established best and took the longest days to flower. Higher number of grains per panicle was obtained in SRI 3. SRI 2 produced the highest plant height, panicle length, panicle weight, tiller count and plant biomass. SRI 2 also produced the highest yield (4026 kg/ha) which was not statistically different from the yields produced in SRI 3 (3866 kg/ha) and SRI 4 (3737 kg/ha) as compared with the control – FP 1 (2410 kg/ha). The benefit – cost analysis showed that SRI 2 (1.97) was the most profiting entry followed by SRI 4 (1.35) and SRI 3 (1.31). Where mineral fertilizers are available and affordable, SRI 2 could be chosen under irrigated condition.

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DEDICATION

To my loving friends and family especially my dear wife Lamnatu, son Farhan and Daughter Tasleem for their love, prayers, encouragement and sacrifices.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Rice is the most widely consumed staple food for a large part of the world's human population (FAOSTAT, 2006). Rice is the main source of food for more than half the world's population and its cultivation secures livelihood for more than two billion people (Thiyagarajan and Gujja, 2009).

Rice is the second most important cereal after maize in Ghana and is fast becoming a cash crop for many farmers (Millennium Development Authority, MiDA, 2010). Beyond providing sustenance through earning income and consuming, rice plays an integral, but important cultural role in many rural communities of Ghana (Gangwar *et al.,* 2008).

Annual per capita consumption of rice grew rapidly, from 17.5 kg in 1999 – 2001 to 22.4 kg in 2002–2004 and 24 kg in 2010 – 2011 (MoFA, 2013), and rice demand is projected to grow at a compound annual growth rate of 11.8 % in the medium term (MiDA, 2010).

In 2012, average rice yield in Ghana was estimated to be 2.5 t/ha while the achievable yield based on on-farm trials was 6–8 t/ha (MoFA, 2013). In the same year, northern region recorded the regional average yield of rice of 2.3 t/ha, which was below the national average of 2.5 t/ha and far below the highest regional average (greater Accra region) of 6.5 t/ha (MoFA, 2013). Meanwhile the majority of local rice production in Ghana is realised from the northern region with 37 % of the estimated national production. Northern

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region is followed by Upper east (27 %) and Volta regions (15 %) of national production (MoFA, 2013).

National and agricultural development plans and strategies, such as the Ghana Poverty Reduction Strategy (GPRS I), Growth and Poverty Reduction Strategy (GPRS II), Food and Agricultural Sector Development Policy (FASDEP) I and II, Medium Term Agriculture Sector Investment Plan (METASIP), and Accelerated Agricultural Growth and Development Strategy (AAGDS), have featured rice as one of the targeted food security crops (Ragasa *et al.,* 2013).

Since 2003, various strives were made by government and non-governmental organisations in the rice sector in Ghana. These include the establishment and operation of the National Rice Development Strategy (NRDS) in 2009, the national fertilizer subsidy program in 2008 and seed subsidy in 2012. Also, various rice projects undertaken by donor agencies, majority of which were implemented in the period 2004 – 2009. Marked increased in yield was realised in 2008 and this was attributed to the fertilizer subsidy program. In addition, import levies of rice was about 20 % of the value of rice imports (Angelucci *et al.,* 2013), rendering the local rice more affordable in order to boost its demand and as well as production. In northern region, Agence Française de Dévelopment (AFD) (France), Alliance for a Green Revolution in Africa (AGRA), African Development Bank (AfDB), Japan International Cooperation Agency (JICA), Food and Agriculture Organisation (FAO), United Nations Industrial Development Organisation (UNIDO) and United States Agency for International Development (USAID) are very helpful in funding several rice projects to increased yield of rice in the zone.

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Despite all these interventions, the national average yield has remained low, between 2.5 t/ha (MoFA, 2013) and 2.2 t/ha (CRI/SARI/IFPRI, 2013). Henceforth, Ghana is unable to meet local demand but relies on external sources. The low yield of rice can be attributed to the farmers' practice - conventional management in rice production. Over 50 % of the rice farmers in the country still broadcast seed rice. In northern region less adoption of improved or high yielding varieties is substantial.

This significant yield potential can be achieved through improvements in agronomic practices and adoption of underutilized beneficial innovations. There is the need for farmers to adopt good innovations such as System of Rice Intensification (SRI).

The System of Rice Intensification (SRI) is a methodology aimed at providing good conditions to unearth the optimum genetic potential of the rice plant which eventually increases the yield of rice produced in farming. SRI is a methodology for increasing the productivity of rice by changing the management of plants, soil, water and nutrients. It was developed in 1983 by the French Jesuit Father Henri De Laulanie in Madagascar.

According to SRI-Rice (2012), the earliest discussions of SRI in Ghana took place in 2001/2002 by Norman Uphoff. During 2007 – 2008, JICA collaborated with CRI and carried out SRI trials in the Ashaiman Irrigation Scheme, Accra, under the management of the Ghana Irrigation Development Authority (GIDA) (SRI-Rice, 2012). These early trials recorded some challenges. Shuici Sato, who had worked with SRI in Indonesia, was then

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invited by the Chief Executive of Ghana Irrigation Development Authority (GIDA) during 2009 to provide additional information on SRI to GIDA staff.

A farmer, Kwabena Adu Broni, who experimented SRI in 2007, recorded positive results under SRI in Ghana at Aboso-Odumasi in the Western Region in 2009. During 2009 -2011, the General Agriculture Union in collaboration with Action Aid Ghana supported farmers in implementing SRI on a pilot basis under the Asutware Rice Irrigation Project and the Ashaiman Rice Irrigation Project (Africare/Oxfam, 2010).

According to an article in GNA (2011), rice farmers operating under Kpong Irrigation Project at Asutware in Eastern Region realised the benefits of SRI and made an appeal to government of Ghana to adopt SRI as a policy to help increase rice production in the country.

During June, 2012, a SRI training in Ghana was provided by the Regional USAID's Extended Agribusiness Trade Promotion (E-ATP) project. At a regional SRI workshop in Burkina Faso in July, 2012, Gina Odarteifio, CEO of AMSIG Resources, reported that her company trained and undertook SRI trials with more than thousand farmers in 20 communities in Ghana including northern region (SRI-Rice, 2012).

The principles of SRI include applying a minimum quantity of water and the individual transplanting of very young seedlings in a square pattern. The central principles of SRI according to Sato (2012) are:

- Rice field soils should be kept moist rather than continuously saturated before reproductive stage, minimising anaerobic conditions, as this avoids the suffocation and degeneration of rice plant roots and also supports more

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abundant and diverse populations of aerobic soil organisms that provide multiple benefits to the plants. and supports the growth and diversity of aerobic soil organisms;

- Rice plants should be planted singly and spaced optimally, widely (preferably 25 cm × 25 cm) to permit more growth of roots and canopy and keep all leaves photosynthetically active, increase panicle bearing primary tillers per area, more filled grains and as well as higher grain weight; and
- Rice seedling should be transplanted when young less than 15 days old (preferably 8-12 days old) with just two leaves, quickly, shallow and carefully, to avoid trauma to roots and to minimize transplant shock.

Through the effort of Norman Uphoff, Director of International Institute for Food, Agriculture and Development at Cornell University, Ithaca, New York, SRI spread from Madagascar to most parts of the world. Uphoff estimated that by 2013 the number of small scale farmers using SRI will grow to between 4 and 5 million (Uphoff, 2005).

SRI concepts and practices have continued to change as they are being adopted to rain-fed (unirrigated) conditions and with transplanting being superseded by direct-seeding sometimes. SRI is based on the cropping principles of significantly reducing plant population, improving soil conditions and irrigation methods for root and plant establishment methods. SRI applied to other crops such as wheat, sugarcane, teff etc is term as system of crop intensification; SRI can as well be applied to rain-fed conditions (Laulanié, 2011).

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Benefits of SRI include 20 % - 100 % or more increased yields, up to a 90 % reduction in required seed, and up to 50 % water savings The net effect is to improve household incomes and food security while reducing the negative environmental impacts of rice production and making food production more resilient (Africare/Oxfam, 2010)

1.2 Problem statement

According to FAO (2008), between 2000 and 2008, production of milled rice from West Africa grew by 59 % from 4.6 million MT to 7.2 million MT. Over the same period, consumption of the rice also grew from 9.6 million MT to 13.3 million MT representing a 38 % increase. Imports reached 6.3 million MT in 2008, equivalent to 48 % of the West African's rice requirements. The region's self-sufficiency ratio fell from 84 % in the 1970s to 76 % in the 1990s and 63 % in 2006 (WARDA, 2008).

In 2010, rice was the 10th agricultural commodity in Ghana by value of production while it ranked 8th in terms of production quantity for the period 2005-2010 (MoFA/SRID, 2010). It occupies roughly 40 % of the total crop harvested area, although it accounts for about 45 % of the total area planted to cereals (MoFA, 2009a). Productivity is projected to 4 t/ha with a total area of 375,000 hectares (MoFA/SRID, 2010). Productivity remains low (2.5 t/ha) and the country is still dependent on external sources. The self-sufficiency ratio of rice in Ghana has been on the decline. For instance, the ratio declined from 38 % in 1999 to 24 % in 2006 (MoFA, 2009a). According to Ragasa *et al*. (2013), rice import in Ghana account for 50-70 % of domestic consumption.

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According to MoFA (2012), the foreign rice purchases cost an estimated $450 million each year. It is expensive relative to local products, as at then (2012) imported rice cost GHS2.36 ($1.20) per kg, compared to GHS0.97 ($0.49) for domestic varieties.

With the aim of increasing productivity, a national fertilizer subsidy was introduced in 2008, followed by a National Rice Development Strategy in 2009 and a seed subsidy in 2012 with yield still remaining low (Ragasa *et al*., 2013). Low adoption or lack of inputs and improved technologies is often cited as a reason for this gap (Ragasa *et al.*, 2013). For instance, in the northern savannah zone 52 % of farmers did not plant modern varieties from certified sources. 24 % of these farmers planted with seed sourced from other farmers or from the grain market. 50 % of the rice fields were broadcasted in 2012 cropping season (Ragasa *et al*., 2013).

Under the 2009 National Rice Development Strategy (NRDS), the Ministry of Food and Agriculture (MoFA) wants to double rice production by 2018. Among other goals, NRDS seeks to improve land and water management practices, improve access to government services and establish partnerships with the private sector (MoFA, 2009b).

In 2011 a young farmer named Sumant Kumar set a new world record in rice production of 22.4 t/ha using SRI, beating the existing world record held by the Chinese scientist Yuan Longping by 3 t/ha (Gordon, 2013).

A two-acre rice farmer at Golinga, Northern Ghana, by name Mahamudu Yahaya shared his experience with SRI innovation. He reported that his SRI field require reduced rate of chemical fertilizer and quantity of seeds (two bags

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of fertilizer and 6 kg of seeds) per acre, facilitates cultural or agronomic practices due to proper spacing and eventually higher and heavier grain yield than that of his broadcasted rice field (Ghanaweb, 2013).

However, high labor costs make SRI farmers switch to alternative establishment methods such as direct sowing, mechanical transplanting, seedling broadcasting or a combination of methods (Chen *et al*., 2013).

1.3 Significance of the study

Firstly, it is hoped that the findings of this research will help farmers measure the yields of rice under SRI.

Secondly, the study will also provide farmers information on which fertilizer or fertilizer combination dosage will give optimum yield of rice under the SRI.

Thirdly, the study will furnish stakeholders with relevant information on the benefit – cost analysis of rice production under the SRI.

1.4 Research objectives

The main objectives of the study are:

1. To evaluate the grain yield and yield components of rice under the SRI.
2. To determine the optimum fertilizer rate or type for maximum performance of yield components and grain yield under the SRI.
3. To determine benefit – cost analysis of rice production under the SRI.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice taxonomy, botany, origin and distribution

The domesticated rice comprises two species in the Poaceae family: Oryza sativa (Asian rice) and Oryza glaberrima (African rice) (Linscombe, 2006). These plants originated from Tropical and Subtropical Southern Asia and South Eastern Africa, respectively (Linares, 2002).

Rice is grown as a monocarpic annual plant, although in the tropical areas it can survive as a perennial and can produce a ratoon crop and survive for up to 20 years (Boumas, 1985). It is also an important crop in subtropical and temperate zones, the yield being higher in temperate areas than in the tropics (Boumas, 1985).

The major rice growing regions are found in Asia, Latin America, and Africa, but the major exporting countries include Thailand, the United States, Vietnam, Pakistan, and India (Boumas, 1985). De Datta (1981) listed 112 rice growing countries Worldwide. These include all the countries in Asia and most of the countries of West and North Africa, some countries of East and Central Africa, most of the South America countries and Australia. Based on the wide distribution of rice, there are three international research centres focusing on rice (De Datta, 1981)

2.2 Importance of rice

Beyond providing sustenance through consuming and earning income, rice plays an integral, but important cultural role in many countries in the world. Thus rice does not only ensure food security but also provides economic and

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cultural gains throughout the world. Food security is said to be achieved when good quality nutritious food is hygienically packaged, attractively presented, and made available in sufficient quantities all year round at the appropriately located places at affordable prices (MoFA, 2012).

MoFA (2012) records show that Ghana has been food secure in all the major food staples since 2008, with the exception of rice which registered a deficit of 358,516 metric tonnes in 2012. Rice production has expanded to play a key role in achieving national food security, alleviating rural poverty and contributing to the overall economy, through import substitution and foreign exchange conservation (MoFA, 2003).

Consumption per capita and consumer preferences for a given rice type also vary from region to region (Juliano, 1993). According to Angelucci *et al.* (2013), rice is only one of the sources of carbohydrates available in Ghana.

Rice plays important economic and cultural roles in many rural communities of Ghana. For instance, products of rice plant are used for a number of purposes, such as fuel, thatching, industrial starch, artwork and festivities (Gangwar *et al.,* 2008). Rice production in Upper East Region, especially Bawku and surrounding areas have an underpinning motives of achieving desired paddy and straw yields for above purposes and as feed source for animals (Larry *et al.,* 2012). In northern Ghana, rice straw is used for weaving mats, hats, baskets and also added as a binding material during construction of mud houses by some rural folks (Baba, 2012). Rice straw can also be used in the manufacturing of paper and cardboards (Baba, 2012).

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Berisavljevic *et al.* (2003) reported that rice is important to Ghana's economy and agriculture, accounting for nearly 15 % of the Gross Domestic Product. This sector of agriculture provides employment for a lot of rural dwellers. Due to the shift in the diet of Ghanaians to rice consumption, particularly those in the urban areas, imports of rice have been increasing steadily since the 1980s. Imported rice is estimated to account for more than 50 % of all rice consumed in the country (Berisavljevic *et al.,* 2003).

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In addition to being a staple food mainly for high income urban populations, rice is also an important cash crop in the communities in which it is produced. Between 2005 and 2010, Ghana ranked among the top 50 rice producers worldwide, dropping out of the list only in 2007 (FAOSTAT, 2010). The increase in demand for imported rice is primarily attributed to increased income, good storability and ease of cooking (Shabbir *et al.,* 2008). Rice consumption increased by over 20 % per year in the 1990s, with the increased demand being met by imports from the Far East and the Americas (Berisavljevic *et al.*, 2003). They indicated that imported rice, which is also perceived to be of better quality than local rice, is generally sold at higher prices. Currently, local production of rice hardly meets the annual demand of Ghana (Takoradi, 2008).

2.3 Rice production in Ghana

The main rice types produced in Ghana are Oryza sativa and Oryza glaberima (ODI, 2003). In 2010, Rice was the 10th agricultural commodity in Ghana by value of production while it ranked 8th in terms of production quantity for the period 2005-2010 (MoFA/SRID, 2010). It occupies roughly 4 % of the total

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crop harvested area, although it accounts for about 45 % of the total area planted to cereals (MoFA, 2009a).

Rice is also the first imported cereal in the country accounting for 58 % of cereal imports (CARD, 2010) accounting for 5 % of total agricultural imports in Ghana over the period 2005-2009 (Angelucci *et al.,* 2013).

Ghana rice production satisfies around 30/40 % of demand, with a corresponding average rice import bill of USD 450 million annually (MoFA/SRID, 2010). The massive dependency on rice imports has always been a concern for Ghanaian policy makers, especially after food prices soared in 2008. Indeed, in May 2008 Ghana was one of the first countries within the Coalition for African Rice Development (CARD) to launch its National Rice Development Strategy (NRDS) for the decade, 2009-2018. The main objective of the NRDS is to double domestic production by 2018, implying a 10 % annual production growth rate, and enhance quality to stimulate demand for domestically produced rice.

However, import duties and other taxes as well as interventions to boost productivity and quality of local rice do not seem to produce any substantial impact on Ghana import bill (Angelucci *et al.,* 2013).

Rice production increased from 0.09 to 0.16 million hectares while yields fluctuated between 1.7 and 2.7 t/ha. It however appears that from 2007, rice production has been on the increase with 2010 production levels being more than double 2007 levels (from 185 300 t in 2007 to 491 600 t in 2010) with average annual growth of more than 15 % over the period 2005-2010, despite the production drop experienced in 2007 (Angelucci et al., 2013).

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The reasons for this increase could be attributed to the favourable rain patterns as well as the 2008 Fertilizer subsidy programme and the Block Farm programme of 2009 which are also contemplated in the Ghana Rice Strategy (Angelucci *et al.,* 2013). Focusing on the period 2005-2010, rice production accounted for about 19 % of cereal production (MoFA/SRID, 2010). According to a report by the MiDA (2010), rice production takes place in all the ten regions of Ghana; which also cover all the major ecological-climatic areas including the interior savannah area, the high rain forest zone, the semi-deciduous rain forest area and the coastal savannah area with peak production occurring in the Northern, Upper East, Western, Brong Ahafo and Volta Regions (ODI, 2003).

The main rice producing regions, Northern, Volta and Upper East regions, produce between 45 000-60 000 t per year each. The Northern region was the main producer with about 63 000 t in 2009 (USAID, 2009).

In Ghana, most rice production, similarly to other crops, is done by smallholder farmers, most of who have farms of less than one hectare in size. It is estimated that more than 80 % of agricultural production is done by smallholder farmers. Most of the rice is cultivated from low-quality seed with mixed varieties, which brings about uneven maturity at harvest and wide variations in the size and shape of rice grains. Generally, this results in a gap between the quality of local and imported rice (Angelucci *et al.,* 2013). Farmers have benefited from the distribution of high-yielding varieties in addition to other complementary technologies (Angelucci et al., 2013).

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Despite the expected gains from the numerous interventions, the level of adoption of improved technologies among farmers is reportedly low. Most of these farmers use low-yielding varieties and poor agronomic practices. Farm households, especially those in northern Ghana, are still operating at low levels of productivity (Wiredu *et al.,* 2010).

Rice is the second most important cereal after maize in Ghana and is fast becoming a cash crop for many farmers (MiDA, 2010; Osei-Asare, 2010). National and agricultural development plans and strategies, such as the Ghana Poverty Reduction Strategy (GPRS) I, Growth and Poverty Reduction Strategy (GPRS) II, Food and Agricultural Sector Development Policy (FASDEP) I and II, Medium Term Agriculture Sector Investment Plan (METASIP), and Accelerated Agricultural Growth and Development Strategy (AAGDS), have featured rice as one of the targeted food security crops. Annual per capita consumption of rice is growing rapidly, from 17.5 kg in 1999–2001 to 22.4 kg in 2002–2004 and 24 kg in 2010–2011 (MOFA, 2012), and rice demand is projected to grow at a compound annual growth rate of 11.8 % and maize at 2.6 % in the medium term (MiDA, 2010).

Several estimates show very high levels of imports valued at US$500 million annually (Osei-Asare, 2010), putting much pressure on foreign currency reserves and food security in Ghana. Estimates show that imported rice comprises about 70 % of the quantity consumed in Ghana, or a 174 % import penetration ratio (Amanor-Boadu, 2012).

The majority of local rice production comes from the Northern (37 %), Upper East (27 %), and Volta regions (15 %) (Ragasa *et al.,* 2013). Production in the

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Northern and Upper East regions decreased in 2011 due to poor weather condition, but production in Volta continued to increase and did not seem to be affected by less rain in 2011 (Ragasa *et al.,* 2013). In general, rice production and the area cropped with rice are increasing. Since 2007, production has been increasing at a faster rate than area of cultivation which proofs that yields during this period has been trending upward. This growth is encouraging and may have been the result of the various initiatives which were implemented in the period 2004–2009; and the national fertilizer subsidy program introduced in 2008, to which rice farmers have likely responded. There was a jump in production and acreage in 2008, which could be a compounded result of these various initiatives (Ragasa *et al.,* 2013). However, the national average yield has remained low, at 2.5 t/ha per year according to MoFA (2012), or 2.2 t/ha per season according to the recent survey by the Crops Research Institute (CRI), Savannah Agricultural Research Institute (SARI), and International Food Policy Research Institute (IFPRI), indicating significant opportunity to reach potential achievable yields of 6–8 t/ha (Ragasa *et al.,* 2013).

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2.4 Nutrient requirement of low land rice

The major nutrient elements such as nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca) and sulphur (S) and minor elements such as iron (Fe), manganese (Mn) or zinc (Zn) are needed by the rice plant for proper growth and development (Reuter and Robinson, 1986).

The rice plant generally responds significantly to 120 kg N per hectare (Thiyagarajan and Gujja, 2009). Nitrogen fertilizer is supplied to cater for the crop's physiochemical need, especially at the critical growth stages of active tillering and panicle initiation. Several studies have shown that application of

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nitrogen fertilizer to rice, leads to increased plant height, panicle number, leaf size, spikelet number per panicle and grain yield *(Balasubramanian et al.,*1999; Walker *et al.,* 2008). The protein content of grains is increased by nitrogen as it is an essential component of amino acids, nucleotides and chlorophyll.

The rice plant requires 0.14-0.27 % of phosphorus at mid- tiller stage and 0.18-0.29 % at panicle initiation stage (Reuter and Robinson, 1986). Phosphorus is the most important nutrient and most deficient nutrient in the Guinea Savannah rice fields (Kwarteng and Towler, 1994). Experiments carried out by Senayah *et al.,* (2008) and Buri et al. (2010) in Ghana also stressed on the low levels of phosphorus in the low land ecologies. Phosphorus plays a crucial role in root development, early flowering and ripening, active tillering, grain development, formation of hormones and maintains membrane integrity and as a constituent of ATP, nucleotides, nucleic acids and phospholipids of the rice plant (Reddy *et al.,* 1995).

At mid-tillering and panicle initiation stages the quantity of potassium needed by the plant is 1.5-2.7 % and 1.2-2.5 % respectively (Reuter and Robinson, 1986). Potassium promotes tillering, size and weight of grains, strengthening of straw and stem, tolerance to adverse climatic conditions, tolerance to lodging, pests and diseases and also plays an essential function in osmoregulation, enzyme activation, regulation of cellular pH, cellular cation-anion balance, regulation of transpiration by stomata, and transport of photosynthetic products (Laegereid *et al.*, 1999).

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N, P or K single or compound fertilizers are the commonest commercial fertilizers available in the market for farmers. N fertilizers can easily undergo volatilation and ammonification if it is not properly applied in the soil (Reuter and Robinson, 1986). Therefore there is the need to split apply N fertilizers as farmers rely heavily on inorganic fertilizers in enriching their rice fields with plant nutrients.

The rice plant requirement for the other nutrient elements are Ca (0.16-0.39 %) at mid-tiller and (0.19-0.39 %) at panicle initiation Mg (0.12-0.21 %) and (0.16-0.39 %) at panicle initiation, S (0.17 %) at mid-tiller and (0.15 %) at panicle initiation, Fe (89-193 ppm) at mid-tiller and (74-192 ppm) at panicle initiation, Mn (237-744 ppm) at mid-tiller and (252-792 ppm) at panicle initiation and Zn (22-161 ppm) at mid-tiller (Reuter and Robinson, 1986).

FAO (2008) described the pH, Critical limits for diethylene triamine pentaacetic acid (DTPA) extractable micronutrients, Plant nutrients sufficiency range and Critical nutrient concentrations for 90 % yield for the rice crop are as follows:

Table 1. Soil pH values and their corresponding reaction rating

pH range	Soil reaction rating
< 4.6	Extremely acidic
4.6–5.5	Strongly acidic
5.6–6.5	Moderately acidic
6.6–6.9	Slightly acidic
7.0	Neutral
7.1–8.5	Moderately alkaline
> 8.5	Strongly alkaline

Food and Agriculture Organisation. (2008). Fertilizer and Plant Nutrition. Analysis. Guide to Laboratory Establishment Statistics,

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Table 2. Critical limits for DTPA-extractable micronutrients

	Micronutrients			
Availability	Zn	Cu	Fe	Mn
Very low	0-0.5	0-0.1	0-2	0-0.5
Low	0.5-1.0	1-0.3	2-4	0.5-1.2
Medium	1-3	0.3-0.8	4-6	1.2-3.5
High	3-5	0.8-3	6-10	3.5-6
Very high	>5	>3	>10	>6

Food and Agriculture Organisation. (2008). Fertilizer and Plant Nutrition. Analysis., Guide to Laboratory Establishment Statistics,

Table 3. Critical nutrient concentrations for 90% yield for rice

Nutrient	Concentration
N (%)	3.0
P (%)	0.25
K (%)	0.25
Mg (%)	0.15
S (%)	0.15
Mn (ug/g)	30
Zn (ug/g)	20
Cu (ug/g)	5
B (ug/g)	6
Mo (ug/g)	0.3

Food and Agriculture Organisation. (2008). Fertilizer and Plant Nutrition Analysis. Guide to Laboratory Establishment Statistics.

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Table 4. Plants nutrients sufficiency range

Nutrients	Sufficiency or optimal range
Macronutrients	(%)
N	2.0–5.0
P	0.2–0.5
K	1.0–5.0
Ca	0.1–1.0
Mg	0.1–0.4
S	0.1–1.3
Micronutrients	(µg/g)
Zn	20–100
Fe	50–250
Mn	20–300
Cu	5–20
Mo	0.1–0.5
B	10–100

Food and Agriculture Organisation. (2008). Fertilizer and Plant Nutrition Analysis. Guide to Laboratory Establishment Statistics, Food and Agriculture Organisation.

Macro-nutrients and micro-nutrients such as S, Mg, Zn, and Mn will be deficient if chemical fertilizers especially nitrogen fertilizers are used continuously and applied indiscriminately, without the need for applying soil organic matter (Thiyagarajan and Gujja, 2009).

The soil structure is improved when organic matter is applied to it. Soil organic matter provides improved drainage, water holding capacity, aeration for the

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growth and health of crops and soil biota. Organic matter also positively influences cation exchange capacity (CEC) of the soil, which enables the soil to buffer and maintain the concentration of many nutrients in solution (Thiyagarajan and Gujja, 2009). Organic matter is applied to the soil in the form of compost, farmyard manure and plant residues. It is needed to maintain or increase soil organic carbon. Soil organic carbon level is a good indicator of native fertility. In general paddy soils with carbon (about 5 g/kg) are fairly poor in organic matter. Thus, it is essential to use more organic biomass with most soils to achieve and sustain good fertility status (Thiyagarajan and Gujja, 2009).

The carbon released from organic matter is utilized by beneficial microorganism. For instance, the N of urea which is now the major N fertilizer for rice production when applied will become available to the plants only if the amide form of nitrogen in urea is converted into an inorganic form (NH_4^+ or NO_3^-) by the microbes *nitrosomanas* and *nitrobacter* (Thiyagarajan and Gujja, 2009). When soils are healthy, they can mobilize large amounts of nutrients and particularly micronutrients, which are essential to plant growth as compared with soil fertilized by NPK fertilizer. Moreover, they can also facilitate many beneficial processes in the soil (Thiyagarajan and Gujja, 2009). The effect of combined inoculation of *Azospirillum and Trichoderma harzianum* has been found to be more pronounced in SRI (Ravi *et al.,* 2007).

Organic manures are recommended in SRI since they are found to give better crop responses (Thiyagarajan and Gujja, 2009). However, rice farmers find it difficult to adopt organic farming methods. Therefore Integrated Nutrient Management (INM) is generally recommended for SRI. INM involves the

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application of chemical fertilizers along with organic materials such as cattle manure, poultry manure, vermicompost, green manures, green leaf manures and biofertilizers(Thiyagarajan and Gujja, 2009). Both sole and combined application of organic fertilizer or inorganic fertilizer in larger, lower or equal proportion in the field is the practice of most farmers. Experiments conducted at the China National Rice Research Institute, Hangzhou, showed that the highest yield in SRI was obtained with equal proportions of organic and inorganic nutrient applications rather than a 25:75 ratio or 100 % organic (Lin *et al.,* 2011). Besides, Thomas and Ramzi (2011) found that the grain yields under SRI were 66 % higher than with traditional methods, despite using much less or no chemical fertilizer. Ceesay (2011) did not find much effect on the yield of SRI crop by increasing the nitrogen doses by 2 to 3 times. In order to sustain rice crop production, it is essential to integrate inorganic fertilizers with organic fertilizers (Khan *et al.,* 2001). Rice is a heavy feeder and respond very well to the amount and balance of nutrients in the soil, it is therefore crucial to fertilize the crop using both organic and inorganic fertilizers available (WARDA, 2002).

Under the same nutrient application level, SRI plants take up more nutrients than conventional grown plants (Thiyagarajan and Gujja, 2009). They extract more trace elements form the soil. Similarly, Barison and Uphoff (2011) found that SRI phenotypes produce more grain weight per unit of nutrient taken up. It can be deduced that SRI plants are more efficient in utilizing soil nutrient because of their extensive root systems facilitated by the more favourable environments created. Physiological studies have shown that SRI plants have longer periods of photosynthesis, higher photosynthetic efficiency and better

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light utilization than non-SRI crop (Uphoff, 2011). The SRI plants have greater N uptake probably due to greater activity of nitrogen-fixing bacteria living as endophytes within roots, or by free-living microbes within the rhizosphere, or possibly even within the phyllosphere(Thiyagarajan and Gujja, 2009).

SRI plants can deplete nutrient content in the soil because of the higher plant growth and grain yield associated with higher nutrient uptake. However, experiments conducted so far have not shown that the available nutrient status was reduced after the SRI crop. Notably, there is delayed senescence and the higher leaf area index (LAI) present higher N in the leaves after flowering in SRI plants. Besides, studies carried out showed that even though SRI resulted in higher productivity, the nutrient uptake was similar with marginally higher nutrient use efficiency (8, 8 and 12 % of N, P and K respectively) without depleting the available nutrients compared to conventional practice (Mahender Kumar *et al.,* 2009).

Studies by Barison and Uphoff (2011) showed that the soil of plots under both SRI and conventional management practices recorded similar P levels, yet 66 % more P was accumulated in the above ground biomass of SRI plants.

Buri *et al.* (2010) recommended the adoption of effective nutrient and water management rice production systems. Nutrient and better management practices will not only improve soil productivity but also increase and sustain yield to ensure food security. System of rice intensification seeks to achieve this with minimal cost and resources.

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2.5 Systems of rice production

According to Nguyen (2004), there is still a large yield gap in irrigated rice production today and the closing of this yield gap could increase substantially rice production without further investment in land and water development through the following:

- Package of Production Technologies for Transplanted rice which was developed in the Philippines in the 1970s
- The Integrated Pest Management (IPM) System which was developed in mid-1980s and associated systems
- The Rice Check system in Australia in 1986
- The Marbrouk-4 System in Egypt in 1985
- The P-7 Package in Burkina faso in 1992-93
- The WARDA Rice-Integrated Crop Management System which was developed in 1995, and
- The System of Rice Intensification (SRI) which was developed in Madagascar in early 1980s

2.5.1 SRI system

System of Rice Intensification (SRI) is an agro-ecological methodology for increasing the productivity of rice by changing the conventional management of plants, soil, water and nutrients (Laulanié, 2011). Uphoff (2002) viewed SRI as a set of principles and associated methods for getting more productive phenotypes from any existing genotype (that is variety) of rice, modern or traditional, improved or local, hybrid or landrace. SRI has been explicitly conceived of and presented not as a technology but rather as a methodology based on a set of ideas and insights formulated as principles that are to be

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translated into specific practices, which seek to create a more favorable growing environment for irrigated rice plants (Uphoff, 2007).

SRI differs from most agricultural technologies promoted in recent decades in that it is a civil-society innovation, originating not from research stations or laboratories, but from the dedicated work of a Jesuit Priest (Uphoff, 2007).

2.5.2 Origin of SRI

System of rice intensification (SRI) is an environmentally-friendly methodology which involves modifying the way rice plants, soil, water and nutrients are managed (Laulanié, 2011). SRI was developed in 1983 by the French Jesuit Father Henri De Laulanie in Madagascar (Laulanié, 2011). This innovation was experimented for decades by Non-Governmental Organisation (Association Tefy Saina) that De Laulanie established in 1990 with some of his Malagasy colleagues, which was eventually improved and spread when successful outcomes (yield of paddy increased from 3 t/ha to 8 t/ha) were realised (Uphoff, 2005). Their effort was enhanced subsequently through collaboration with a North American university, working with the Cornell International Institute for Food, Agriculture and Development (CIIFAD) (Uphoff, 2007).

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2.5.3 Principles of SRI

According to Laulanié (2011), the basic concepts of SRI are as follows:

- The soil or field is kept moist rather than continuously saturated. This maximises aerobic conditions and improves root growth as well as supports the growth and diversity of aerobic soil organisms.

- Also rice plants should be planted singly and spaced widely to permit

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- Also rice plants should be planted singly and spaced widely to permit more growth of roots and canopy and keep all leaves photosynthetically active.
- Furthermore, rice seedling should be transplanted when young less than 15 days old with just two leaves, quickly, shallow and carefully, to avoid trauma to roots and to minimize transplant shock.
- Actively aerating the soil as much as possible, using a rotary hoe or weeder to control weeds.
- Finally, enhance soil fertility conservation as much as possible by applying solely compost, or manure to the soil. Chemical fertilizers can also be used in SRI. The effect of the compost is boosted when chemical fertilizers are used as supplements.

Some useful practices such as selection of most suitable varieties, quality seed selection, seed priming and seedbed solarisation (Culman *et al.,* 2005)were later recommended for use with SRI. These practices are not from the work and insights of Laulanié, so there is no need to associate them with SRI (Uphoff, 2007). However, proponents emphasize that SRI is not completed yet and is awork in progress, still evolving and improving. It is continuously being adapted for diverse environments as these environments and SRI becomes well understood (Uphoff, 2007).

SRI is also an innovation that is not a material set of inputs or a packaged set of instructions to be implemented like the Green Revolution technology (Uphoff, 2007). It can best be described as a set of ideas or insights, rather than fixed prescriptions. The actual practice of SRI has been dynamic while at the

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same time the core ideas of SRI that emerged from Laulanié's work have remained quite stable and robust over the years (Uphoff, 2007). With the exception of rice, when this methodology is applied to any other crop is termed as System of Crop Intensification (SCI). Crops that are produced under system of crop intensification are wheat, sugarcane and teff.

2.5.4 Types of SRI

SRI will be defined technically by key practices (menu) mentioned above, but not a fixed package to be followed strictly. Even though only a part of key practices is adopted, it can be considered as SRI as far as SRI effects appear. SRI is categorized by Sato (2012) as follows.

2.5.4.1 Basic SRI

The principles of SRI originally proposed by Fr. Henri de Laulanié in 1983 are adhered to. That is transplanting single young seedlings at wider spacing as well as applying intermittent irrigation. Chemical fertilizer is used, but occasionally some organic matter or compost is used to improve or enhance soil immediate release of nutrient (Sato, 2012).

Recommended activities under basic SRI are listed below.

- Seeds can be nursed either on nursery bed or on trays
- To transplant a hectare a nursery plot size of 10m × 10m which can be divided in to two plots for easy movement and watering is needed.
- A farmer needs 8-10kg of paddy for a hectare
- Prepare the nursery bed and level it, water the bed to make the soil moist. Either raised or sunken bed can be used.

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- After preparing the seedbeds,soak seeds in warm water for a period of 24hours. Floating grains must be removed because they are empty.
- Divide the seeds into three parts: one-third for sowing the first half of the seedbed and one-third for sowing the second part of the seedbed. The last third will be use to fill the empty spots.
- The seeds are either hand sowed or broadcast evenly on the nursery bed
- Use the shovel handle to plane the surface and hit slightly with the palm of the hand to toss the soil.
- Cover the seeds with organic manure or sand mix manure. Cover with straw or mulch to prevent birds from picking the seeds.
- Remove the straw or mulch after 4 days.
- Start counting from the day of nursing the seeds. It takes 8-10 days to transplant
- Watering is done every morning and evening but do not flood the field.
- Plough the plot
- Harrow the field after a week of ploughing
- Organic manure is not applied before transplanting
- Transplanting has to be done in a muddy plot with sticky water
- Remove the seedling from the nursery using a spade or hand hoe.
- Taking out the seedling with soil around it allows the seedling to recover very fast as compared to the traditional method.
- Transplant seedlings immediately they are removed from the nursery. Do not delay for 30 minutes.
- The recommended mineral fertilizer application rate in northern Ghana is 250kg of NPK (15-15-15) per hectare at a week after germination or

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transplanting followed by 125kg of ammonium sulphate per hectare after 4 weeks.

- Start irrigation on the second week after planting.
- Water is sent to soak the soil up to a level of 2-5cm
- Apply alternating dry-wet irrigation on the field.
- During the flowering stage maintain water at a level of 2cm - 3cm keep water pressure over 10cm

2.5.4.2 Organic SRI

This type of SRI has similar menu as Basic SRI, but the chemical fertilizer is replaced by compost or manure. The organic materials that is compost or manure improves soil fertility and also enhances biological activity. This is the most preferable and ideal SRI (Sato, 2012). The recommended practices under the Organic SRI are:

- The procedure of setting up of the nursery on seed beds is the same as that of the Basic SRI
- Apart from the application of organic manure one month before transplanting, the planting of the seedlings is the same as that of the Basic SRI.
- Muddy the plot
- Apply first retovation in 2 days' time
- Spread organic matter on the field
- Apply second retovation
- Level the soil

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- Transplant when seedlings are 8-12 days after planting (when seedlings are at 2- leaf stage)
- Planting is done in line with a space of 25 cm × 25 cm.
- Transplant one seedling per hole
- When planting, the root should be in L shape to allow for easy development.

The principle of SRI is to alternate irrigation with drying out the soil.

- Start irrigation on the second week after transplanting.
- Water is sent to soak the soil up to a level of 2 cm - 5 cm
- Stop irrigation and allow for the soil to dry out until cracks are seen, which then means watering is needed.
- During the flowering stage maintain water at a level of 2 cm - 5 cm.

2.5.4.3 Partial SRI

This is a type of SRI which involves applying part of the principles of the SRI, even if the SRI effects will be decreased. The practice of partial SRI can be attributed to either the combined effect or any effect of farmer's preference, capability or soil condition. For example, a set of practices to transplant "not young" seedlings at wider spacing is considered as a partial SRI. Rainfed SRI will also be categorized as a partial SRI due to difficulty to control soil moisture (Sato, 2012).

2.5.5 Effects of SRI on the crop

Thiyagarajan and Gujja (2013) categorized the effects of SRI on the rice crop into two. These are: creating a better growing environment for the plant and exploiting more fully the genetic potential of rice plant.

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2.5.5.1 Creation of better environment for the plant

SRI creates more room for root growth, root activity, nutrient availability, soil microbial activity, soil aeration and redox potential than the conventional management practices (Thiyagarajan and Gujja, 2013).

The optimally wide spacing (25 cm × 25 cm) and single plant per hill do not only expose the leaves of the plant for optimum interception of sunlight for greater photosynthesis to occur but also creates room for root growth below ground (Thiyagarajan and Gujja, 2013).

Thakur *et al.*(2011) reported from the experiment they conducted that beyond 60 days after planting (DAP), light interception with SRI was significantly more than with conventional management practice (CMP). They realised that light interception reached 89 % and 78 % at panicle initiation stage in SRI and CMP canopies respectively. The SRI had 15 % advantage over the CMP. Experiments conducted by Gani (2002) in Indonesia confirmed that the radiation intercepted, increased with wider spacing than with conventional narrow spacing. The lower third leaves were suppressed and deprived of enough sunlight for photosynthesis. Instead of contributing to the plant's pool of photosynthate, these leaves relied upon that pool for their own metabolism, becoming in effect parasitic (Gani, 2002). The lower leaves supply most of the photosynthate to rice plant roots (Tanaka, 1958). If these leaves are suppressed by the upper leaves as a result of poor spacing of plant to carry out photosynthesis, poor roots' growth and metabolism will be prominent (Thiyagarajan and Gujja, 2013).

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The poor growth of roots and functioning is prominent in hypoxic soil condition (Uphoff, 2008). Rice plants in the SRI plots can produce 10 times more root mass, 5 times more root length and 7 times more root volume in the top 30 cm of the soil profile, compared with roots in the flooded rice plots (Rupela *et al.*, 2006). Thakur *et al.* (2011) confirmed this assertion as they recorded 40 % more root volume per square meter and 125 % more root length in the SRI plants over that of the conventional management practice of plants. SRI methods record better nodal root development than conventional methods at the initial growth stage when soil nutrients are not a limiting factor (Thiyagarajan and Gujja, 2013). Reduced intra hill competition favours the development of more lateral roots (Mishra and Salokhe, 2011). Keeping the soil moist rather then flooded supports proper root development and functioning (Thiyagarajan and Gujja, 2013).

Degeneration of roots is common in flooded soil (Kar *et al.*, 1974). However, there is negligible root degeneration in SRI field as the water management system does not support continuous flooding (Thiyagarajan and Gujja, 2013). Brownish roots due to coating of ferrous compounds and degeneration are common from the panicle initiation stage onwards (Thiyagarajan and Gujja, 2013). Ramasamy *et al.*(1997) reported from their experiment that drained field conditions enhanced the root oxidizing power and reduced the fraction of dark coloured roots. Whitish roots with virtually no degeneration were observed in the SRI.

It is worth noting that SRI plant root system is more active than conventional management rice crop. Thakur *et al.* (2011) found greater xylem exudation rates from SRI plant roots, indicating enhanced root activity. Mishra and

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Salokhe (2011) observed higher root-oxidizing activity at the later growth stage of the SRI plant.

Also, the intermittent irrigation in SRI creates a condition in the soil which permits aerobic soil organisms to survive and contribute substantially to the fixing and the release of nutrients to the rice plant. According to Lin *et al.* (2011), root growth is positively and significantly influenced by aerobic irrigation and by organic manure application. The mixing of aerobic and anaerobic soil horizons encourages greater biological nitrogen fixation (Magdoff and Bouldin, 1970). SRI water management practices that is alternate wetting and drying the soil can enhance the growth of phosphobacteria and possibly of N-fixing bacteria (Uphoff *et al.,* 2009).

Phosphorus solubilization is increased under alternating aerobic and anaerobic soil conditions (Uphoff, 2002). Thiyagarajan and Gujja (2013) measured large increases in soluble organic P with alternate wetting and drying. The biological weathering processes probably also increased the availability of other nutrients such as S and Zn.

Mycorrhizal fungi cannot grow in anaerobic soil. Therefore, flooded field deprive the plant of the benefits of mycorrhizae such as increased volume of soil accessed by plant root and growing well in soil with minimal P supply (Uphoff, 2002).

Benefits from Rhizobia bacteria induce more efficient acquisition of N, P, K, Mg, Ca, and Zn in rice. Rhizobia increase yield and total protein quantity per hectare, by producing auxins and other plant growth promoting hormones (Uphoff, 2002).

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The microbial flora causes a large number of biochemical changes in the soil that largely determine the fertility of the soil (De Datta, 1981). Biological nitrogen fixation can occur with all gramineae species, including rice. In flooded paddies, biological nitrogen fixation is limited to anaerobic processes. SRI provides both aerobic and anaerobic conditions which supports biological nitrogen fixation. Mixing aerobic and anaerobic soil conditions increases biological nitrogen fixation (Magdoff and Bouldin, 1970). According to Wilson (undated) sulfur deficiency normally occurs when a soil is permanently flooded.

The higher root biomass in SRI plants produces larger rhizosphere, and according to Armstrong (1970) plants with larger rhizosphere regions will be significantly better protected from absorbing large amounts of reduced products.

The higher levels of enzyme activity in SRI plant rhizosphere indicates an increase of N and P availability as well as more soil microbial C and N, which would boost the nutrient pool for both plants and microbes (Thiyagarajan and Gujja, 2013). Gayathry (2002) recorded 50 % increased in all the populations of aerobic bacteria in the SRI rhizosphere than conventionally grown rice of same variety before and during panicle initiation. The populations of the aerobic bacteria include *Azospirillum, Azotobacter, diazotroph* (N-fixing bacterium) and phosphate solubilizing. Kumar *et al. (*2007) also reported 23 % increase in dehydrogenase activity in the rhizophere and bulk soil during the vegetative stage in the SRI plants as compared to those transplanted conventionally. Lin *et al.* (2011) observed that more input of organic material

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and aerobic irrigation, individually or together, increased the number of actinomycetes significantly.

Redox potential is decreased when organic manure is applied. However, the same redox potential is increased when the weeder is used several times on the field. Therefore, the SRI may be used in managing the effects of redox potential (Lin *et al.,* 2011).

Data obtained from farmers using SRI methods in Madagascar showed that each weeding beyond two added 1-2.5 t/ha to yield (Uphoff, 2002). Similarly, data solicited from farmers in Nepal showed that farmers who used the weeder three times got mean yield of 2 t/ ha higher than the farmers who weeded only twice (Thiyagarajan and Gujja, 2013). Vijayakumar *et al.* (2005) also found a significant yield increase of 9.7 % (with 20 × 20 cm plant spacing) and 11.1 % (with 25 × 25 cm plant spacing) which could be attributable to weeder use when compared to conventional weeding (herbicide + hand weeding). Vijayakumar *et al.* (2005) found that the weeder use has a sort of earthing up effect and the plants produce new roots which probably help in additional nutrient uptake. Rajendran *et al.* (2005) found 22-24 % yield increase due to weeder use.

Application of organic manures to the soil in SRI is favourable to microbes as these materials become a source of energy for them (Thiyagarajan and Gujja, 2013). Compost used with SRI methods increased yield up to 10.5 t/ha which could be partly attributed to high *Azospirillum* effect which enhanced the microbiological activity in the soil boosted by alternative management practices of the SRI (Uphoff, 2003). The analysis on changes in *Azospirillum*

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populations living in rice roots associated with SRI practices compared to conventional practices showed a dramatic positive correlation in yield, as reported by Uphoff (2003). Organic matter application promotes the enzyme nitrogenase nitrogen fixing activity. Nitrogenase production is suppressed by the use of chemical fertilizers (Uphoff, 2002).

Farmers reported that SRI practices "improve their soil quality" over time as yields went up rather than down just by continuous addition of compost (Uphoff, 2002).

2.5.5.2 Exploiting more fully the genetic potential of the rice plant

SRI effects are shown in plant root growth and function, profuse tillering, non-lodging, prolonged leaf greenness, higher number of panicles, higher number of grains per panicle, and lower spikelet sterility which are easily observable (Thiyagarajan and Gujja, 2013).

SRI brings out greater root performance in terms of length, volume, cation exchange capacity and enzyme activity. This assertion is confirmed by Nisha (2002) who recorded, in SRI plants, greater root length and root volume, about 40 % higher root cation exchange capacity (CEC) and about 27 % more ATPase activity and cytokinin content of roots. Higher CEC implies higher absorption of cations or nutrients. ATPase is a key enzyme responsible for the absorption of nutrients while cytokinin is a growth hormone involved in cytogenesis, as it is being synthesized in the root tips and translocated to other parts of the plant (Thiyagarajan and Gujja, 2013). Similarly, Anas *et al.* (2011) reported that SRI methods affected the size and performance of roots, which reciprocally had positive effects on the soil biota through root exudation. The

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combined effects of higher root oxidizing activity at the later growth stage of the SRI crop with better root distribution in the soil, might be related to the delayed senescence and prolonged photosynthetic activity of the lower leaves and which is translated into more yields from SRI plants (Mishra and Salokhe, 2011).

Alterations in management practices can induce phenotype alterations such as longer panicles, more grains of panicle, higher grain-filling, more open plant architecture with more erect and larger leaves, more light interception, higher leaf chlorophyll content at ripening stage, delayed senescence and greater fluorescence efficiency, higher photosynthesis rate, and lower transpiration (Thakur *et al.,* 2009). Thiyagarajan and Gujja (2013) also observed profuse tillering, leaves' remaining green even after physiological maturity, and resistance to lodging in the SRI plants. Dingkuhn *et al.* (1991) indicated that the growth dynamics and partitioning patterns of rice depend on cultural practices, particularly on planting methods. This is in agreement with IRRI (2008) that transplanting enables optimal spacing, and good spacing can increase tillers and paddy yield over poor spacing and/or other planting methods. SRI transplanting preserves the plants' vigour and growth potential for tillering and root development which is forfeited by using older seedlings beyond their 4th phyllochron of growth (Stoop *et al.*, 2002).

Chen *et al.* (2013) observed that the net photosynthetic rate was greater in SRI plants which produced higher tillering rate and greater biomass accumulation in those plants. Their results indicated that carbon fixation in conventional management plants was not as great as in SRI plants at the tillering stage. This confirms the hypothesis that energy supply regulates tillering of plants and the

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findings that tiller appearance depends on carbon supply (Chen *et al.*, 2013). In addition, the advantage in photoassimilate accumulation and remobilized dry matter to the main shoots might partly explain the increased panicle size in SRI plant (Chen *et al.*, 2013).

Larry *et al.* (2012) recorded early flowering and shorter maturity days in direct seeding rice plants because it had better crop establishment, with higher intra competition due to shorter spacing and plant density per unit area, triggering quicker reproductive phase responses. IRRI (2008) also reported that depending on a cultivar, direct seeded rice matures seven to ten days earlier than transplanted rice.

SRI plant productive panicle is improved as this plant has greater competitive advantage over the plant under conventional management practices. SRI promotes the efficient use of resources such as nutrients, solar radiation and water in the vegetative stage (Chen *et al.*, 2013). Chen *et al.*(2013) reported that reducing unproductive tillers in the middle growth stage promoted the development of heavy panicles in the late growth stage

There is visual and measured evidence of differences in root size and health (presence of necrosis) of the same variety cultivated under SRI and conventional management practices. The SRI plant root is larger and healthier than the conventional management practice plant root but of the same variety (Uphoff, 2007). The yield increase under SRI ranges from 44 to 99 % (Styger *et al.,* 2011). Similar positive response of all five varieties studied in Afghanistan was reported by Thomas and Ramzi (2011).

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The quality of the seed produced in SRI is far superior to that produced conventionally (Subba Rao *et al.*, 2007). The quality traits of basmati rice was also found to be enhanced with the SRI methodology (Tewari and Barai, 2007; TildaRicelands Pvt. Ltd., 2008). A higher milling percentage has also been reported by Thiyagarajan and Gujja (2013).

Among all the SRI principles evaluated through diligent experiments, with the exception of fertilization effect, transplanting very young seedling (8-12 days old) registered the greatest effect, followed by alternate dry and wet irrigation (aerobic soil conditions) as the next most influential factor (Thiyagarajan and Gujja, 2013). The greatest fertilizer effect was observed when NPK was used with an improved variety while the local variety responded very well to compost (Uphoff, 2008).

The synergy of SRI principles produces large canopies and high root exudation. Larger canopies and root systems increase exudation deposition. 30-60 % of C fixed in canopy is sent to the roots, and 20-40 % of this exuded or deposited in rhizosphere. Roots and shoots are "two-way streets". However, little is known about exudation in rice (Uphoff, 2002).

2.5.6 Adoption of SRI

For easy acceptance as well as continuous practice of SRI by local farmers, there is the need to employ a gradual and systematic approach in disseminating the innovation. Henceforth, farmers are trained to start from the basic SRI or the partial SRI and then upgrade to the organic SRI. Each practice of SRI can be adjusted flexibly by farmer so as to meet with site conditions and available resources Sato (2012).

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SRI is an unusual innovation and it should not be surprising that the ways in which it has been disseminated are themselves not typical (Uphoff, 2007). SRI was not planned as a civil-society innovation as it never started from a research institution nor tested in a green house or laboratory. Agricultural researchers and government personnel from Madagascar earlier on resisted SRI crippling the efforts that were being made by Laulanié and TefySaina in the propagation of this innovation. Sadly, this has been true, at least initially, in practically all other countries where the ideas have been introduced (Uphoff, 2007).

Thus, SRI has spread, by force of circumstance, through the efforts of a great variety of individuals, NGOs, universities, farmer organizations or other affiliations who shared an interest in more economical and environmental friendly agriculture (Stoop and Kassam, 2005). In Ghana GIDA and NGOs such as AMSIG Resources and ADVANCE have made several strives in disseminating SRI.

2.5.7 Overview of SRI on the globe

SRI is adopted in more than 50 countries, including Madagascar, China, Indonesia, Cambodia, Laos, Myanmar, Thailand, Philippines, India, Bangladesh, Sri Lanka, Nepal, Ghana, Sierra Leone, Cuba, Benin, Guinea, Mozambique, Peru, Vietnam, Pakistan, Senegal, Mali, Bhutan, Iran, Iraq Zambia, Afghanistan, Brazil, Japan, Rwanda, Egypt, Costa Rica, Ecuador, East Timor, Malaysia, North Korea, Taiwan, Kenya and Panama (Katambara *et al.*, 2013).

According to Katambara *et al.* (2013), since its introduction, SRI practice has been widely promoted globally due to these benefits:

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- Yield per hectare is increased usually by 50 % -200 % or more,
- SRI fields are not kept continuously flooded, thus water requirements are reduced generally by 25 % - 50 %,
- The system does not require purchase of new varieties of seed, chemical fertilizer, or agrochemical inputs, although less rates of commercial inputs can be used with SRI methods,
- Minimal capital costs make SRI methods more accessible to poor farmers, who do not need to borrow money or go into debt, unlike many other innovations, and
- Costs of production are usually reduced, typically by 10 % - 20 %. Although these percentages vary according to input-intensity of farmers' current production, the need for more research is still high to evaluate SRI impacts under various local conditions.

Katambara *et al.* (2013), opined that the dissemination and adoption of SRI has been slow due to the necessity of undergoing training as well as the anticipated effective extension services needed for successful adoption. Peer-reviewed scientific articles lacked information on SRI. The lack of information incurred the hostility of SRI by stakeholders in agriculture. Considering the adoption of SRI in Timor for example, adoption was slow until the extension agency and farmers were convinced that the innovation was going to be more economical compared to the conventional input-intensive rice cultivation system (Katambara *et al.,* 2013).

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2.5.8 Overview of SRI in Africa

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SRI in western, northern, and southern Africa was introduced at various periods ranging from year 2000 to 2011. Currently more than 18 countries have introduced SRI to its farmers as listed in the overview of countries involved in SRI globally. SRI practice has been inspired by various issues. For instance, although, introduced in 2006, the Zambian agricultural innovations have been improved since the introduction of SRI through the following (Katambara *et al.,* 2013).

- The yields have risen to 11.8 t/ha depending on the region applied.
- With respect to water use, a saving of up to 50 % can be realized depending on climatic conditions. The number of days required to wet the fields range between 3-6 days in Zambia.
- In order for the rice plant to achieve optimum number of productive tillers, the spacing is supposed to be higher, ranging from 15 cm to 40 cm grid. However, the optimum spacing varies and has raised some arguments.
- The yield is likely to have been influenced by the number of weedings done. For instance, the number of weedings done in Zambia were single, twice, thrice, and four times and the respective yields realized were 7.7, 7.4, 9.1, and 11.8 t/ha, respectively.
- The age of transplanted seedlings is important to a rice plant and also requires some investigation.
- Also, the use of organic manure is more preferred, but the type and the composition of the manure it not well understood.

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2.5.9 SRI in Ghana

The earliest discussions of SRI in Ghana took place in 2001/2002 by Norman Uphoff (SRI-Rice, 2012). During 2007 – 2008, JICA in conjunction with CRI carried out SRI trials in the Ashaiman Irrigation Scheme, Accra, under the management of the Ghana Irrigation Development Authority (GIDA) (Uphoff, 2008). These trials faced some challenges. Therefore Shuici Sato, who had worked with SRI in Indonesia, was invited by the Chief Executive of Ghana Irrigation Development Authority (GIDA) during 2009 to provide additional information on SRI to GIDA staff.

Kwabena Adu Broni, a farmer who began experimenting with SRI in 2007, reported on successful SRI evaluations in Ghana at Aboso-Odumasi in the Western Region in 2009. During 2009 -2011, the General Agriculture Union in collaboration with Action Aid Ghana supported farmers in implementing SRI on a pilot basis under the Asutware Rice Irrigation Project and the Ashaiman Rice Irrigation Project (Africare/Oxfam, 2010).

According to an article in Ghana News Agency, on October 27, 2011, rice farmers operating under Kpong Irrigation Project at Asutware in Eastern region called on the government of Ghana to adopt SRI as a policy to help increase rice production in the country.

During June, 2012, an SRI training in Ghana was provided by the Regional USAID's Extended Agribusiness Trade Promotion (E-ATP) project. At a regional SRI workshop in Burkina Faso in July, 2012, Gina Odarteifio, CEO of AMSIG Resources, described how her company had trained and undertaken

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SRI trials with over thousand farmers in 20 communities in Ghana (SRI –Rice, 2012).

2.5.10 Benefits from SRI

In 2011 a young farmer named Sumant Kumar set a new world record in rice production of 22.4 t/ha using SRI, beating the then existing world record held by the Chinese scientist Yuan Longping by 3 t/ha (Gordon, 2013). Benefits of SRI include: 20 % - 100 % or more increased yields, up to a 90 % reduction in required seed, and up to 50 % water savings. SRI principles and practices have been adapted for rainfed rice as well as for other crops such as wheat, sugarcane and teff, among others, with yield increases and associated economic benefits (Laulanié, 2011). The net effect of SRI is to improve household incomes and food security while reducing the negative environmental impacts of rice production and making food production more resilient (Africare/Oxfam, 2010). According to Ghanaweb (2013), two acre rice farmer at Golinga, Northen Ghana, by name Mahamudu Yahaya shared his experience with SRI technology. He noted that his SRI field required only two bags of fertilizer and 6 kg of seeds per acre, facilitates weeding and movement through the field due to proper spacing and heavier grains than that of his broadcasted rice field.

In the history of rice research, SRI is the only technique available which can:

- Increase yields up to 200 %
- Reduce seed and nursery costs (68 % reduction)
- Reduce labour especially for planting and weeding
- Reduce irrigation water and as well as power requirements for irrigation
- Reduce or eradicate lodging and pest damage

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- Reduce cost of herbicides and mineral fertilizers

In addition, farmers report and researchers have verified that SRI crops are more resistant to most pests and diseases, and better able to tolerate adverse climatic influences such as drought, storms, hot spells or cold snaps (Uphoff, 2007). The length of the crop cycle is also reduced, with higher yields (Uphoff, 2007). Resistance to biotic and abiotic stresses will become more important in the coming decades as farmers around the world have to cope with the effects of climate change and the growing frequency of "extreme events" (Uphoff, 2007). The resistance of SRI rice plants to lodging caused by wind and/or rain was due to their larger root systems and stronger stalks (Uphoff, 2007). In general, one can say that use of SRI methods reduces the agronomic and economic risks that farmers face (Uphoff, 2007).

Besides its lower cost, a weeder has several other advantages:

- Weed biomass is incorporated into the soil, adding organic carbon
- The nutrients taken up by the weeds return to the soil
- The earthen up of the soil activates microbial, physical and chemical processes which are beneficial to crop growth
- If fertiliser top dressing precedes weeder operation, fertilisers are incorporated and nutrient loss by leaching is reduced
- Some earthing up takes place when the weeder is used. This makes the plants produce new roots which increases root activity.

Using the weeder in both directions yields the maximum benefit, but labour availability and soil conditions can make this difficult for some farmers to achieve. Attempts are being made to develop a hand held motorised weeder but

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so far no one has been able to develop an effective and efficient one. However, it would be a big advantage for SRI farmers who do not have enough labour for hand-operated weeders.

2.5.11 Farmer difficulties in adopting SRI

Throughout history humankind has been resistant to change and to the acceptance of new ideas. SRI is no exception (Thiyagarajan and Gujja, 2009). The many new techniques proposed by SRI are often greeted with scepticism by the farmer who has been cultivating rice for decades (Thiyagarajan and Gujja, 2009). Thus, farmers must first be convinced through demonstrations and training. The farmer should then try SRI in a small part of his rice crop, then build up from there (Thiyagarajan and Guja, 2009). In major rice producing areas, labour shortages are becoming a serious problem (Thiyagarajan and Guja, 2009). The partial mechanization introduced in SRI should be increased further to reduce labour requirements. In areas where agricultural labourers are still dependent on rice cultivation, efforts to train them in SRI are essential (Thiyagarajan and Gujja, 2009).

Some of the common problems faced by farmers in adopting SRI as reported by Thiyagarajan and Gujja (2009) are:

- SRI demands more personal attention and constant involvement by farmers.
- Apprehensions about the new way of raising seedlings, handling young seedlings and square planting.
- Difficulties in leveling the main field properly.
- Resistance of contract labourers to planting.
- Labour scarcity for transplanting.

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- Drudgery of using a weeder.
- Unsuitability of weeder for some soils.
- Unavailability of weeders.
- Potential pest attack due to lush growth of the crop.

2.5.12 SRI controversies

Some scientists have criticized SRI, describing the SRI results as "unconfirmed field observations" (UFOs) (Sinclair and Cassman, 2004; Sinclair, 2004). Some also state that scientifically accepted standards were not followed in the experimental work. These criticisms are based on past research carried out on agronomic practices that have no comparison with those of SRI (Thiyagarajan and Gujja, 2009). For example, the physiology of rice when it is grown under combined conditions of low plant density and shallow irrigation with alternate wetting-and-drying, plus soil-aerating intercultivation with mechanical hand weeders has not been studied (Thiyagarajan and Gujja, 2009). Some people are of the view that SRI's workable recommendations are already widely used by farmers, and do not need to be promoted. However, this is not all true because no other system advises farmers to transplant single seedlings at the 2-leaf stage at a density of 16 seedlings per sq m, and to intercultivate them with a weeder (Thiyagarajan and Gujja, 2009).

Similarly, SRI cannot be compared with other water-saving technologies like alternate wetting and drying (AWD) unless all the other practices that make up SRI are also evaluated (Thiyagarajan and Gujja, 2009).

Researchers have shown the positive effects on crop growth and yield from interactions among practices that cause simultaneous growth increases in both

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root systems and canopy (Randriamihariam and Uphoff, 2002). Changing water management practices alters many other parameters associated with crop growth and health because there are profound differences between nonflooded and flooded soil conditions (Thiyagarajan and Gujja, 2009).

Sinclair (2004) commented that SRI emphasises organic nutrients to the exclusion of mineral fertiliser and thus faces serious challenges in obtaining enough mineral nutrients from organic sources to achieve high yields. This is also incorrect. Proponents of SRI do not claim it is possible only with organic manures (Thiyagarajan and Gujja, 2009). On the other hand, SRI does emphasise the importance of the soil organic matter content and of soil health (Thiyagarajan and Gujja, 2009). This is because the response of rice under SRI is more pronounced when organic manure is added along with mineral fertilisers (Thiyagarajan and Gujja, 2009). In fact, most farmers apply chemical fertilisers along with available organic manure.

In any case, the academic debate is meaningless to those farmers who are able to appreciate the benefits of switching to SRI (Thiyagarajan and Gujja, 2009). It is actual experience that sustains any new technology or practice and farmers are better judges than anybody else (Thiyagarajan and Gujja, 2009). That more and more farmers (about one million since 2003) are coming forward to adopt SRI is proof alone of its beneficial effects (Thiyagarajan and Gujja, 2009).

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2.5.13 Procedure for dissemination of SRI

To introduce SRI in areas without experience on SRI, careful selection of lead farmers in farmer based organizations (FBOs) and full support for them is paramount (Sato, 2012). SRI training for lead farmers will be done by SRI

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experts, experienced NGOs, and trained extension workers (Sato, 2012). Support by local government will be necessary (Sato, 2012). Recommended procedures for SRI dissemination in such areas are as follows.

- To conduct SRI training to field extension officers by SRI experts.
- To conduct general SRI training to farmers at farmer based organizations level, and to select candidates of SRI lead farmers (SLFs).
- To conduct intensive SRI training to SLFs before the start of cropping season.
- To continue monitoring and supervising SLFs during the cropping season.
- To use SLFs' paddy fields as a demonstration farm to show SRI to other farmers of the FBOs.
- To use active SLFs as SRI extension workers in the area for SRI dissemination within their groups and eventually beyond.

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of experimental site

The trial was carried out during the 2014 dry season from January to June on the Golinga irrigation field at Golinga about 15 km from Tamale in the Tolon District in the Northern Region of Ghana. Golinga lies on an altitude of 183 m above sea level within latitude 09°21' 346" N and longitude 0°56'678" W of the equator. It has a unimodal annual rainfall of 991 mm (in 2013 rainy season) which was evenly distributed from April to November with the peak in August and September. The mean minimum and maximum temperatures were 23.4° C and 34.5° C respectively. The minimum and maximum relative humidity of 46 % and 76.8 % were also recorded (SARI, 2013).

3.2 Field layout and materials

The Randomized Complete Block Design (RCBD) was used in laying out the field. This design allowed block differences to be removed, and treatments compared under more uniform conditions within a block.

The total field was 378 m^2 (42 m × 9 m) on the experimental site. Each block was 126 m^2 (42 m × 3 m) and each plot measurement was 21 m^2 (7 m × 3 m). Each block consisted of 6 randomly assigned treatment plots with 1m and 2m alleys between adjacent treatment plots in a block and adjacent blocks respectively. Each treatment was replicated three times.

The treatments were T1 = FP 1, T2 = FP 2, T3 = SRI 1, T4 = SRI 2, T5 = SRI 3 and T6 = SRI 4.

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Notes:

- FP 1 = farmers' practice 1 = seeds directly broadcast on plots, plots flooded continuously, hand pulling of weeds and application of recommended rates of chemical fertilizer that is 37.5 kg/ha each of N, P_2O_5 and K_2O from the NPK (15–15–15) and 26.25 kg/ha N from sulphate of ammonia as basal application and top dressing respectively.
- FP 2 =farmers' practice 2 = seeds directly broadcast on plots, plots flooded continuously, hand pulling of weeds and application of 13 t/ha compost.
- SRI = System of Rice Intensification. Nursing of seeds, early transplanting of seedlings (14 days old), wide spacing (25 cm × 25 cm), intermittent irrigation and earthing up of the soil through weeding by hoe were common practices in all the SRI treatments. However,
- SRI 1 received 13 t/ha of compost,
- SRI 2 received the recommended rates of chemical fertilizer application that is 37.5 kg/ha each of N, P_2O_5 and K_2O from NPK (15-15-15) and 26.25 kg/ha N from sulphate of ammonia as basal application and top dressing respectively,
- SRI 3 received both 13 t/ha of compost and half recommended rate of N, P_2O_5 and K_2O (18.75 kg/ha each) from 15-15-15 and
- SRI 4 received both 13 t/ha of compost and half recommended rate of N (13.13 kg/ha) from sulphate of ammonia.

3.3 Land preparation

The field was ploughed at a depth of about 20 cm, to loosen the soil as well as to eradicate undesirable vegetation. The land was later harrowed and leveled using the harrow and hand hoe respectively to make the land suitable for

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compost application, irrigation and planting as well as emergence and establishment of seeds. The field was then carefully pegged and divided into 18 plots, each measuring 3 m × 7 m. Blocking was done across the gentle slope to control erosion and to minimize any incidence of soil fertility gradient that may exist on the field. Compost was applied at the rate of 13 t/ha and incorporated on four plots in each replication, 3 weeks before planting.

3.4 Planting seeds and transplanting seedlings of rice

Sowings on both the nursery bed and broadcasted treatment plots were done on 16th February, 2014. A raised nursery bed of 1m × 1m was prepared, leveled and watered to make the soil moist but not flooded. One hundred kg/ha of paddy was soaked for 24 hours and then broadcast gently on the nursery bed. The seeds were thinly covered with soil compost mixture. In order to prevent birds from picking the seeds, the nursery bed was covered with dried rice straw. Watering was done every morning and evening. The mulch was removed after 5 days of nursing. On the farmers' practice treatment plots, 100 kg/ha rice seeds were evenly spread on the soil and covered with soil using the hoe.

The nursed rice seeds were transplanted with a wider spacing of 25 cm × 25 cm onto their respective treatment plots on 1st March, 2014 (14 DAP). Very young seedlings (14 days old) at two-leaf stage were removed from the nursery using the spade. Each seedling was removed with soil around its root and immediately transplanted per hill on a muddy field to minimize transplanting shock and easy development.

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3.5 Irrigation of plot

The principle of intermittent irrigation was applied on all the SRI plots. Irrigation started on the second week after transplanting. The plots were watered to soak the soil up to a level of 2 cm. The soil was then allowed to dry out until cracks were seen, before next watering was carried out. During the flowering stage water at a level of 2 cm – 3 cm was maintained. On the other hand, the farmers' practice plots were flooded all the time.

3.6 Application of fertility amendments

Four plots in each replication received 13 t/ha compost. The compost was incorporated into the soil 3 weeks before planting on 16th January, 2014. Each plot with recommended rates (RR) received an amount of 37.5 kg/ha each of N, P_2O_5 and K_2O from NPK (15-15-15) as basal application and 26.25 kg/ha of N from sulphate of ammonia as top dressing. Two plots out of the four plots which received 13 t/ha compost in each replication with half recommended rate (HRR) received either 18.75 kg/ha each of N, P_2O_5 and K_2O from NPK (15–15-15) as basal application or 13.13 kg/ha of N from sulphate of ammonia as top dressing. To ensure uniformity in all the treatment plots receiving the inorganic fertilizers, both NPK 15-15-15 and sulphate of ammonia fertilizers were broadcast on their respective plots. Basal application and top dressing were carried out at three weeks after planting (3 WAP) and six weeks after planting respectively (6 WAP).

3.7 Weeding

Using a hoe, the first weeding was carried out on 14th March, 2014 (4 WAP) on all the SRI plots. The subsequent weedings were carried out at 7 and 10 WAP. On the farmer practice fields, weeds were hand pulled as it was impossible to use the hoe. Weeding was done not only to earthen up the soil but also to eliminate grasses, sedges and broadleaves which were found on the field to reduce their competition with the rice plant for space, light, water and nutrients.

3.8 Pest control

The field was mulched with grass immediately after sowing in both the nursery and the Farmers' Practice fields to reduce picking on the sown seeds by birds. Using scar crows, birds were kept away from the field from grain filling to maturity.

3.9 Data collection

3.9.1 Rainfall distribution in the 2013 cropping season

Rainfall data was taken from the Savannah Agricultural Research Institute latitude 09°25'41" N longitude 0°58' 42" W altitude 183m above mean sea level (MSL). Record of rainfall measured at 09 HR GMT and entered against days preceding that on which read.

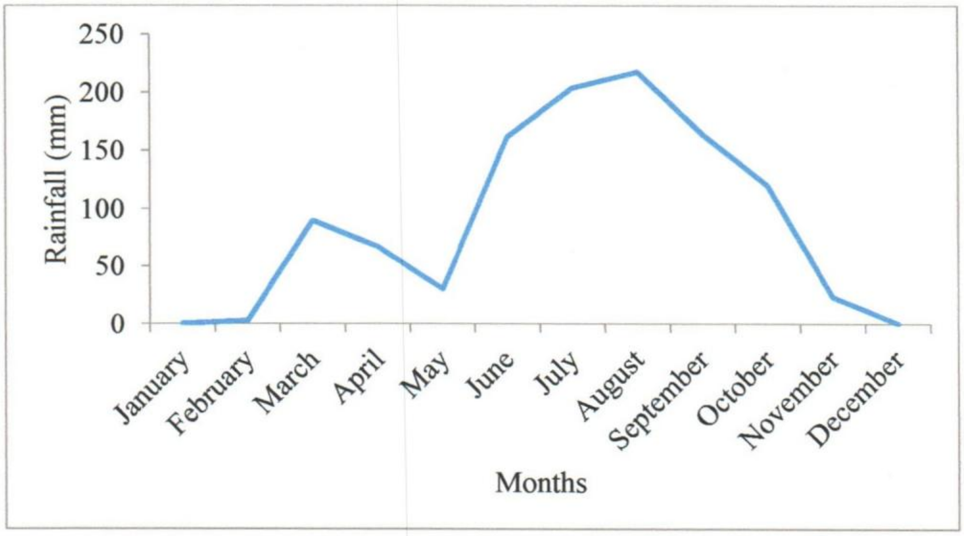

Figure 1. Rainfall distribution in the 2013 cropping season

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3.9.2 Soil chemical analysis

Baseline composite soil at the experimental site was obtained and soil chemical analysis carried out on it to determine the soil nutrient content. Soil composites were also obtained per treatment after harvest and analyzed to determine the nutrients available in those soils. The soil chemical analyses were carried out at the Savannah Agriculture Research Institute (SARI) laboratory, Nyankpala. The method developed by Walkley and Black (1939) was used to determine the organic carbon concentration, Kjeldahl method developed by Bremmer (1965) in determining the nitrogen concentration and the Bray method developed by Bray and Kurtz (1945) to determine the phosphorus concentration. Soil samples were analysed for pH as described by McLean (1982). Procedures described by Tel and Hargerty (1984) were adopted in determining the K, Mg and Ca concentrations of the soil.

The results of the soil analysis of the experimental site are presented in Table 5. The nitrogen, phosphorus and potassium concentrations were evenly distributed on the experimental site. The experimental site had a soil pH that ranged from 4.75 – 5.9, organic matter (%) content that ranged from 0.48 – 0.73 and total nitrogen (%) that ranged from 0.0139 – 0.059. Based on the standard set by FAO (2008), the soil at the experimental site had a low nitrogen percentage and the soil was moderately to strongly acidic.

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Table 5. Baseline and post harvest soil chemical properties

Treatment	pH (1:2.5 soil:water)	OC (%)	N (%)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
Baseline soil chemical properties							
Baseline soil sample	4.75	0.48	0.054	4.524	55.63	78.54	42.99
Post harvest soil chemical properties							
FP 1	5.6	0.57	0.042	5.562	51.84	156.75	155.67
FP 2	5.15	0.73	0.059	5.187	54.97	135.90	148.96
SRI 1	5.31	0.59	0.0139	7.225	114.29	162.56	137.89
SRI 2	5.32	0.62	0.0287	6.562	98.54	178.98	172.52
SRI 3	5.9	0.54	0.026	5.966	61.28	164.69	198.74
SRI 4	5.23	0.55	0.017	4.225	42.67	154.96	132.67

3.9.3 Emergence percent and establishment percent

Seedlings that had emerged were counted and divided by the total number of expected seedlings which was 375 and then multiplied by 100 to obtain the emergence percentage. This was done at 12 DAP before seedlings were transplanted from the nursery.

Establishment percent of the seedlings transplanted per plot was calculated at 3 WAP by counting the number of seedlings over the expected total number of seedlings per plot that is 525 multiplied by 100. The emerged seedlings in the farmers' practice fields were used to compare the established seedling percentage.

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3.9.4 Plant height

Plant heights were measured and recorded at 3, 6, 9 and 12 WAP from each of the tagged plants in each of the plots. Their means were then calculated.

3.9.5 Tiller count

Tiller count was done per plot at 6, 9 and 12 WAP. This was done by sampling two quadrats from each plot. Plants within these quadrats were tagged, their tillers counted and recorded. The tagged plants were also used for subsequent data to be taken. The mean number of tillers per plot was calculated.

3.9.6 Chlorophyll content

Chlorophyll content of the youngest leaf and the flag leaf (at maturity) of ten sampled plants from each plot was measured on the 9 and 15 WAP, using the Minolta SPAD chlorophyll meter.

3.9.7 Days to 50 % flowering

The numbers of days taken for half of the plant population in the individual plots to flower were visually observed and recorded.

3.9.8 Score for pests weeds and diseases

Weeds that were scored on the field were: grasses – *Roetboella cochinchinensis*, *Echinochloa pyramidalis*; sedges – *Cyperus iria*; and broadleaves – *Ludwigia spp* and *Marsilea minuta*. Pests and disease incidence specifically gall midge, birds and domestic animals such as cattle as well as brown spots, leaf scald and leaf blast were also scored by visual observation for associated symptoms. Scores were awarded based on the intensity of the symptoms. However, the presence of these weeds, pests and diseases did not significantly affect the experiment.

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3.9.9 Number of panicles

Panicles on each of the tagged plants in each plot were counted and recorded. The counted value was then divided by the total number of the tagged plants to obtain the mean number of panicles per plant.

3.9.10 Panicle weight

Ten panicles were selected from each plot, weighed and recorded. Their means were subsequently calculated.

3.9.11 Panicle length

Ten panicles were selected from each plot, their lengths were measured and recorded. Their means were later calculated.

3.9.12 Number of grain per panicle

The number of seeds per each of the ten sampled panicles was counted and their means were calculated.

3.9.13 Number of unfilled grains per panicle

The number of unfilled grains of the ten sampled panicles was counted and their means were calculated.

3.9.14 Plant biomass

The above ground biomass of the tagged plants was immediately weighed after harvest and the fresh biomass weight for each plot was determined. This biomass was air-dried and weighed and dry biomass for each plot was determined.

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3.9.15 Grain yield

Grain yield was weighed at 14 % moisture content after harvesting and winnowing.

3.9.16 Harvest index

Harvest index was calculated by dividing the grain weight (economic yield) by the total dry weight (biological yield) of the plant per plot.

3.9.17 Panicle harvest index

Panicle harvest index was calculated by dividing the grain weight by the total dry weight of the panicle.

3.9.18 Sterility percent

Sterility percent was calculated by dividing the number of unfilled grains by the number of filled grains of the panicle.

3.9.19 Benefit – cost analysis

Benefit – cost analysis was calculated by dividing the total revenue by the total cost obtained from each treatment. That is,

$$BC = \frac{TR}{TC}$$

Where BC = benefit cost analysis, TR = total revenue and TC = total cost.

3.10 Data analysis

Data collected were subjected to Analysis of Variance (ANOVA) and the means separated by the Least Significant Difference test (LSD) at 5 % using Genstat statistical package (12th Edition).

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CHAPTER FOUR

4.0 RESULTS

4.1 General observation

The results presented in the figures and tables showed that emergence %, plant establishment %, plant height at 6, 9 and 12 WAP, tiller count/m^2, chlorophyll content, days to 50 % flowering, plant biomass/m^2, panicle number/m^2, panicle weight/m^2, panicle length, number of grains/panicle, number of unfilled grains/panicle and grain yield were significantly enhanced by the SRI. However, plant height at 3 WAP, harvest index, 1,000 grain weight and sterility percent were not significantly enhanced by the SRI.

4.2 Emergence percent and establishment percent

The SRI significantly ($p < 0.001$) enhanced plant seedling emergence. The SRI nursery recorded the highest emergence (86 %) which was significantly different from the control – FP 1 (81.7 %) (Fig. 2). According to the means comparison FP 2 treatments recorded the least value (80.7 %).

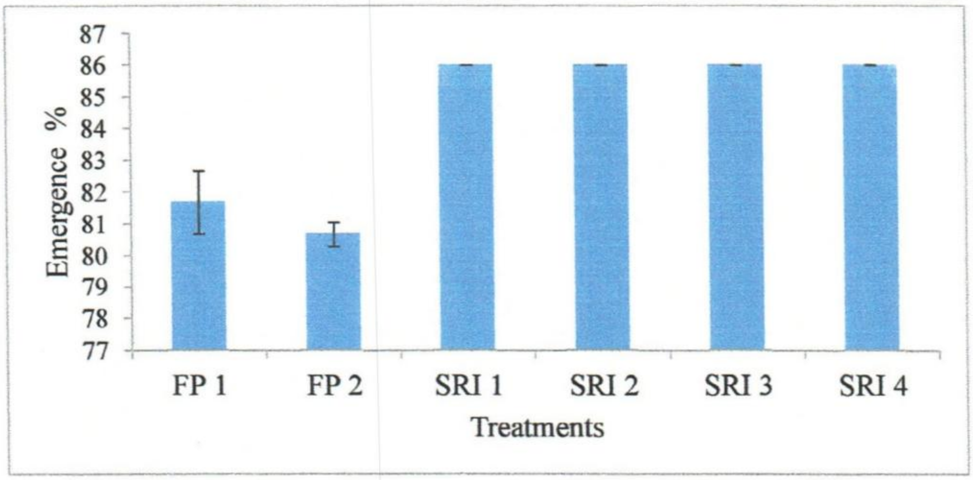

Figure 2. **Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on rice seedling emergence. Bars represent SEM.**

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The SRI significantly ($p < 0.001$) enhanced plant seedling establishment. The SRI 1 (97.3 %) and SRI 4 (94.7 %) treatments recorded the highest, which were significantly different ($p < 0.001$) from the other treatments but were not different from each other (Fig.3). According to the means comparison, FP 1 - the control (81.7 %) and FP 2 treatments recorded the least values (80.7 %).

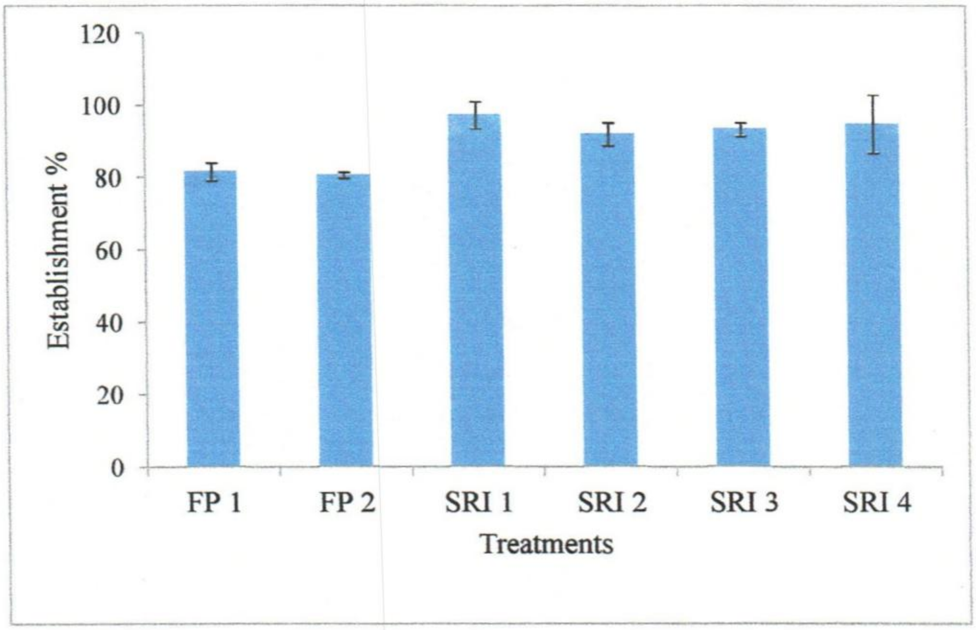

Figure 3. Effective of System of Rice Intensification (SRI) and Farmer Practice (FP) on rice seedling establishment. Bars represent SEM.

4.3 Plant height

At 3 WAP, plant height was not significantly ($p < 0.109$) increased by the SRI. However, SRI significantly ($p < 0.040$, $p < 0.007$ and $p < 0.004$) enhanced plant height at the 6, 9 and 12 WAP respectively.

At 6 WAP, SRI significantly increased plant height. SRI 2, SRI 1 and SRI 3 recorded higher (42 cm, 36 cm and 38 cm respectively) plant height over the control – FP 1 (33 cm) (Fig. 4).

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At 9 WAP, the value 53 cm recorded in SRI 1 was the highest which was statistically at par with 52 cm, 49 cm and 47 cm values recorded in SRI 2, FP 1 and SRI 3 respectively. The lowest value recorded, 38 cm was on FP 2 (Fig. 4).

At the 12 WAP, the SRI 2 produced the highest (97 cm) while FP 2 produced the lowest (67 cm) plant height. SRI 1, SRI 4, SRI 3 and FP 1 recorded 83 cm, 83 cm, 81 cm and 79 cm heights respectively (Fig. 4).

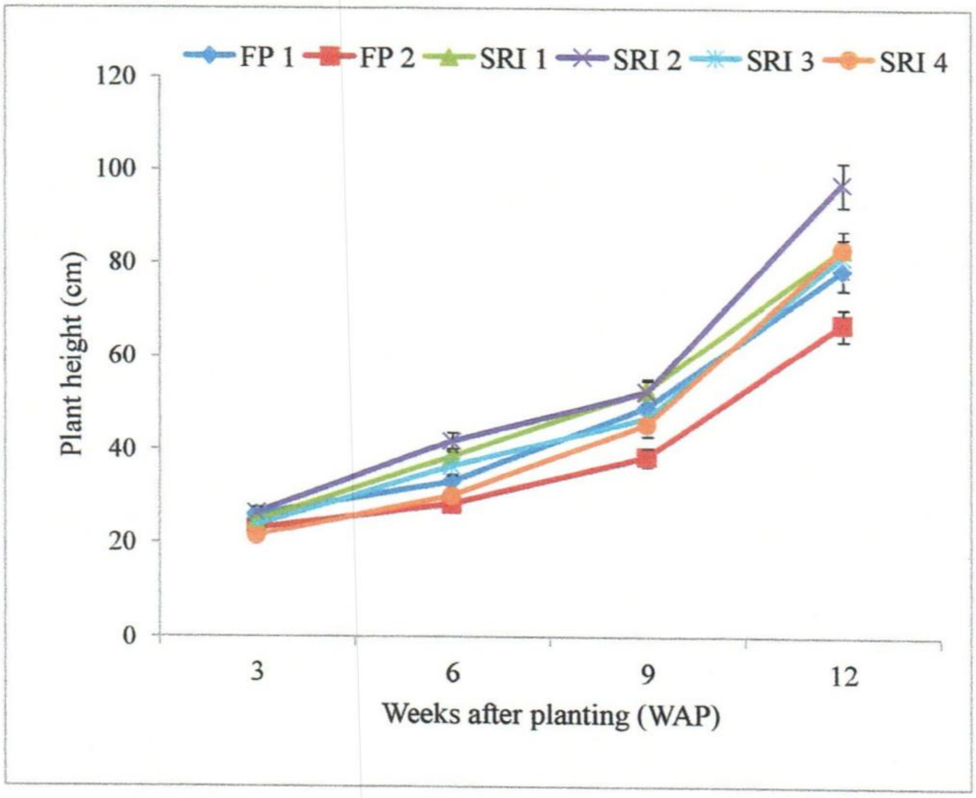

Figure 4. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on rice plant height. Bars represent SEM

4.4 Tiller count

Tillering was significantly enhanced ($p < 0.034$, $p < 0.001$ and $p < 0.001$) by the SRI at the 6 , 9 and 12 WAP respectively. At 6 WAP, the highest tiller count ($363/m^2$) was recorded in SRI 4 which was not significantly different

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from the tiller counts recorded in SRI 2 (352/m^2), SRI 3 (288/m^2) and FP 1 (275/m^2) (Fig. 5).

At 9 WAP, the SRI enhanced tillering of the plant. The highest tiller count (1018/m^2) was obtained in the SRI 2 as compared with FP 1 (413/m^2) - the control (Fig. 5). At 12 WAP, similarly SRI significantly boosted the number of productive tillers produced by the plant. The highest productive tillers (839/m^2) were obtained in SRI 2 as compared with the control - FP 1 (225/m^2) (Fig. 5).

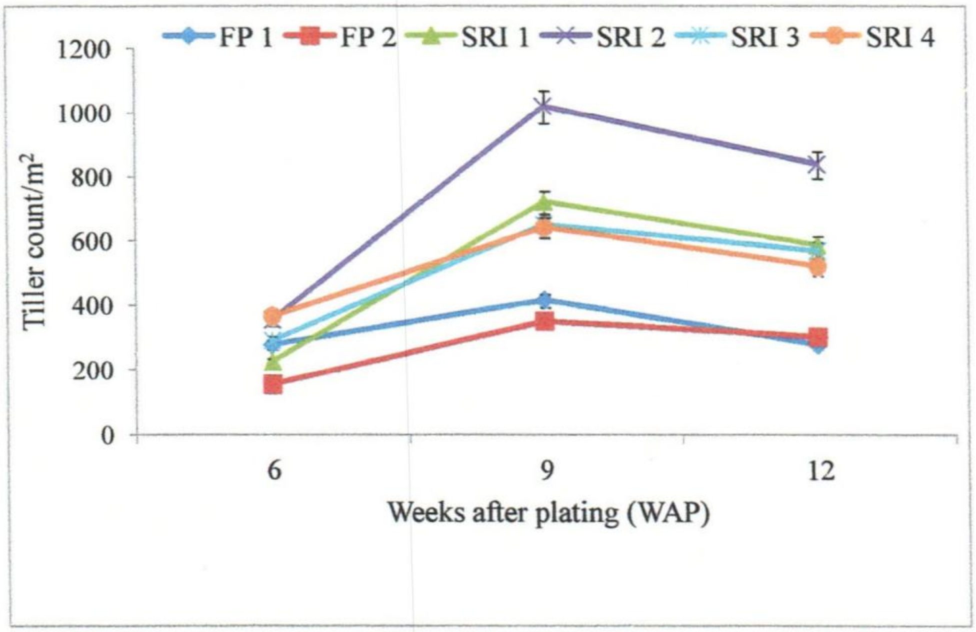

Figure 5. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on tillering of rice plant. Bars represent SEM.

4.5 Chlorophyll content

Chlorophyll content was significantly ($p < 0.001$) enhanced by chemical fertilizer applied at all levels at 9 WAP while the effect of SRI significantly ($p < 0.001$) enhanced the chlorophyll levels at 15 WAP.

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At the 9 WAP, the chemical fertilizers at all levels boosted the chlorophyll content of the plant. The plant with highest chlorophyll was obtained in SRI 2 (43.5) which was statistically similar to SRI 4 (43.3) and the control - FP 1 (39.4) (Fig. 6).

SRI improved the chlorophyll content of the plant at 15 WAP (Fig. 6). The flag leaf chlorophyll in SRI 2 (33.4) was the highest which was statistically similar to SRI 4 as compared with the control FP 1 (25.9) (Fig. 6).

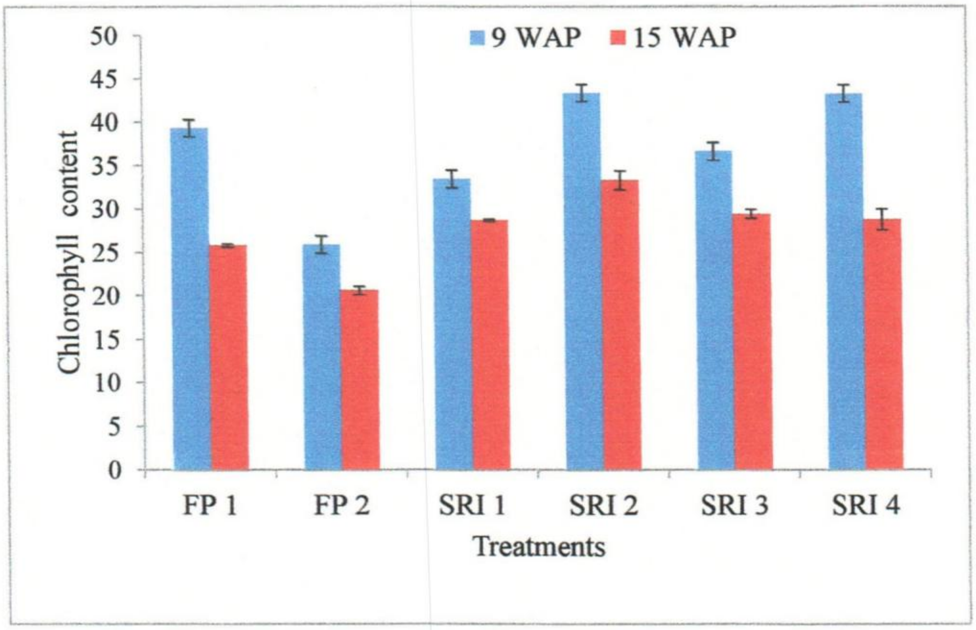

Figure 6. **Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on chlorophyll of rice plant. Bars represent SEM**

4.6 Days to 50 % flowering

The SRI ($p < 0.001$) enhanced the days to 50 % flowering. SRI 1 took the longest (104) days to flower, while FP 1 (control) took the shortest (91) days to flower (Fig. 7).

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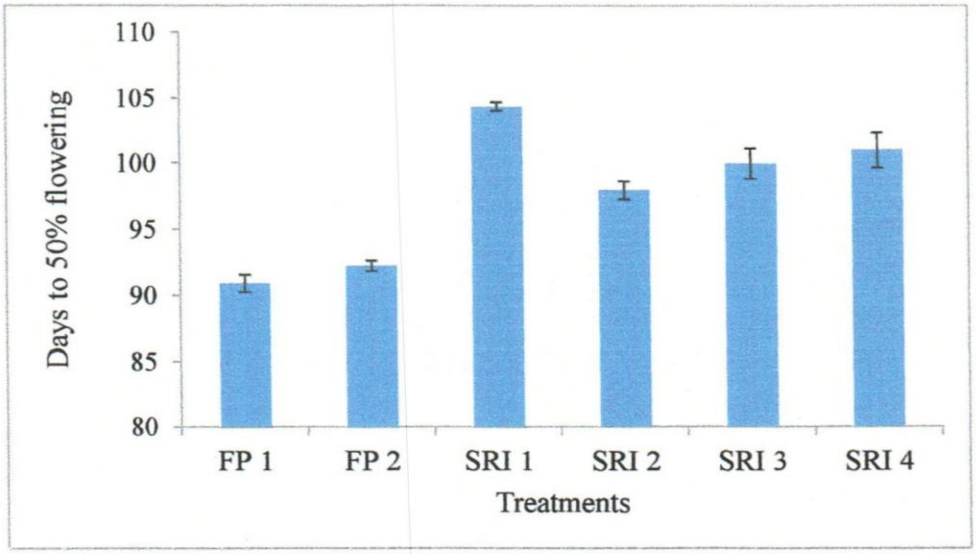

Figure 7. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on 50 % flowering of rice plant. Bars represent SEM.

4.7 Plant dry biomass

SRI with the chemical fertilizer application significantly ($p < 0.001$) enhanced the dry biomass of the plant. The SRI 2 recorded the highest (1.236 kg m^2) dry biomass over the control FP 1 (0.64 kg/m^2). The farmer practice (FP 1 and FP 2) and the sole compost applied (SRI 1and FP 2) entries recorded the lowest dry matter (Fig. 8).

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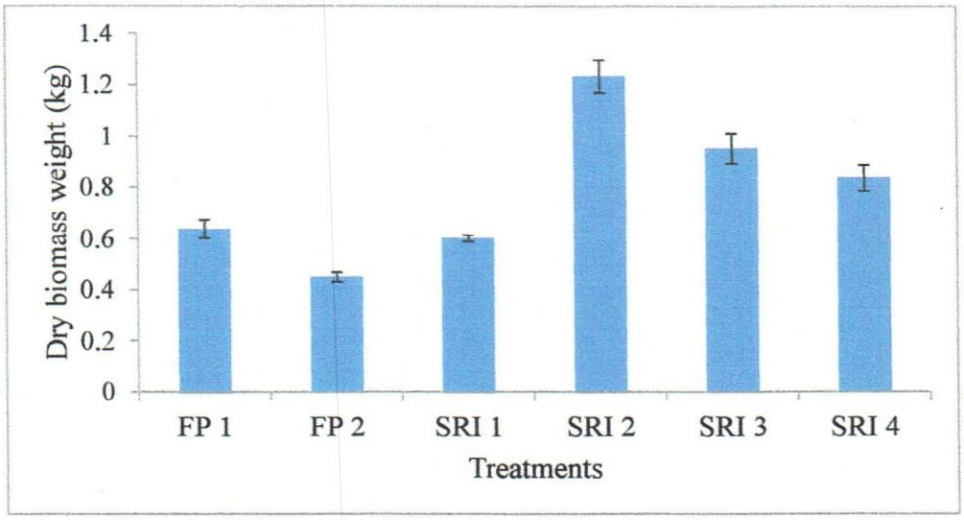

Figure 8. **Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on dry biomass of rice plant. Bars represent SEM.**

4.8 Plant straw weight

The chemical fertilizer application at all levels in the SRI significantly ($p < 0.010$) enhanced the straw weight of the plant. Similar to the dry biomass, it was observed that the SRI 2 recorded the highest straw weight (0.833 kg/m^2) while the control (FP 1) recorded the lowest straw weight (0.4 kg/m^2) (Fig. 9).

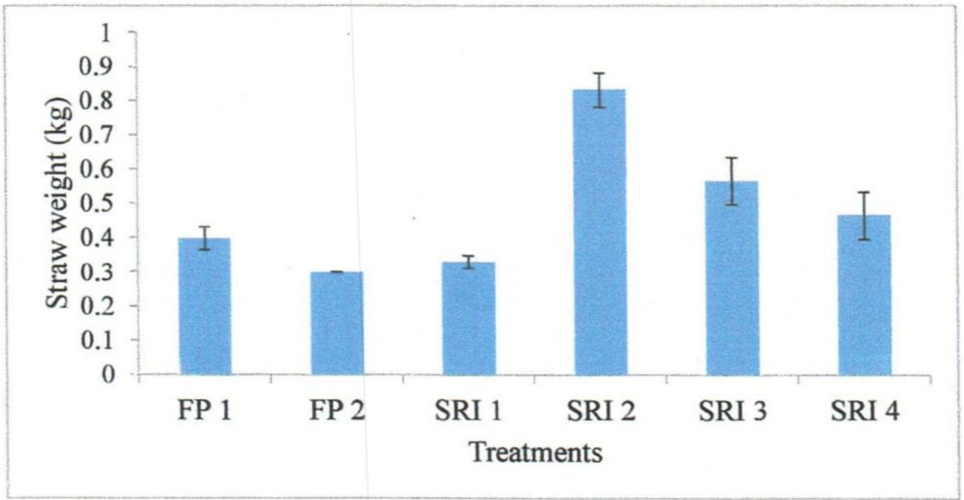

Figure 9. **Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on straw weight of rice plant. Bars represent SEM.**

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4.9 Panicle number

The effect of SRI significantly ($p < 0.004$) enhanced the plant panicle number/m^2. Thus the SRI 2 (457/m^2), SRI 3 (372/m^2), SRI 4 (351/m^2) and SRI 1 (338/m^2) which were not significantly different among themselves produced the highest panicle numbers over the control - FP 1 (215/m^2) (Fig. 10).

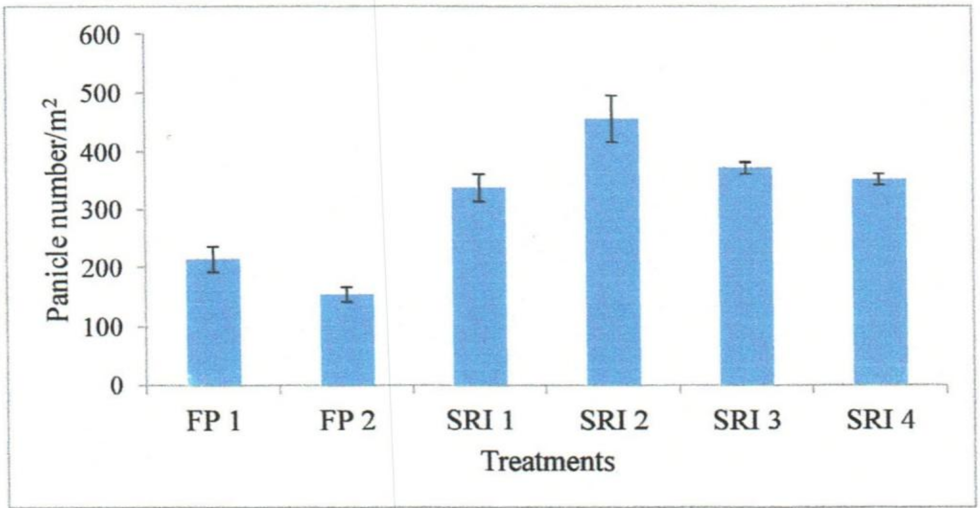

Figure 10. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on panicle number per m^2. Bars represent SEM.

4.10 Panicle weight

SRI with chemical fertilizers entries significantly ($p < 0.010$) enhanced the panicle weight of the plant. The SRI with the chemical fertilizer combination at all levels promoted the panicle weight / m^2 of the plant over the control (Fig. 11). SRI 2 produced the greatest weight (3.1 g) which did not differ statistically with SRI 3 (2.7 g) and SRI 4 (2.6 g) but differed significantly with the FP 1 – control (1.3 g) (Fig. 11).

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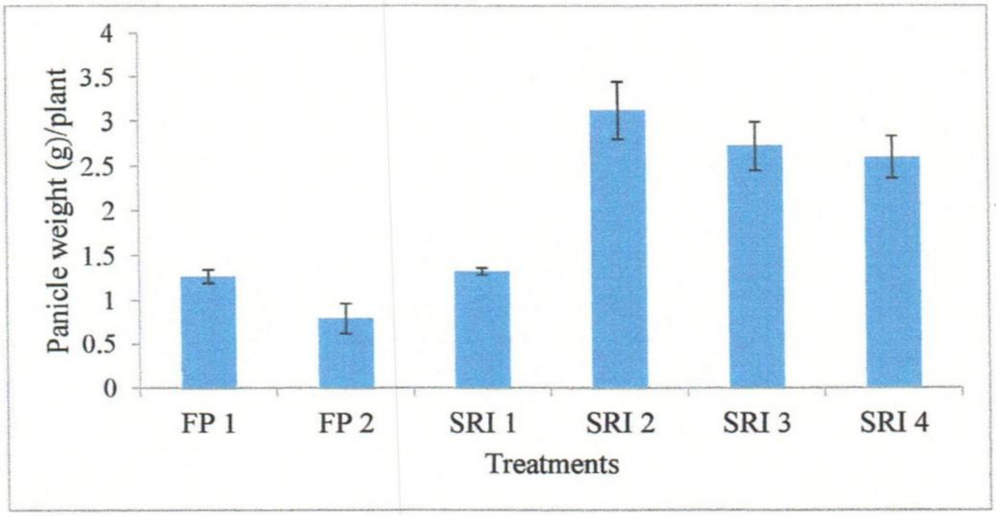

Figure 11. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on panicle weight (g). Bars represent SEM

4.11 Panicle length

SRI significantly ($p < 0.001$) enhanced the panicle length of the plant. All the SRIs promoted the panicle length of the rice plant over the control (Fig. 12). Highest panicle length (26 cm) recorded in SRI 2 was statistically similar to SRI 4 (24 cm), SRI 3 (24 cm) and SRI 1 over the control – FP 1 (19 cm) (Fig. 12).

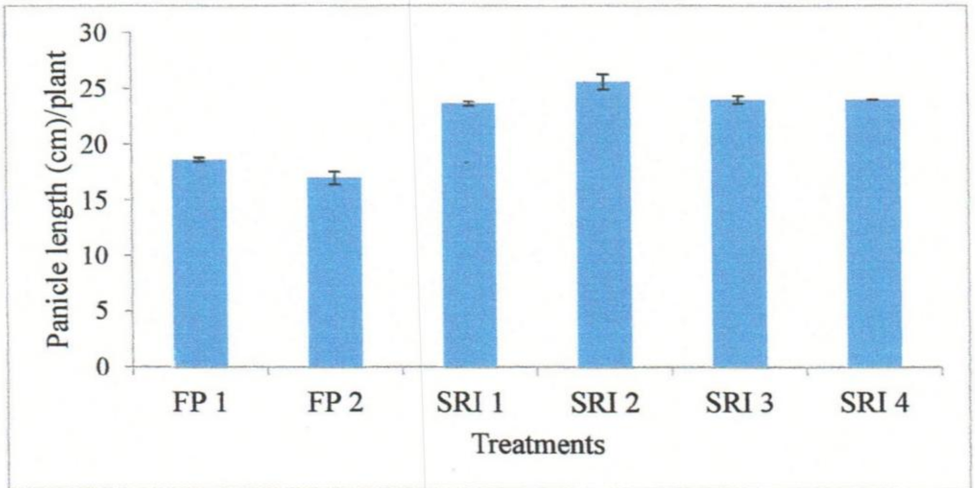

Figure 12. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on panicle length (cm). Bars represent SEM.

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4.12 Number of grains per panicle

SRI significantly ($p < 0.001$) enhanced the number of grains per panicle of the plant. Rice plant under SRI produced significantly higher number of grains per panicle than that of the control (Fig. 13). The highest number of grains per panicle (136) was recorded in SRI 3 which was statistically at par with SRI 4 (135), SRI 2 (128) and SRI 1 (112) over the FP 1 - control (68).

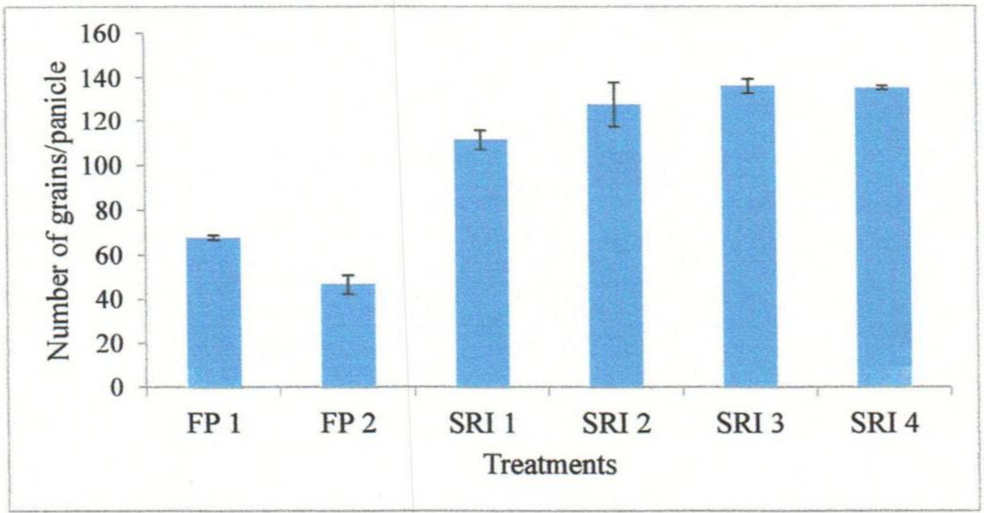

Figure 13. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on number of grains per panicle. Bars represent SEM.

4.13 Number of unfilled grains per panicle

SRI entries performed poorly as they recorded the higher number of unfilled grains per panicle of the plant (Fig. 14). SRI 4 recorded the highest (28.7) unfilled grains per panicle which did not differ statistically with SRI 3 (24) and SRI 1 (21.7) but however differed significantly over the control – FP 1 (13.3).

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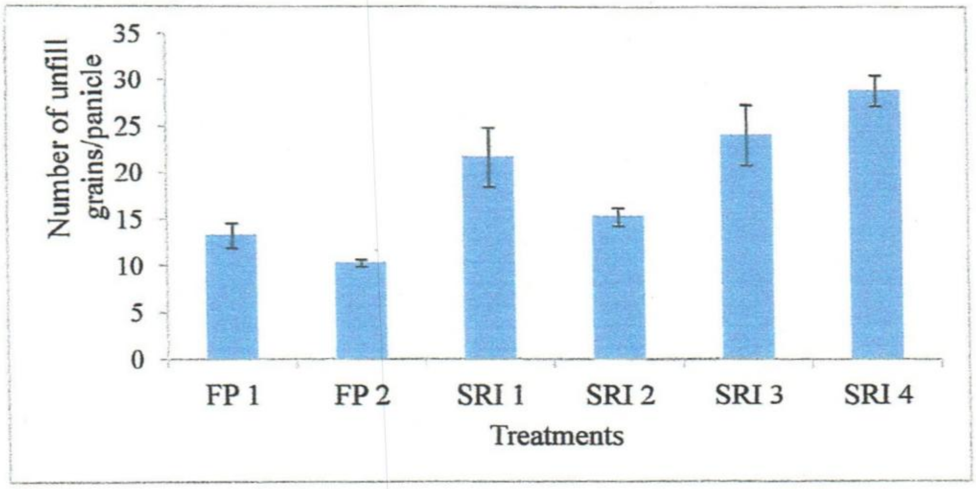

Figure 14. **Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on number of unfilled grains per panicle. Bars represent SEM.**

4.14 Thousand grain weight

SRI did not significantly ($p < 0.23$) enhance thousand grain weight. From the means comparison, it was realised that the statistical difference between the highest value recorded in SRI 4 (22.00 g) and the lowest value recorded in FP 2 (18.67 g) were not significant (Table 7).

Table 6. **Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on Thousand grain weight**

Treatments	Thousand grain weight (g)
FP 1- (control)	21.33
FP 2	18.67
SRI 1	18.67
SRI 2	21.33
SRI 3	19.33
SRI 4	22.00
Standard errors of difference of means (S.e.d)	1.65
Least significant difference of means (5 % level)	3.68

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4.15 Grain yield

Grain yield was significantly ($p < 0.006$) enhanced by the treatments. SRI 2 maximised grain yield (4026 kg/ha) but similar results were observed with SRI 3 (3866 kg/ha) and SRI 4 (3737 kg/ha) treatments (Fig. 15). SRI 1 performed similar to the control – FP 1 (2410 kg/ha) while FP 2 performed poorly.

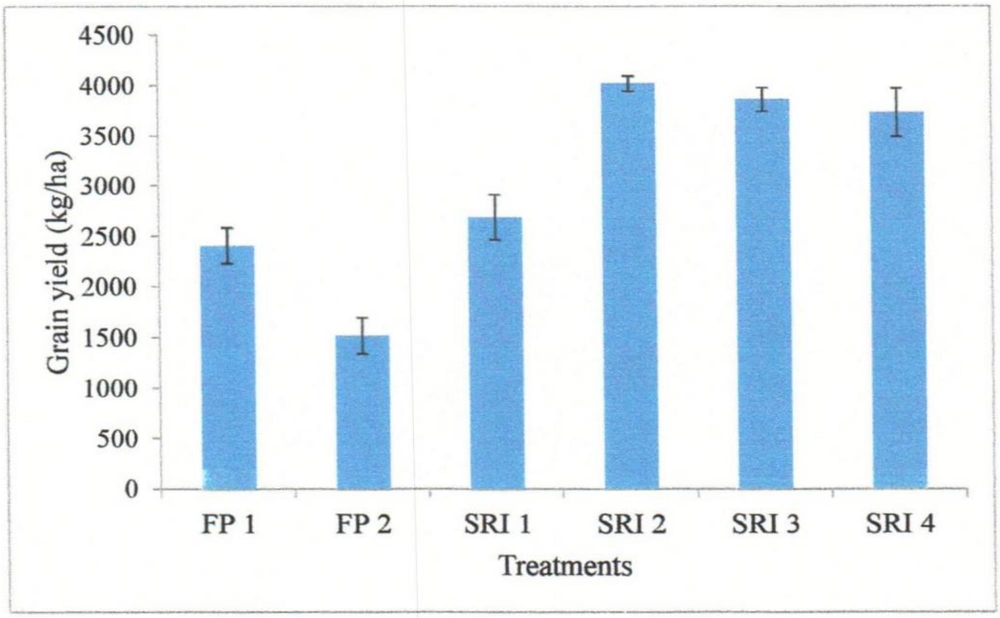

Figure 15. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on rice grain yield kg/ha. Bars represent SEM.

4.16 Harvest index

SRI did not significantly ($p < 0.481$) influence harvest index. The highest and the lowest harvest indexes were recorded in SRI 4 (0.45) and SRI 2 (0.32) which did not differ significantly among each other (Table 7).

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Table 7. Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on harvest index of rice plant.

Treatments	Harvest index (HI)
FP 1- (control)	0.37
FP 2	0.32
SRI 1	0.43
SRI 2	0.32
SRI 3	0.41
SRI 4	0.45
Standard errors of difference of means (S.e.d)	0.08
Least significant difference of means (5 % level)	0.18

4.17 Panicle harvest index

SRI significantly ($p < 0.039$) influenced panicle harvest index of the plant. From the treatment means comparison, the highly performing panicles were noticed in the SRI (Fig. 16). The lowest performing panicle (0.87) was observed in the control (FP 1) which was statistically similar to the FP 2 (0.85). Both treatments differed significantly from the highest performing panicle in SRI 4 (0.92) which did not differ significantly with SRI 2 (0.92), SRI 3 (0.90) and SRI 1 (0.89).

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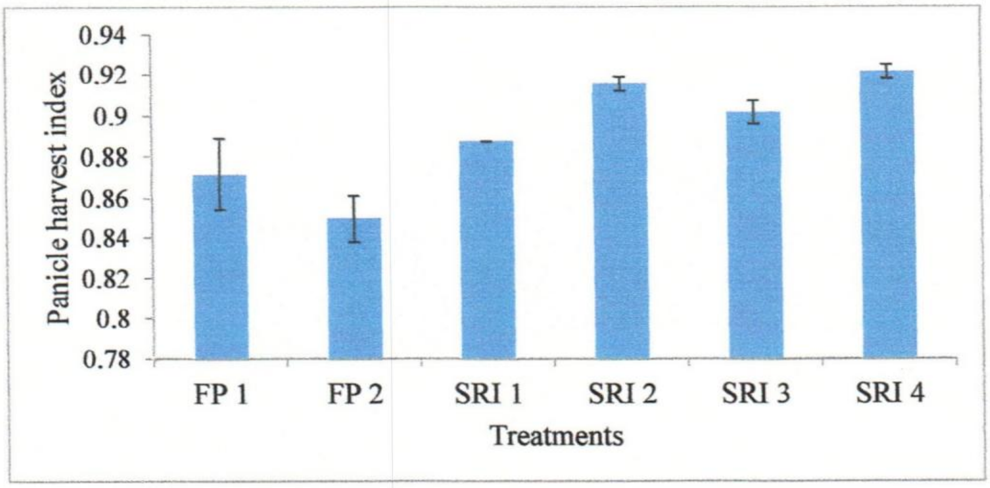

Figure 16. **Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on panicle harvest index of rice plant. Bars represent SEM.**

4.18 Sterility percent

SRI did not significantly ($p < 0.353$) affect the sterility of the grains of the treatments. The lowest sterility (15.00) recorded in SRI 3 did not differ significantly from the highest sterility (18.33) recorded in FP 2 (Table 8).

Table 8. **Effects of System of Rice Intensification (SRI) and Farmer Practice (FP) on sterility percent of rice plant.**

Treatments	Percent sterility
FP 1- (control)	16.00
FP 2	18.33
SRI 1	15.67
SRI 2	10.67
SRI 3	15.00
SRI 4	17.67
Standard errors of difference of means (S.e.d)	3.41
Least significant difference of means (5% level)	7.60

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4.19 Correlation and regression analysis

The linear regressions of grain yield over panicle length and productive tiller count are represented in Fig. 17 and 18 respectively.

Grain yield of rice positively correlated with panicle length (r=0.692) and productive tiller count (r=0.507).

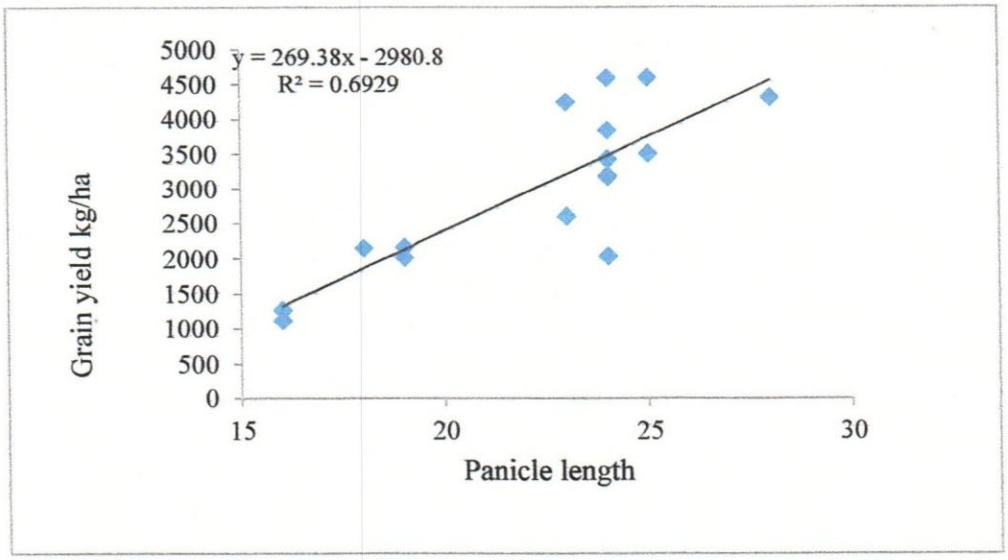

Figure 17. Linear relationships between grain yield and panicle length

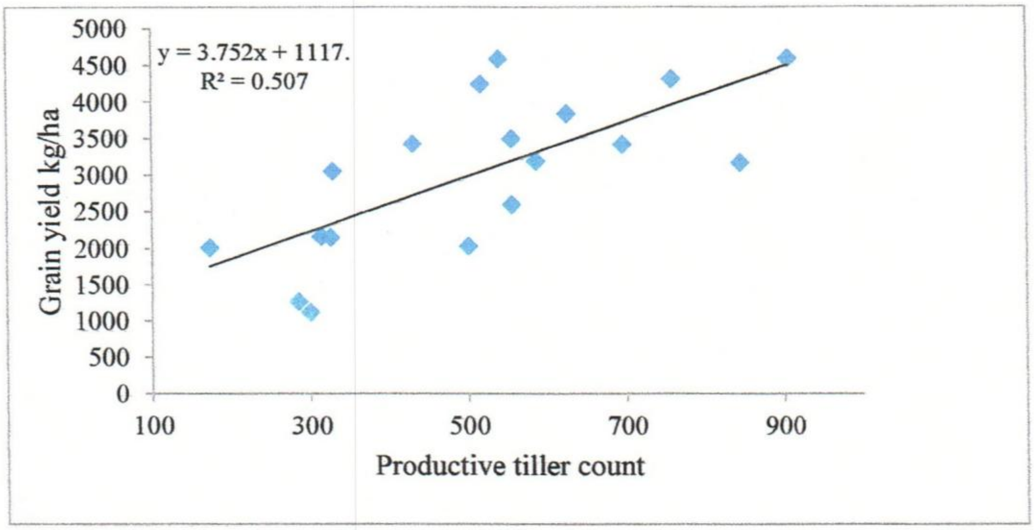

Figure 18. Linear relationship of grain yield and productive tiller count

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4.20 Benefit – cost analysis

The benefit - cost analysis of the SRI and farmer practice entries are presented in Table 9.

Table 9. Benefit - cost analysis of System of Rice Intensification (SRI) and Farmer Practice (FP)

Treatment	Service Charge (GHc)	Input Cost (GHc)	Labour Cost (GHc)	Total Cost TC(GHc)	Total Revenue TR(GHc)	B/C Analysis (TR/TC)
FP 1	567.26	762.94	1605	2935.20	3446.3	1.17
FP 2	551.13	1563.11	1582.58	3696.82	2175.03	0.59
SRI	567.26	1301.32	1822.10	3690.68	3846.7	1.04
SRI 2	583.39	501.16	1844.52	2929.07	5757.18	1.97
SRI 3	583.39	1679.71	1959.12	4222.21	5528.38	1.31
SRI 4	583.39	1413.10	1959.11	3955.60	5343.91	1.35

According to Adegeye and Ditto (1985), when Benefit – Cost analysis (B/C) is less than one (that is B/C < 1) the business enterprise is running at loss. When B/C is equal to one (that is. B/C = 1) the business enterprise is running at break even and when B/C is greater than one (B/C > 1) the business enterprise is running at profit. The higher the B/C values from one, the higher the profit margin. Therefore Table 9 revealed that FP 2 (0.59) produced loss whilst SRI 2 (1.97) was the most profiting venture. SRI 1 enterprise nearly produced (1.04) a break even, whilst SRI 4 (1.35) and SRI 3 (1.31) produced more profits than the control FP 1 (1.17).

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CHAPTER FIVE

5.0 DISCUSSION

5.1 Plant emergence and establishment percent

The SRI significantly ($p < 0.001$) enhanced both plant seed emergence and seedling establishment. The SRI nursery recorded the highest (86 %) seed emergence percent over the control (82 %) (Fig.2). This could have arisen partly from the inability of seeds to have proper contact with the soil to facilitate water uptake, and partly probably due to seed loses due pests, diseases and environmental factors. This is in line with Larry *et al.* (2012) findings.

The high establishment of seedlings in the SRI entries (Fig. 3) might be due to careful handling of seedlings as well as transplanting of very young seedlings which prevented desiccation and trauma of the roots. This led to little or no interruption of plant growth and no 'transplant shock'. The findings of Muhammad and Abdullah (2013) confirms this assertion.

In contrast, broadcast fields have been reported by Chen *et al.* (2013) to have an advantage in rapid seedling establishment and root vigor at the early stage than transplanted rice. The number of seedlings established influenced the number of tillers produced per area. Chen *et al.* (2013) finding confirms this.

5.2 Plant height

It was noticed that the SRI and/or the fertilizer application at all levels had greater impact in increased plant height (Fig 4). Increased plant height in the SRI was probably due to the wider spacing which promoted better roots and canopy spread. The findings of Latham (2012) confirms this. The continuous

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weeding or earthen up associated with SRI could have also contributed to the increased plant height. This is similar to the findings of Muhammad and Abdullah (2013) who reported that fields with continuous weeding with the weeder / hoe produced higher plant height as compared with fields whose weeds were hand pulled or applied with herbicides.

Also, increased plant height in chemical fertilizer applied treatments was probably due to the increased availability of nitrogen from chemical fertilizer sources which enhanced vegetative growth.

5.3 Tiller count

The high tillering response of plants to chemical fertilizer at all levels than the compost at 6 WAP (Fig. 5) was probably due to increased nutrient availability, especially nitrogen from the chemical fertilizers. The adequate nutrient availability enhanced the translocation of more photosynthates from source to sink and cell division which led to large sink size of the rice plant. This eventually translated into improved tiller number per plant. The findings of Ramamoorthy *et al*. (2001) confirms this.

It was noticed that the SRI enhanced tillering of the plant at 9 WAP (Fig 5). The early transplanting in the SRI probably preserved the plants' vigour and growth potential for tillering and root development. This observation is similar to Stoop *et al*. (2002) findings. The higher tiller count in the SRI which is associated with seedling transplanted methods could have been due to optimal plant spacing. This agrees with IRRI (2008) that transplanting enables optimal spacing, and good spacing can increase tillers over poor spacing and/or other planting methods.

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Also, the higher tillering rate in the SRI was probably due to the greater net photosynthetic rate of the fully expanded leaves at mid-tillering stage as well as greater carbon fixation in SRI plants at the tillering stage. This is in agreement with Larry *et al.* (2012) that seedling transplanted produce higher tillering, due to plant spacing in seedling transplanting, resulting in limited competition as compared with seed broadcasting method.

The SRI significantly influenced the number of productive tillers produced per plant (Fig 5). The improved percentage of productive tillers in the SRI could have been facilitated by the conducive conditions created and efficient use of resources of the plant such as nutrients, solar radiation and water in the vegetative stage of plant. Chen *et al.* (2013) and Muhammad and Abdullah (2013) findings support this. Organic sources might have also offered enhanced nutrition to the plants, especially micro nutrients which led to higher number of tillers in plants (Miller, 2007).

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5.4 Leaf chlorophyll content

Chlorophyll content was significantly enhanced ($p < 0.001$) by the SRI at the 9 and 15 WAP. The SRI enhanced the chlorophyll content of the flag leaf of the plant at 15 WAP (Fig. 6). This was probably due to the optimally wide spacing (25 cm × 25 cm) and single plant per hill in the SRI which did not only expose the leaves of the plant for optimum interception of sunlight but also ensured greater photosynthesis. This is similar to the findings of Thiyagarajan and Gujja (2013). Also, the intermittent irrigation in SRI probably created a condition in the soil which permitted aerobic soil organisms to survive and contributed meaningful in fixing and the releasing of nutrients to the rice plant. Enhanced nutrition especially nitrogen in plant led to enhanced chlorophyll

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content of the plant. The hoe/weeder used earthen up the soil which probably facilitated the production of new roots which help in additional nutrient uptake. This could imply the reason why the net photosynthetic rate was greater in SRI plants than in FP plants (Fig. 6).

5.5 Days to 50 % flowering of the plant

The effect of the various soil amendments in the SRI significantly ($p < 0.001$) enhanced the days to 50 % flowering. Seeds were broadcast under farmers' practice (FP) entries. Therefore the early flowering and shorter maturity days recorded in FP entries (Fig. 7) was probably due to higher intra competition for nutrients, space and light which triggered quicker reproductive phase in the plant. This agrees with the IRRI (2008) study which reports that depending on a cultivar, direct seeded rice matured seven to ten days earlier than transplanted rice due high intra competition among the plants.

The delay in flowering in the SRI plants was probably due to longer and higher accessibility of nitrogen by the SRI plants. This confirms the finding of WARDA (2004) that higher levels of nitrogen in rice plant prolonged vegetative growth phase of the plant which in turn increased days to flowering.

5.6 Dry biomass and straw of the plant

The chemical fertilizer application at all levels in the SRI significantly ($p < 0.001$) influenced the dry biomass of the plant. The SRI practice of careful and single seedlings establishment coupled with wider spacing probably facilitated both roots and canopy spread which resulted in higher dry biomass (Fig. 8).

Also, the practice of not continuously flooding the rice field in the SRI might have promoted the profuse growth of the plant biomass. This is in agreement

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with Latham (2012) findings that profuse shoot growth of the plant is facilitated by intermittent irrigation which provides good environment for proper growth and functioning of the plant root. Beneficial soil organisms also function well under intermittent irrigation.

Furthermore, the chemical fertilizer(s) entries in the SRI probably enriched the soil with mostly N which promoted increase shoot growth. The P release in the soil might have also boosted straw and stem growth.

The chemical fertilizer application at all levels in SRI significantly ($p < 0.010$) influenced the straw production of the plant (Fig. 9). The SRI practices might have created a condition which avoided the suffocation and degeneration of rice plant roots (Kar *et al.*, 1974). This condition in turn supported more abundant and diverse populations of aerobic soil organisms that provided multiple benefits to the plants. Thiyagarajan and Gujja (2013) findings support this.

Besides, active soil aeration created by non-flooding field was conducive to passive soil aeration, which led to biological processes that improved soil structure and functioning. Muhammad and Abdullah (2013) finding supports this.

5.7 Panicle of the plant

SRI significantly influenced the proper growth and development of the panicle (Fig. 10). This is probably due to photo assimilate accumulation and remobilized dry matter to the main shoots. This is in line with Chen *et al.* (2013) findings.

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High panicle number/m^2 obtained in the SRI plots (Fig. 10) was probably due to profuse tiller development of the rice in the SRI plots. The finding of Larry *et al*. (2012) confirms this. Also, SRI might have promoted an increase in panicle bearing primary tillers per unit area as reported by Muhammad and Abdullah (2013).

The increased panicle weight/m^2 of the SRI entries over the control (Fig. 11) was probably because SRI rice plants had an advantage in individual tillers over the control due to nutrient availability and usage. This is in agreement with Chen *et al.* (2013) findings.

Heavy panicles might be the key to the high yield performance in SRI as indicated in Fig. 11. SRI might have played an important role in single panicle development from the strong individual tiller associated with the SRI. Chen *et al.* (2013) finding confirms this.

Increased panicle length in plants in the SRI entries (Fig. 12) was probably due to more availability of macro-nutrients as well as micro-nutrients for the SRI plants. Muhammad and Abdullah (2013) findings support this.

Also the increased panicle length was due to the high response of the SRI plant to the sole or combined organic or/and inorganic fertilizers which promoted the availability of macro-nutrients as well as micro-nutrients. Therefore, from the treatment means comparison, the highly performing panicles were recorded in the SRI (Fig. 16)

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5.8 Grains per panicle

The response of the SRI to the number of grains per panicle was significantly higher than that of the control (Fig. 13). Effective land preparation and practices under SRI probably resulted to positive and significant response of the rice plant to the fertilizer additions which led to increased number of grains per panicle (Fig. 13). This is in line with the findings of Buri *et al.* (2004) that there was a net accumulation and retention of total carbon, and the exchangeable cations (K, Ca, Mg) under effective land preparation and practices of rice cultivation. This explains why effective and healthy panicles (higher PHIs) were realised from rice plants under the SRI (Fig.16).

Besides, more number of grains per panicle in SRI treatments might be due to enhanced consumption of phosphorus, as being a part of DNA, phosphorus played an imperative role in building genetic parts of the plant. Muhammad and Abdullah (2013) findings confirms that more number of panicles per hill might be due to more availability of macro-nutrients as well as micro-plant nutrients with the addition of organic matter in to soil.

SRI ($p < 0.043$) negatively influenced the number of unfilled grains per panicle of the plant. Less number of unfilled grains recorded in the FP (Fig. 14) was probably due to the less number of grains per panicle recorded in the FP.

5.9 Thousand grain weight

SRI did not significantly ($p < 0.233$) enhance thousand grain weight. This is contrary to the findings of Chen *et al.* (2013) who recorded significant increase in 1,000 grain weight in the SRI treatment which received both compost and recommended dose of mineral fertilizer than the treatment that received solely

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the compost or mineral fertilizer. Therefore the weight of individual grains in all treatments probably had uniform grain development (Table 6).

5.10 Grain yield

The outstanding grain yield obtained from the three treatments, SRI 2, SRI 3 and SRI 4 (Fig. 15) could be due to the adequate nutrients made to the test crop (rice). The improved conditions probably promoted better soil microbial activity, nutrient availability, soil aeration, redox potential, root growth, root activity and consequently grain yield. The plants utilised these conditions to their maximum genetic potentials which led to higher crop establishment, more vigorous crop growth and development as well as increased resistance to insect pests and diseases.

The conducive conditions facilitated by the SRI treatments included the wide spacing which ensured greater photosynthesis. In addition, alternate dry and wet irrigation promoted better root growth and functioning as well the existence and activities of anaerobic microorganisms. Also, early transplanting (less than 14 days old) of seedlings prevented transplanting shock.

These conditions eventually translated into 100 % or more increased yields in the SRI as compared with the farmer practice. This is similar to the report by IRRI (2003) that a combination of higher crop emergence, vigorous early crop growth and increased crop resistance to insect pests and diseases will result to a 5-20 % increase in yield.

The compost provided the micro-nutrients and increased the cation exchange capacity of soil. This probably improved nutrients availability. The compost

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combined with inorganic fertilizers might have also enhanced the growth and yield of the test crop. Muhammad and Abdullah (2013) findings confirms this. The supply of required nutrients from either the sole chemical fertilizer sources or in combination with the compost boosted proper nutrition of the crop which resulted in enhanced grain yield (Jeyabal *et al.,* 1999). The application of compost with inorganic nitrogen fertilizer sources combinations ensured longer supply of nutrients especially N which might have delayed senescence in the plants resulting to more photosynthesis during the seed filling stage (Kadyal *et al.,* 2002). Good photosynthesis at seed filling stage enhanced the yield parameters (Figs. 17 and 18) which translated into higher yields in the plants under the SRI. This is similar to the findings of Fageria and Baligar (2005) that grain yield in rice is a function of the yield components.

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Higher yield and harvest index in that of compost plus chemical fertilizer probably indicates better partitioning of photosynthetic substance to economic yield. Appreciably high harvest index shows the efficiency of converting biological yield into economic yield. However, the low yield recorded in SRI 1 was probably due to too long days the plants took to flower.

5.11 Benefit – cost analysis

Table 9 revealed that FP 2 (0.59) produced loss whilst SRI 2 (1.97) was the most profiting venture. SRI 1 almost produced (1.04) a break even, as SRI 4 (1.35) and SRI 3 (1.31) produced more profits than the control FP 1 (1.17). The above assertions were as a result of the chemical fertilizers used were more efficient and economical than the 13 t/ha compost used. Henceforth the plots that received more of the chemical fertilizers had higher Benefits – Cost Analysis values.

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CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The field experiment was conducted in the dry season of 2014 from January to June in the Golinga Irrigation farm (Latitude 09°21'N and Longitude 0°56' W). This was to evaluate the System of Rice Intensification (SRI) for enhanced grain yield, yield components and economic viability of Gbewaa rice (Jasmine 85) variety production under irrigated conditions. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

The results of the study revealed that SRI plant responded better to the soil amendment and was superior to farmer practice in all parameters measured. This was probably due to SRI enhanced nutrients accessibility and utilization by the plant. The experiment also showed that the SRI 2 [that is SRI practices including basal application of 37.5 kg/ha each of N, P_2O_5 and K_2O (15-15-15) + top dressing of 26.25 kg/ha N (sulphate of ammonia)] enhanced grain yield and almost all other parameters above all other treatments. The SRI 3 [SRI practices including the application of 13 t/ha compost + basal HRR (18.75 kg/ha) each of N, P_2O_5 and K_2O (15-15-15)] and SRI 4 [SRI practices including the application of 13 t/ha compost + top dressing of HRR (13.13 kg/ha) of N (sulphate of ammonia)] also enhanced all parameters including grain yield after SRI 2. Similarly, the benefit – cost analysis results showed that SRI 2 was the most economically viable entry, followed by SRI 4 and then SRI 3. From the soil analysis FP 2 produced the highest accumulation of soil organic matter (Table 5). This entry can help improve upon the soil organic

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matter content in the soil for sustainable soil fertility management and crop productivity in subsequent years.

6.2 Recommendations

1. Statistically SRI 2, SRI 3 and SRI 4 can be recommended to farmers based on grain yield performance.
2. With regards to Benefit – Cost Analysis, SRI 2 was more profitable followed by SRI 4 and then SRI 3. Therefore, SRI 2 can be recommended to farmers.
3. However, SRI 3 and SRI 4 had organic matter (compost) which could enhance general soil fertility and improve on Integrated Soil Fertility Management (ISFM) in Guinea Savannah Zone. Therefore, SRI 3 and SRI 4 could be recommended to farmers to enhance sustainable soil fertility management and crop productivity.
4. FP 2 produced the highest accumulation of soil organic matter and could be recommended if the sole aim is to improve upon the soil organic matter content. This could improve yield in subsequent cropping seasons.

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APPENDICES

Appendix 1. Analysis of variance for emergence percentage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	0.7778	0.3889	0.85		0.3
Treatment	5	94.9444	18.9889	41.68	<.001**	0.8
Residual	10	4.5556	0.4556			
Total	17	100.2778				

**Significant at $p < 0.001$

Appendix 2. Analysis of variance for establishment percentage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	37.444	18.722	4.69		2.0
Treatment	5	741.611	148.322	37.18	<.001	2.2
Residual	10	39.889	3.989			
Total	17	818.944				

**Significant at $p < 0.001$

Appendix 3. Analysis of variance for plant height 3 weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	10.333	5.167	1.17		3.8
Treatment	5	53.833	10.767	2.43	0.109NS	8.7
Residual	10	44.333	4.433			
Total	17	108.500				

NS= Not significant

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Appendix 4. **Analysis of variance for plant height 6 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	14.78	7.39	0.34		3.2
Treatment	5	389.61	77.92	3.61	0.040*	13.4
Residual	10	215.89	21.59			
Total	17	620.28				

*Significant at $p < 0.040$

Appendix 5. **Analysis of variance for plant height 9 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	30.11	15.06	1.11		3.3
Treatment	5	424.94	84.99	6.29	0.007*	7.8
Residual	10	135.22	13.52			
Total	17	590.28				

*Significant at $p < 0.007$

Appendix 6. **Analysis of variance for plant height 12 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	102.78	51.39	1.38		3.6
Treatment	5	1394.94	278.99	7.49	0.004*	7.5
Residual	10	372.56	37.26			
Total	17	1870.28				

*Significant at $p= 0.004$

Appendix 7. **Analysis of variance for tiller count 6 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	2622	1311	0.26		5.4
Treatment	5	94716	18943	3.82	0.034*	25.5
Residual	10	49608	4961			
Total	17	146946				

*Significant at $p < 0.034$

Appendix 8. **Analysis of variance for tiller count 9 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	8090	4045	0.84		3.8
Treatment	5	890008	178002	36.80	<. 001**	11.2
Residual	10	48370	4837			
Total	17	946468				

**Significant at $p < 0.001$

Appendix 9. **Analysis of variance for tiller count 12 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	7285	3642	0.72		5.1
Treatment	5	949870	189974	37.32	< .001**	14.9
Residual	10	50905	5091			
Total	17	1008060				

**Significant at $p < 0.001$

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Appendix 10. **Analysis of variance for chlorophyll 9 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	8.334	4.167	0.62		2.2
Treatment	5	663.125	132.625	19.62	<. 001**	9.0
Residual	10	67.583	6.758			
Total	17	739.042				

**Significant at $p < 0.001$

Appendix 11. **Analysis of variance for chlorophyll 12 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	26.590	13.295	2.97		4.1
Treatment	5	446.624	89.325	19.93	<. 001**	5.8
Residual	10	44.821	4.482			
Total	17	518.036				

**Significant at $p < 0.001$

Appendix 12. **Analysis of variance for chlorophyll 15 weeks after planting**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	8.082	4.041	0.78		2.9
Treatment	5	269.638	53.928	10.39	<. 001**	8.2
Residual	10	51.911	5.191			
Total	17	329.631				

**Significant at $p < 0.001$

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Appendix 13. Analysis of variance for 50 % flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	1.778	0.889	0.51		0.4
Treatment	5	401.778	80.356	45.77	<.001**	1.4
Residual	10	17.556	1.756			
Total	17	421.111				

**Significant at $p < 0.001$

Appendix 14. Analysis of variance for fresh biomass/m^2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	0.2878	0.1439	0.59		5.9
Treatment	5	3.9294	0.7859	3.20	0.056NS	18.9
Residual	10	2.4589	0.2459			
Total	17	6.6761				

NS= Not significant

Appendix 15. Analysis of variance for dry biomass/m^2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	0.03651	0.01825	1.00		7.0
Treatment	5	1.19632	0.23926	13.08	<.001**	17.2
Residual	10	0.18299	0.01830			
Total	17	1.41581				

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Appendix 16. Analysis of variance for straw weight kg/m^2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	0.04000	0.02000	0.97		11.9
Treatment	5	0.57833	0.11567	5.60	< 0.010*	29.7
Residual	10	0.20667	0.02067			
Total	17	0.82500				

*Significant at $p < 0.010$

Appendix 17. Analysis of variance for panicle number/m^2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	3027	1514	0.30		5.0
Treatment	5	183458	36692	7.16	< 0.004*	22.8
Residual	10	51267	5127			
Total	17	237752				

*Significant at $p < 0.004$

Appendix 18. Analysis of variance for panicle weight/plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	10.031	0.0156	0.03		2.3
Treatment	5	13.8044	2.7609	5.57	< 0.010	6.1
Residual	10	4.9556	0.4956			
Total	17	18.7911				

*Significant at $p < 0.010$

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Appendix 19. **Analysis of variance for panicle length/plant**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	1.000	0.500	0.29		1.3
Treatment	5	180.500	36.100	21.24	<. 001**	5.9
Residual	10	17.000	1.700			
Total	17	198.500				

**Significant at $p < 0.001$

Appendix 20. **Analysis of variance for number of grain per panicle**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	433.8	216.9	0.92		5.8
Treatment	5	21686.3	4337.3	18.41	<. 001**	14.7
Residual	10	2355.6	235.6			
Total	17	24475.6				

**Significant at $p < 0.001$

Appendix 21. **Analysis of variance for number of unfilled grain per panicle**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	63.44	31.72	0.76		12.2
Treatment	5	738.44	147.69	3.52	< 0.043*	34.3
Residual	10	419.89	41.99			
Total	17	1221.78				

*Significant at $p < 0.043$

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Appendix 22. Analysis of variance for thousand grain weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	12.444	6.222	1.52		5.0
Treatment	5	33.778	6.756	1.65	0.233NS	10.0
Residual	10	40.889	4.089			
Total	17	87.111				

NS= Not significant

Appendix 23. Analysis of variance for grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	197190	98595	0.22		4.2
Treatment	5	14898846	2979769	6.51	$< 0.006^{*}$	22.3
Residual	10	4580353	458035			
Total	17	19676388				

*Significant at $p < 0.006$

Appendix 24. Analysis of variance for grain moisture content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	0.0178	0.0089	0.01		0.3
Treatment	5	3.3178	0.6636	0.97	0.481NS	7.1
Residual	10	6.8489	0.6849			
Total	17	10.1844				

NS= Not significant

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Appendix 25. Analysis of variance for HI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	0.012959	0.006480	0.66		8.6
Treatment	5	0.046446	0.009289	0.95	0.492NS	25.8
Residual	10	0.098097	0.009810			
Total	17	0.157502				

NS= Not significant

Appendix 26. Analysis of variance for grain PHI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	0.0005139	0.0002570	0.42		0.7
Treatment	5	0.0111312	0.0022262	3.64	$< 0.039^*$	2.6
Residual	10	0.0061095	0.0006109			
Total	17	0.0177546				

*Significant at $p < 0.039$

Appendix 27. Analysis of variance for grain sterility %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	10.11	5.06	0.29		5.9
Treatment	5	109.78	21.96	1.26	0.353NS	26.9
Residual	10	174.56	17.46			
Total	17	294.44				

NS= Not significant

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Appendix 28. **Analysis of variance for grain number of spikelets/panicle**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	c.v.
Rep.	2	0.778	0.39	0.35		2.7
Treatment	5	43.611	8.722	7.77	< 0.003*	11.4
Residual	10	11.222	1.122			
Total	17	55.611				

*Significant at p < 0.003

Appendix 29. **Correlation coefficient (r) among yield components and grain yield.**

Parameters	PBW	NGPP	PL	PW	PTN	TSW	GY
PBW	-						
NGPP	0.5850	-					
PL	0.4132	0.8277	-				
PW	0.7045	0.7949	0.7510	-			
PTN	0.5654	0.6950	0.8141	0.6384	-		
TSW	0.5827	0.4106	0.4742	0.4645	0.552	-	
GY	0.5827	0.4106	0.4742	0.4645	0.5526	0.4062	-

PBW= Plant biomass weight, NGPP=Number of grain per panicle, PL= Panicle length, PW=Panicle weight, PTN=Productive tiller number, TSW=Thousand seed weight, GY=Grain yield.

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Appendix 30. Benefit/Cost analysis

Treatment	Service charge (GHc)	Input cost (GHc)	Labour cost (GHc)	Total Cost (TC) (GHc)	Total Revenue (TR) (GHc)	B/C analysis (B/C) = TR/TC
FP 1	567.26	762.94	1605	2935.20	3446.30	1.17
FP 2	551.13	1563.11	1582.58	3696.82	2175.03	0.59
SRI 1	567.26	1301.32	1822.10	3690.68	3846.7	1.04
SRI 2	583.39	501.16	1844.52	2929.07	5757.18	1.97
SRI 3	583.39	1679.71	1959.12	4222.21	5528.38	1.31
SRI 4	583.39	1413.10	1959.11	3955.60	5343.91	1.35

Appendix 31. Field layout

R1		R2		R3
SRI 1		FP 1		FP 2
FP 2		SRI 4		SRI 3
SRI 3		SRI 2		SRI 4
FP 1		SRI 1		SRI 2
SRI 2		FP 2		SRI 1
SRI 4		SRI 3		FP 1

Notes:

- SRI 1 = SRI principles + 13 t/ha compost
- SRI 2= SRI principles + recommended rates of chemical fertilizer application that is 37.5 kg/ha each of N, P_2O_5 and K_2O (15-15-15) and sulphate of ammonia (26.25 kg/ha N) as basal application and top dressing respectively,

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- SRI 3 = SRI principles + 13 t/ha compost + half recommended rate of 18.75 kg/ha of N, P_2O_5 and K_2O as basal application and
- SRI 4 = SRI principles + 13 t/ha compost + Half recommended rate of sulphate of ammonia (13.13 kg/ha N) as top dressing.
- FP 1 = farmer practice principles + recommended rates that is 37.5 kg/ha each of N, P_2O_5 and K_2O and sulphate of ammonia (26.25 kg/ha N) as basal application and top dressing respectively and
- FP 2 = farmers' practice principles + 13 t/ha compost

SRI principles = nursing seedlings, transplanting seedlings early (14 days old), singly (one seedling/hill) and widely (25 cm × 25 cm), irrigating the plots intermittently and earthen up the soil regularly by hoe/weeder.

Farmer practices principles = seeds directly broadcast on the plots and continuous flooding of the plots.

R1 = Replicate or block 1

R2 = Replicate or block 2

R3 = Replicate or block 3

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Appendix 32. **Questionaire for benefit - cost analysis of rice production under SRI for enhanced rice production in the Guinea Savannah Zone of Ghana.**

OBJECTIVE

1. To determine the cost and revenue involved in rice production under SRI in the Guinea Savannah zone, Ghana.

A. GENERAL INFORMATION

1. Name of farmer...
2. Date & Name of community ....
3. Religion 1. Christianity [ ] 2. Islam [ ] 3. Traditional [ ] 4. Others [ ]
4. Main occupation ....
5. Age 1. 15-20[ ] 2. 21-25[ ] 3. 26-30[ ] 4. 31-35[ ] 5. 35-40 [ ] 6. 40+[ ]
6. Sex 1. Male [ ] 2. Female[ ]
7. What is your educational background ? 1. Basic [ ] 2. Secondary [ ] 3. Tech/voc [ ] 4. Tertiary [ ]5. No education [ ] 6. Other (specify) ....
8. What is the size of your rice farm? 1. 1 acre [ ] 2. 1-3 acres [ ] 3. 4-5 acres [ ] 4. 5-8 acres [ ]

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B. COST OF PRODUCTION

9. Service charge or cost

Service	Quantity	Unit cost	Total cost
Land charge/rent			
Water dues			
Transportation charge			
Total			

10. Cost of inputs

Inputs/equipment	Quantity	Unit cost	Total cost
Seeds			
NPK			
Sulphate of ammonia			
Compost			
Jute sacks			
Total			

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11. Labour and other related services cost

Activity	Quantity	Unit cost	Total cost
Land clearing			
Ploughing			
Harrowing			
Spreading of compost			
Nursery operations			
Sowing/broadcasting of seeds			
Transplanting			
Irrigation/watering			
Compost application			
Chemical fertilizer application			
Weeding/earthening up			
Watching/guarding			
Bagging			
Transportation			
Storage			
Others(specify)			
Total			

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Transportation cost

12. How do you transport your produce to the market centres? 1. Head load [ ] 2. Vehicles [ ] 3. Bicycles [ ] 4. Tractor [ ] 5. Other specify ………………………….

13. How much did it cost you for transporting one bag of rice?…………………………….

Storage cost

14. Do you store your rice after harvest? Yes [ ] No [ ]

15. If yes how and at what cost per month ……………………………………

16. If no why not?………………………………………………………………

C. REVENUE

17. Where do you sell your rice after harvesting 1. Local market [ ] 2. Farm gate [ ] 3. Restaurant [ ]

18. Do you always get ready market? Yes [ ] No [ ]

19. How much did you sell a bag of rice at different times of harvest?

Period	Selling price (per 84 kg bag)
Early harvest	
Peak harvest	
Late harvest	
Off season	
Total	

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