KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF ENGINEERING

EFFECTS OF TILLAGE AND WEEDING FREQUENCY ON RICE PERFORMANCE AND SOIL PHYSICAL PROPERTIES

A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY IN AGRICULTURAL MACHINERY ENGINEERING

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Philosophy in Agricultural Machinery Engineering and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Tillage and weed control are two important inputs that affect rice (*Oryza sativa* L.) performance and soil properties. A field study was conducted under rainfed conditions at Nyankpala, located in the Guinea Savannah agro-ecological zone of Ghana to determine the effects of tillage and weeding frequency on the growth and yield of NERICA 4 rice, and soil physical properties. The experiment was set up as a split plot design with three tillage practices as main plots, and four weeding frequencies as sub-plots. Each treatment was replicated three times. The tillage practices comprised of disc ploughing only, disc ploughing followed by disc harrowing, and no tillage. The weeding frequencies consisted of weeding with a hand hoe three times, two times, and one time. The fourth weeding frequency treatment was no weeding. Apart from plant height and number of leaves per plant, the results indicated significant differences in the growth and yield of NERICA 4 rice between the different tillage practices. The disc ploughing followed by disc harrowing treatment produced the tallest plant, highest number of leaves per plant, highest number of tillers per plant, highest number of panicles, longest panicle, highest panicle weight and highest number of spikelet's per panicle. Similarly, the disc ploughing followed by disc harrowing treatment presented the highest dry matter yield, highest number of grains per panicle, highest 1000-grain weight, and highest grain yield. The no tillage treatment gave the lowest growth and yield performance. There was statistically significant difference in the growth and yield of NERICA 4 rice between the different weeding frequencies. In general, weeding thrice resulted in the best growth and yield of NERICA 4 rice. The no weeding treatment recorded the poorest performance of the crop. Overall, there was no significant difference in soil bulk density, moisture content, air content and total porosity between the different tillage practices. Similarly, in general, the results did not show significant difference in soil physical properties between the different weeding frequencies. Therefore, under the soil and weather conditions of the experiment, the best tillage practice and weeding frequency identified for NERICA 4 rice production is disc ploughing followed by disc harrowing, and weeding three times.

DEDICATION

I wish to dedicate this thesis to my dear father, Mr. Komrabai Bangura, and my mother, Mrs. Mariama Bangura.

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1. INTRODUCTION

1.1 Background to the study

Rice (*Oryza sativa* L.) is the second most important cereal crop in the world after wheat (Zhang *et al.,* 2014). In sub-Saharan Africa, rice is the most important cereal crop (Dibba *et al.,* 2012) while in Ghana, rice is ranked as the second most important cereal crop after maize (*Zea mays*, L.) (Addison *et al.,* 2014). In Ghana, rice, which is an important food and cash crop, is mostly produced by smallholder farmers. In 1961, the area under the production of rice in Ghana was 27,518 ha while in 2013, the area was 215,905 ha, an increase in area of about eight times that of 1961. Similarly, in 1961, the production of rice in Ghana was 30,400 tonnes while the production in 2013 was 569,524 tonnes, an increase in production of nearly nineteen times that of 1961 (FAOSTAT, 2015). Ghana has been importing rice using its scarce foreign exchange. Osei-Asare (2010) reported that annual rice imported into Ghana amounts to about US$500 million. Rice production in Ghana is constrained by several factors. Some of the factors include land tenure problems, removal of subsidy on inputs, absence of water control systems, erratic rainfall distribution, declining soil fertility, little or inadequate use of chemical fertilisers, poor insect pest control, poor weed control, and inappropriate tillage practices.

Tillage and weed control are two important inputs that affect crop performance and soil properties. Tillage may be described as the practice of modifying the state of the soil in order to provide conditions favourable for crop growth. Soil tillage is an important agricultural activity because of its impact on crop production, soil properties and environments (Boone and Veen, 1994 cited by Lal, 1997). Tillage is used for a variety of purposes, including the preparation of seedbeds, placing seeds, reducing soil compaction, incorporating crop residues and controlling weeds (Liu *et al.,* 2008). The task of tillage is to prepare soils for productive use or to place the soil in the best physical condition for the crop to grow. To be sure of normal plant growth, the soil must be in such condition that roots can have enough air, water and nutrients (Husnjack *et al.,* 2002).

There are two major tillage systems namely conventional tillage and conservation tillage (Srivastava *et al.,* 2006). The reference system for tillage is the conventional tillage system, which is based on a high intensity of soil engagement and inversion of the soil. Conventional tillage is used to prepare the seedbed (improving seed-soil contact), facilitating regular, unvarying early plant emergence (Josa *et al*., 2010). Conservation tillage is defined to be any tillage or sowing system which leaves at least 30% of the field covered with crop residue after sowing has been completed. In such soils, erosion is reduced by at least 50% as compared with bare, fallow soils (Karayel, 2009).

Successful weed control in rice is essential for the optimum production of the crop. Weeds compete for moisture, nutrients, space and light. Timely weed control is of essence in the production of rice. Delayed weed control may cause severe crop yield loss. If weeds are not controlled in crop field, yield losses could even exceed 90% (Ahmed *et al.,* 2014). However, the magnitude of weed-related losses depends on the type and density of a particular weed species, its time of emergence and the duration of interference (Hussain *et al.,* 2015, cited by Fahad *et al.,* 2015). Yield losses are most severe when resources are limited and weeds and crops emerge simultaneously which reduce the competitive advantage of the crop (Ahmed *et al.,* 2014). Crop yields decrease with increasing weed competition. A strong relationship exists between the duration of crop-weed competition and the competition pressure exerted on the crop, which reduces the yield (Fahad *et al.*, 2014). Timely weed management is thus crucial to ensure high crop performance.

1.2 Problem statement

The Northern Region of Ghana contributes significantly to the production of rice in Ghana. However, the yield of rice in the area is low, about 2.85 t ha^{-1} (MOFA/SRID, 2011). In the Northern Region of Ghana, some farmers disc plough before planting. Other farmers disc-harrow their land before planting. Some farmers disc plough and follow this operation with disc harrowing before planting. Some farmers use no tillage. Many farmers perform tillage operations without being aware of the effect of these operations on soil physical properties and crop responses (Ozpinar and Isik, 2004). Furthermore, the control of weeds in rice in the Northern Region of Ghana is one of the major constraints limiting rice production in the area, and different weeding practices are used.

1.3 Justification for the study

There are a variety of tillage systems available for crop production. While tillage operations are performed for various reasons, producers must evaluate the need for every field operation conducted in order to improve profitability (University of Nebraska Extension, 2014). The effects of tillage and weed management on crop growth, yield and soil physical properties are often mixed. Some authors have reported better crop performance under conventional tillage in comparison with that under no-tillage (Aikins and Afuakwa, 2012; Aikins *et al*., 2012; Gangwar *et. al*., 2004). Other authors have reported better crop performance under no-tillage compared with conventional tillage (Ujoh and Ujoh, 2014; Ngwira *et al.,* 2012; Sharma *et al*., 2011; Rockstroem *et al.*, 2009). Different tillage methods and weed control practices are being used by farmers for the production of rice in the Northern Region of Ghana. Rice farmers are concerned about the effects of tillage and weeding frequency on the growth and yield of rice, and also soil properties. Hence, there was the need to undertake the study.

1.4 Aim and objectives

The aim of the study was to evaluate the effects of tillage and weeding frequency on the performance of NERICA 4 rice and soil physical properties. The specific objectives of the study were:

1. To assess the effects of tillage and weeding frequency on NERICA 4 rice growth, yield components and yield,
2. To assess the effects of tillage and weeding frequency on soil physical properties, and
3. To assess the effects of tillage and weeding frequency on weed dry matter

1.5 Research Questions

1. What are the effects of tillage and weeding frequency on the performance of NERICA 4?
2. What are the effects of tillage and weeding frequency on soil physical properties?
3. What are the effects of tillage and weeding frequency on weed dry matter?

2. LITERATURE REVIEW

2.1 Brief Description of Rice

Rice is the seed of the grass species *Oryza sativa* (Asian rice) or *Oryza glaberrima* (African rice) (Umadevi *et al.*, 2012). As a cereal grain, rice is the food most consumed for much of the human population of the world, especially in Asia (Subudhi *et al.*, 2012). After maize (corn), rice has the second-highest global production and as such it is considered as the most significant grain with regard to human nutrition and caloric intake, providing more than a fifth of the calories consumed globally by the human species (Wagan *et al*., 2015).

Rice is a monocot plant, is mostly grown as an annual plant. However, in tropical areas it can survive as a perennial and can produce a ratoon crop for up to 30 years (International Rice Research Institute, 2009). Rice plant can grow to 1–1.8 m tall, sometimes more depending on the variety and soil fertility. It has long, narrow leaves 50–100 cm long and 2–2.5 cm broad. The small wind-pollinated flowers are produced in a branched arching to pendulous inflorescence 30–50 cm long. The edible seed is a grain (caryopsis) 5–12 mm long and 2–3 mm thick (International Rice Research Institute, 2009). Rice is extensively cultivated throughout the tropics and it is a versatile crop grown in a wide range of soil and water regimes ranging from irrigated, rainfed upland and lowland, mangrove and deep-water ecosystems (Africa Rice, 2011).

In Ghana, rice is regarded as the second most important cereal after maize and is rapidly becoming a cash crop for many farmers (Addison *et al.*, 2014). It's increasing value, demand and productivity is generally experienced in most rural and urban communities. According to the Ministry of Food and Agriculture (MoFA, 2010), rice production accounted for about 18% of total cereal production in Ghana in 2010. As a growing diet and major staple, it is gradually replacing other traditional staples of rural and urban dwellers. For instance, the per capita consumption of rice in 2010/2012 was pegged at about 28 kg with urban areas accounting for about 76% of total rice consumption (Angelucci *et al.*, 2013). Several estimates, however, revealed very high levels of rice imports valued at US$500 million annually (Osei-Asare, 2010), putting much pressure on foreign currency reserves and food security in Ghana. On the other hand, imported rice constitutes about 70% of the quantity consumed in Ghana (Amanor-Boadu, 2012). The crop is grown in all the 10 regions of Ghana. However, its production is highly concentrated in three regions (Northern, Upper East and Volta) accounting for nearly 80% of total national output and 73% of total production area in 2010 (Ragasa *et al.,* 2013). These three regions also fall in three of the country's six agro-ecological zones – Guinea savannah, Coastal savanna and Sudan savanna. The national average rice yield in Ghana was estimated to be 2.4 t ha^{-1}, while the achievable yield based on on-farm trials is 6–7 t ha^{-1} (MOFA/SRID, 2011).

2.2 Nerica Rice

The Africa Rice Centre, as a principal authority concerning various kinds of rice research in Africa, developed various new rice varieties called NERICA (New Rice for Africa), which is the first extensive scale of success in crossing African rice, *Oriza glaberrima* and Asian rice, *Oriza sativa* by a team of rice breeders led by Dr. Monty Jones at the M'be research center of WARDA in Bouaké, Côte d'Ivoire in the early 1990s (AfricaRice, 2008). NERICA combines traits of *O. glaberrima* such as weed competitiveness, drought tolerance, resistance to local pests and diseases and the ability to grow under low input conditions with a high yield potential of *Oriza sativa*. In the period of 2000 - 2006, Africa Rice classified 18 upland NERICA and 60 lowland NERICA varieties, all being tested on farmer's fields across Sub Saharan Africa on their specific performance and tolerance levels to biotic and abiotic stresses. Within this period of six years, NERICA varieties have been implemented on 200, 000 ha in Nigeria and helped to increase rice production levels all around Sub-Saharan Africa (AfricaRice, 2010). For instance, Uganda decreased its rice imports between 2002 and 2007 by half by introducing and expanding NERICA to 35 000 ha (AfricaRice, 2010). Similar successes have also been reported in other countries, such as Burkina Faso, Ethiopia, Guinea, Mali, Sierra Leone and Togo (AfricaRice, 2010).

2.3 Importance of Rice

Rice is the staple food of over half the world's population. It is the principal dietary energy source for many countries in Asia-Pacific region, North and South America and eight countries in Africa including Côte d'Ivoire, the Gambia, Guinea, Guinea Bissau, Liberia, Senegal and Sierra Leone (Singh and Yadav, 2014). About 50% of consumed calories by the entire population of humans depend on wheat, rice and maize (Gnanamanickam, 2009). Rice alone provides 20% of the world’s dietary energy supply, while wheat supplies 19% and maize (corn) 5% (Singh and Yadav, 2014).

Africa has become a big competitor in the international rice market, accounting for 32% of worldwide imports in 2006, at a recorded level of 9 million tonnes in that year (AfricaRice, 2008). In 2009, rice imports into sub-Saharan Africa translated into 9.68 million tonnes, worth more than $5 billion (Onyango, 2014). However, Africa’s emergence as a big rice importer is explained by the fact that during the last decade rice has become the most speedily increasing food source in sub-Saharan Africa (Onyango, 2014). Certainly, due to population growth (4%

per annum), increasing incomes and a move in consumer desire in favour of rice especially in urban areas, the comparative growth in demand for rice is faster in this region than anywhere in the world (Conteh *et al.*, 2012). However, West Africa still remains the major rice importing region in Africa, accounting for 20% of global imports (Mendez and Bauer, 2013).

2.4 Global Production of Rice

In 2013, the area under the production of rice globally was 164,721,663 ha and the total production was about 745,709,788 tons. The world average yield for rice was 4.5 t ha^{-1} in 2013 (FAO, 2015). In Africa, rice production is mainly concentrated in North and West Africa. The two regions constituted about 73% of the total rice production in Africa in 2013. The area under the production of rice in Africa was 10,931,051 ha and a total production of 29,318,488 tonnes in 2013. North Africa recorded a total rice production area of 712,742 ha and a total production of 6,813,036 tonnes in 2013 (FAO, 2015). West Africa on the other hand exhibited a production area of 6,412,136 ha and total production of 14,500,784 tonnes in 2013. West Africa therefore accounted for about 58.7% of rice production area and 49.5% of total rice production in Africa in 2013. In Ghana, the rice production area for 2013 was 215,905 ha and total production of 569, 524 tonnes (FAO, 2015). Therefore, there is great potential for increasing rice production in sub-Saharan Africa through productivity improvement. Notwithstanding, successful rice production depends on the correct application of production inputs that will sustain the environment as well as agricultural production. These inputs are improved rice varieties, plant population, soil tillage, fertilization, weed, insect-pest and disease control, and harvesting.

2.5 Climatic requirements for rice production

Temperature and precipitation are the two predominant aspects of climatic variation worldwide. The seasonal and spatial difference of temperature and rainfall have great implication in agricultural sustainability and to some extent, regulate the agricultural activities in many parts of the world (Bhandari, 2013); more so as most of the smallholder farmers depend on suitable weather conditions to commence their farming activities. However, the optimum temperature required for rice cultivation is between 25°C and 35°C (Zada *et al.*, 2014). Any further increase in the optimum temperature especially during reproductive stages may cause significant yield and yield component losses (Krishnan *et al.*, 2011). Zhang *et al.* (2013) also reported that high temperature during night time has serious effects on the tillering and spikelet fertility which, in turn, decreases the total biomass production and grain yield. On the other hand, rice is a cold-sensitive plant that originated from tropical or subtropical zones. When low temperatures below 15°C occur during the growth stages, it can cause serious damage to the growth and development of the crop (Krishnan *et al.*, 2011).

2.5.1 Water requirement

It is clear that water is a limiting factor in upland and lowland rice cultivation areas worldwide. Among the cereal crops, rice is one of the largest water consumers in the world (Chapagain and Hoekstra, 2011). Every stage of rice growth and development needs at least some amount of water in order to meet its full potential. Rice production needs a threshold rainfall of 200 mm/month or 600 mm for a crop season depending on the climate (Matsumoto *et al*., 2014).

2.5.2 Soil requirement

Soil types and characteristics also serve as important factors in rice cultivation. Nevertheless, the most suitable soil for rice production is one with a good soil tilth, sufficient depth, adequate but not excessive nutrient supply, small population of plant pathogens and insect pests, good soil drainage, large population of beneficial organisms, low weed pressure, no chemicals or toxins that may harm the crop, resilience to degradation and unfavourable conditions (Tripathi *et al*., 2015). While rice is a versatile crop, it is adapted to a wide range of soil regimes in the tropics, ranging from sand to heavy clays. Most rice is grown on well-structured soils of texture ranging between sandy loam to clay loams, which provide enough soil water, aeration and penetrability. In the tropics for example, Oxisols, Alfisols, Ultisols, Lixisols and Inceptisols have the appreciable potential for rice production (Jalloh *et al.*, 2011). Vertisols and Mollisols are also found to be very good cereal soils but are sparse in area in the tropics (Jalloh *et al.*, 2011). Rice does well on nearly all soils but less so on very thick clay and very sandy soils.

2.6 Rice Grain Yield

Africa held an average grain yield of about 2.7 t ha^{-1} in 2013 which is about two times below the world average yield (4.5 t ha^{-1}). The average grain yield of Africa shows a little improvement with time. North Africa has the highest average grain yield of about 9.5 t ha^{-1} in 2013. Egypt for example remains the highest rice producing country in North Africa with an average grain yield of 9.6 t ha^{-1} in 2013 (FAO, 2015). However, the high grain yield reported in North Africa as a whole, comes as a result of the high level of production technologies and cropping intensities and the dominance of the irrigated ecosystem. West Africa and East Africa, on the other hand, have the lowest average grain yields in Africa (about 2.3 and 2.4 t ha^{-1} respectively) in 2013. Côte d'Ivoire and Mauritania produced the highest grain yield in West Africa (4.9 and 4.5 t ha^{-1}) respectively in 2013, while in Ghana the average rice yield in 2013 was 2.6 t ha^{-1} (FAO, 2015). It should be noted that West Africa, which contributes 58.7% of the rice production area, accounts for 49.5% of the total rice production, while North Africa, which is responsible for only 6.4% of the rice area, accounts for 23.2% of total production as of 2013.

2.7 Tillage

Tillage is the physical improvement of soil properties for the purpose of supporting crop growth. It is a process which involves the use of human, animal or machine energy for physical manipulation of soil to provide conditions favourable for plant growth (Kishor *et al*., 2013). The choice of the most suitable type of tillage depends on physical factors, such as soil properties, rainfall regime, climate, drainage conditions, rooting depth, soil compaction, erosion hazards, cropping systems, and socio-economic factors, including farm size and availability of inputs (Sornpoon and Jayasuriya, 2013). Furthermore, the use of correct tillage methods may help to promote higher profits, crop yields, soil improvement and protection, weed control and optimum use of water resources for the fact that tillage has direct impact on soil and water quality (Hanna and Al-Kaisi, 2009 cited by Sornpoon and Jayasuriya, 2013).

2.8 Tillage Systems

Tillage systems may be grouped into two, namely, conventional and conservation tillage, depending on the kind, amount and sequence of soil disturbance.

2.8.1 Conventional tillage

Conventional tillage system is based on mechanical soil manipulation and it involves mouldboard or disc ploughing followed by no disc harrowing, one or two disc harrowing. Conventional tillage embraces soil cultivation based on ploughing or soil inversion, secondary cultivation using discs and tertiary, working by cultivators and harrowers (Fasinmirin and Reichert, 2011). These tools are commonly drawn by animals or tractors or by other mechanically powered devices. Conventional tillage systems are to a greater degree aimed at weed control, residue incorporation and seed bed preparation and include disruption, inversion, pulverization and mixing of soil in the tilled zone (Kishor *et al*., 2013). However, conventional tillage operations pose some serious concerns internationally for example, high fuel and time requirements, increases the possibility of soil erosion, soil compaction and deterioration in soil structure (Mitchell *et al*., 2009). On the other hand, conventional tillage systems have been found to improve soil physical properties and increase crop performance. According to studies conducted by Amin *et al.* (2014), on the effect of different tillage practices on soil physical properties under wheat in semi-arid environment, the study indicated that conventional tillage practices performed better than conservation tillage practices, as conventional tillage improved crop performance and soil physical properties. Furthermore, studies conducted by Zein EL- Din *et al*. (2008) on the effect of tillage and planting practices on rice yield and engineering characteristics of milling quality, also discovered that maximum total grain yield was obtained from conventional tillage compared to conservation tillage. The results further stated that higher values of yield components (number of tillers, number of filled grains per panicle and 1000-grain weight) were obtained with conventional tillage in comparison to the same planting system under conservation tillage practices. Other authors have also reported better crop performance on conventional tillage compared with conversation tillage practices (Ujoh and Ujoh, 2014; Aikins and Afuakwa, 2012; Aikins *et al*., 2012; Kihara *et al.,* 2011, Gangwar *et. al*., 2004).

2.8.2 Conservation Tillage

Conservation tillage is defined as a tillage system in which at least 30% of crop residues are left in the field and is considered as a significant soil conservation practice especially to reduce water and wind erosion. In areas where wind erosion is the foremost concern, conservation tillage may also be defined as, any tillage system that maintains at least 1,100 kg ha^{-1} of flat, small grain residue equivalent on the surface all year round. Conservation tillage is an alternative to conventional agriculture and it is already recognized in many parts of the world (Dumanski *et al.,* 2006). The main aim of conservation tillage, however, is to improve agricultural production by increasing the productivity of farm resources (SoCo, 2009). Conservation tillage has lots of benefits like reduction in soil erosion and greenhouse gas emissions, improvement in water infiltration, labour reduction and energy savings and improves soil biodiversity and profitability (Amini and Asoodar, 2015). Conservation tillage reduces the number of tillage, therefore herbicides especially glyphosate is the main tool to control the weeds under this tillage system (Schmitz *et al*., 2014). In some cases, other authors have reported better crop performance under conservation tillage in comparison with that of conventional tillage (Mitchell *et al.,* 2012; Ngwira *et al.,* 2012; Sharma *et al*., 2011; Saharawat *et al.,* 2010; Rockstrom *et al.,* 2009). On the other hand, regardless of its potential benefits in terms of reducing energy use and soil conservation, conservation tillage also had some disadvantages. Normally, there is a transition period of 5 – 7 years before a conservation agriculture system reaches equilibrium, yields may be lower in the early years, cost and availability of agro-chemicals to control weeds, and insect-pests, farmers may require more initial investments to buy specialized machinery and farmers may also need training and skilled advisory services to adapt conservation agriculture system compared to conventional farming (SoCo, 2009). The total area under conservation tillage in Sub-Saharan African is about 981,640 ha (Friedrich *et al.*, 2012). South Africa had about 37% of the total area under conservation tillage in Sub-Saharan African, followed by Zambia and Mozambique, 20% and 15% respectively. Ghana had about 3% of total area under conservation tillage in Sub-Saharan African (Friedrich *et al.*, 2012).

2.9 Conservation tillage systems

2.9.1 No-tillage (Zero Tillage)

No tillage, also known as zero tillage, is a tillage system where the soil is left undisturbed from harvest to planting except for nutrient placement. Planting is accomplished in a narrow seedbed or slot created by coulters, row cleaners, row chisels or rotor tillers (Ajirloo and Ahangar, 2014). No tillage is slowly gaining some attention globally. For example, in 2011, South America had about 45% of the total global area under no-tillage; North America, 32% followed by Australia and New Zealand 14%. Europe had 1.35 million ha under no-tillage which is about one percent of the total global area while Africa had 1.01 million ha under no-tillage which is also about one percent of the global area under conservation agricultural (Friedrich *et al.,* 2012). The adoption of zero or no-tillage is therefore much higher in the American and Australian continents than other continents.

2.9.2 Mulch tillage

According to Fasinmirin and Reichert (2011), mulch tillage is a tillage system that ensures maximum retention of crop residues on soil surface all year round, more so for the purpose of soil and water conservation. The soil is prepared in such a way that plant residue or other mulching materials are specifically left on or near the soil surface. Mulch tillage uses conventional tillage implements such as discs, chisel ploughs, rod weeders, or cultivators, but with limited passes across a field so as to maintain crop residue on the soil surface year round (American Society of Agricultural Engineers, 2005). Major existence of mulch tillage is in the USA and Germany because the arable soils in these areas are often vulnerable to wind and water erosion (Michael *et al.,* 2014). Weed control is generally accomplished with herbicides and/or cultivation.

2.9.3 Strip or zonal tillage

The concept of strip or zonal tillage is described by Schmitz *et al*. (2014). This type of tillage system is mostly applicable for soil which is naturally compact. It involves the use of a mole knife as a tool to till which is normally about 25 cm wide, and 10 to 13 cm high in the fall. The seedbed is mainly divided into two parts namely, seeding zone, and soil management zone. The seeding zone which is normally 5 to 10 cm wide would be mechanically tilled to optimize the soil and micro-climate environment for germination and seedling establishment (Schmitz, *et al*., 2014). The inter-row zone or soil management zone is left undisturbed and protected by mulch. Strip tillage can also be achieved by chiselling in the row zone to assist water infiltration and root proliferation.

2.9.4 Ridge till

Ridge tillage is a system where the soil is not disturbed from planting to harvest except for nutrients application and the crop planting is accomplished on the ridges with disc openers, cleaners, sweeps, coulters and/or row cleaners and furrowing wings. Crops are seeded and grown on ridges or shallow beds that have been formed or built during the prior growing season (Mid-West Plan Service, 2000, cited by Mitchell *et al.*, 2009). The crop residues are retained between ridges on the soil surface creating a clean seed row. Weed control is accomplished by herbicides, cultivation, or both. This system increases soil resistance to both wind and water erosion, especially when working against wind and water flow directions. The system is also mostly suitable for annual row crops, and wheel spacing and other machinery modifications may be needed (Fasinmirin and Reichert, 2011).

2.9.5 Reduced or minimum tillage

The term "minimum tillage" refers to systems that reduce tillage passes and as a result conserve fuel for a given crop by at least 40% relative to conventional tillage. This tillage system describes a standard that is based on achieving the 40% or more reduction in the number of tillage or soil-disturbing passes (Mitchell *et al.*, 2009). But, this system of tillage is more conducive to European conditions than no-tillage due to better suitability of reduced tillage under humid temperate climate. As such reduced tillage practices have become a favourable yet challenging option for organic farmers across Europe (Mäder and Berner, 2011). Weeds are controlled by herbicides applications.

2.10 Soil physical properties

Soil physical properties have a significant influence on crop growth and development. Soil texture and structure are the most important of these properties. One of the primary methods of addressing many of these soil physical properties has been the use of tillage. Tillage can change the soil structure, improve moisture intake and storage, improve aeration and fertility with time. On the other hand, tillage can also impact on soil loss from both soil water and wind erosion. As long as the majority of food crops are grown in the soil, a basic understanding of soils will continue to be essential to crop production.

2.10.1 Soil texture

Soil texture is the relative proportions of sand, silt, or clay in a soil. Soil texture is most important in the areas of water holding, nutrient supply, and on ease of tillage. Soils that are too sandy (course textured) leach quickly and do not hold water well. This can influence both fertility and the environment, as well as limit the plant's ability to obtain water for turgor, photosynthesis, and nutrient uptake.

2.10.2 Soil structure

Soil structure refers to the arrangement of soil particles by cementing agents like organic matter. Except for sand, the mineral proportion of soil occurs in groups of particles bonded together by organic compounds to form soil aggregates. These give soil its “structure.” Soil with a good structure is loose and friable. However, soil structure has a primary impact on soil porosity and aeration. If water does not move through soils, air is excluded and plant roots may die. On the other hand, if water does not infiltrate the soil and instead runs off, the plant might lose water and erosion will occur (Kishor *et al.*, 2013). Conventional tillage practices are found to modify soil structure by changing its physical properties such as bulk density, penetration resistance and moisture content (Keshavarzpour, 2012). Annual disturbance and pulverizing caused by conventional tillage has been found to produce a finer and loose soil structure as compared to conservation tillage methods which leave the soil intact (Rashidi and Keshavarzpour, 2007).

2.11 Effect of tillage on soil physical properties

2.11.1 Bulk density

Soil bulk density is a measure of compaction and denseness of soil and has considerable influence on soil structure, porosity, aeration, water-holding capacity, drainage, and nutrient availability, which in turn affect root growth and microbial activity (Davidson, 2014). The finer the soil the lower the bulk density. The magnitude of bulk density for ideal agricultural soils oftentimes varies from 1.1 to 1.6 g/cm^3 (Davidson, 2014). As densities begin to exceed the ideal, root growth and microbial activity are affected. Bulk density is almost always altered by tillage operations (Kishor *et al.*, 2013). Rashidi and Keshavarzpour (2011) reported that zero tillage increases the bulk density of soil compared to reduced and conventional tillage. On the other hand, after four years of Wheat-Mungbean-Rice cropping cycle, Alam *et al*. (2014) reported that bulk density varied considerably among tillage practices. They found the highest bulk density reduction in zero tillage compared with conventional tillage practices.

2.11.2 Porosity and aeration

Porosity is the amount of pore space in the soil. There is strong reciprocal dependence found between porosity and soil bulk density: higher bulk density reduces total porosity and changes the ratio of water holding capacity to air capacity in favour of water holding capacity (Bogunovic *et al.,* 2014). Furthermore, as compaction increases bulk density from 1.3 to 1.5 g/cm^3, porosity decreases from 50 to 43% (Davidson, 2014). Tillage has been reported to affect the soil aeration status and total porosity as well as pore size distribution. Tillage increases the macro-porosity which enables good infiltration of water into the soil for plant utilization while compaction increases micro-porosity thereby suppressing plant growth (Kishor *et al.*, 2013).

2.11.3 Soil moisture content

Tillage plays an essential role in the conservation of soil moisture at different depths in rainfed cultivation. It would also improve the soil condition by modifying the mechanical impedance to root penetration, hydraulic conductivity and water holding capacity (Dexter and Birkas, 2004). Tillage operations are often always performed to break up and pulverize the soil and to facilitate the movement of air and water to promote plant growth. The success or failure of crop production systems surrounded by other factors largely depends on seedbed environment. In general, tillage helps to improve the soil water storage capacity and other soil physical properties. The influence of tillage implements on soil moisture content and soil physical properties remains significantly important in crop production system. As such tillage techniques that will conserve moisture are key for increasing crop performance and yields (Amin *et al.*, 2014). Khurshid *et al*. (2006) reported that tillage methods considerably affect the physical properties of soils. He found higher soil moisture contents with conventional tillage compared to conservation tillage practice.

2.12 Effect of Tillage on Soil Chemical Properties

2.12.1 Soil Organic Carbon

Organic carbon content in the soil is directly commensurate to the organic matter content. Organic matter is made up of partially decayed and partially synthesized plant and animal residues. It is repeatedly being broken down as a result of microbial activities in the soil. It must, therefore, be replenished by the addition of plant residues to the soil (Chand, 2014). Soil organic carbon has profound effects on soil physical, chemical and biological properties. Maintenance of soil organic carbon in cropland is therefore important, not only for improvement of agricultural productivity but also for reduction in carbon emission (Rajan *et al*., 2012). Agricultural practices such as tillage methods are conventionally used for loosening soils to grow crops (Zhu *et al.*, 2014). However, long-term soil disturbance by tillage is believed to be one of the major factors reducing soil organic carbon in agriculture (Baker *et al*., 2007). Frequent tillage may destroy soil organic matter and on the other hand, conservation tillage has been reported to increase soil organic carbon in cropland compared to conventional tillage practices (Zhu *et al.,* 2014). Further research also revealed that continuous no-till can increase organic matter in the top 5 cm of soil for about 0.1% each year (Amini and Asoodar, 2015).

2.12.2 Soil pH

The soil pH is a measure of the acidity or alkalinity in soils. A pH below 7 is acidic and above 7 is alkaline. Soil pH is considered a principal variable in soils as it controls many chemical activities that take place. It specifically affects plant nutrients availability by controlling the chemical forms of the nutrients. The optimum pH range for most plants is between 5.5 and 7.0 (Leonard, 2012). However, many plants have adapted to thrive at pH values outside this range. Soil pH is important because it influences several soil factors affecting plant growth, such as: soil bacteria, nutrient leaching, nutrient availability, toxic elements, and soil structure. Bacterial activity that releases nitrogen from organic matter and certain fertilizers is particularly affected by soil pH, because bacteria operate best in the pH range of 5.5 to 7.0. Plant nutrients leach out of soils with a pH below 5.0 much more rapidly than from soils with values between 5.0 and 7.5. Plant nutrients are generally most available to plants in the pH range 5.5 to 6.5. At low pH, aluminium may become toxic to plant growth and can severely restrict root growth and thus uptake of water and nutrients in certain soils (Leonard, 2012). This can occur as a result of tillage practices which render the soil surface very loose and susceptible to rain drops. This situation exists in the high rain forest of the Western Region of Ghana where soils are highly acidic. Soils of drier regions are likely to be alkaline or only slightly acidic (Quaye *et al.*, 2003).

2.12.3 Nitrogen

Among the macro nutrients in the soil, nitrogen plays an important role in the growth and development of plants. It is an essential constituent of metabolically active compounds like protein, nucleic acids, chlorophyll and enzymes (Pervez *et al.*, 2004). Nitrogen is primarily in ammonium (NH_4^+ ions) form but is normally changed by bacteria sooner in the soil to nitrate

(NO_3^- ions) form. Large amounts of nitrogen are used by plants during vegetative growth. Nitrogen stimulates the production of the vegetative growth parts at the expense of fruiting and food storage parts (Quaye *et al.*, 2003, cited by Ignatius, 2011). However, tillage system can influence soil nitrogen availability due to its impact on soil organic carbon and nitrogen mineralization and subsequent plant nitrogen use or accumulation (Al-Kaisi and Licht, 2004). Wang *et al.* (2011), reported a significant increase in soil nitrogen with no-tillage system compared to conventional tillage system, while conventional tillage had deleterious impact on soil microbial biomass and also reduced soil organic carbon.

2.12.4 Phosphorus

Phosphorus is one of the limiting nutrients for plant growth (Redel *et al.,* 2007). Phosphorus is available to plants after it is hydrolyzed into orthophosphate by phosphatases in the soils. Thus, the soil phosphatase activities greatly affect the bioavailability of organic phosphorus (Wang *et al*., 2011**).** As nitrogen is affected by tillage systems, phosphorus availability can equally be affected, leading to a phosphorus deficiency in many cereal cropping systems around the world. Many soils have large reserves of total phosphorus, but low levels of available phosphorus (Ortiz-Monasterio *et al*., 2002). Tillage practices therefore have significant effects on phosphorus composition in the soil. Wei *et al.* (2014) reported that, although no tillage facilitated more phosphorus stored in the organic phosphorus form and increased phosphatase activities, however, soils with no tillage had lower total and plant available phosphorus compared to conventional tillage soils and therefore concluded that conventional tillage may be the right practice to conserve soil phosphorus.

2.12.5 Potassium

Potassium is a macronutrient element which is required for higher concentration for the growth of plants. It plays an important role in the activation of enzyme, stomata opening and closing, tropisms, photosynthesis and regulation of osmotic pressure (Golldack *et al.*, 2003). Potassium also increases the plant reaction to other elements particularly nitrogen (Rezaeian *et al.*, 2014). Shokati and Ahangar (2014) reported that, soils under conservation tillage showed significant phosphate and potassium accumulation compared to conventional tillage soils. The main reason for the large potassium accumulation near the soil surface is as a result of the relocation of plant residues, which contain only small amounts of phosphorus, from deeper soil layers (Annette *et al.*, 2011).

2.13 Tillage effects on weed growth and dry matter yield

Tillage is many times used as a weed control system, but the effects of tillage on weed growth go far beyond the physical removal of growing weeds. With the development and worldwide adoption of zero-tillage systems, weed management approaches have been developed (Derpsch *et al.*, 2010). Different tillage practices might specifically affect weed population. Irrespective of the weed species, conventional tillage practices have been reported to have considerably reduced the population of weeds while compared to conservation tillage (Vijaymahantesh *et al.*, 2013). The inversion of soil by conventional tillage resulted in deeper placement of weed seeds which could not emerge, causing a significant reduction in the population of weeds (Vijaymahantesh *et al.*, 2013). Auškalnienė and Auškalnis (2009) reported that a high number of weed seed species have being found in no-tillage compared to conventional tillage system. According to Prameela and George (2013), weed population and dry weight varied with tillage practices. They reported higher weed population and weed dry weight in zero tillage compared to conventional tillage systems. A similar trend was also reported by Sornpoon and Jayasuriya (2013).

2.14 Effects of Weeds on crop yield

Weeds are most likely the most ever-present class of crop pests and on the peculiar occasion cause huge crop failure over vast areas (Singh *et al.,* 2012), and still remain the major crop production constraints in rainfed uplands and in the unbunded lowlands, for instance, where they cannot be controlled by flooding the soil surface (Rodenburg and Johnson, 2009). Weeds reduce the crop yield through competition for nutrients, space and light with crop plants, deteriorate the quality of produce and therefore reduce the market value of the produce as well (Arif *et al*., 2006). In a survey of upland rice producing countries covering 80% of the total production area, David (2013) indicated that weeds were the most widely reported biological constraint to yields. Upland rice, specifically, competes poorly with weeds and uncontrolled weed growth many times resulted in negligible or zero crop yield. In West Africa, however, yields of upland rice with farmers' weed control were reported to be 44% lower compared to that of researchers weeded fields (Mola and Belachew, 2015). In India, yield losses due to uncontrolled weed growth in upland rice was reported to be up to 90%, and in both lowland and upland rice systems in Africa losses were within the range 28-100% (David, 2013). Furthermore, there is evidence that parasitic weed problems in rice fields are increasing in Africa and this was reported for *Striga spp*. in Nigeria (Dugje *et al.*, 2006) and Ghana (Aflakpui *et al*., 2008). In Tanzania as well, rice farmers witnessed a continuous decline in yields related with an increased severity of S. *asiatica* infestations (Mbwaga and Riches, 2006, cited by Rodenburg and Johnson, 2009). On the other hand, Ismaila *et al.* (2013) reported better weed control in farmers' fields to increase rice yields by 15 – 23% in both lowland and upland agro-ecosystems in Nigeria.

2.15. Weed Management Practices

Increased production of rice has been slow, down to a large extent by weeds globally. A weed is a plant growing where man does not want it to be. Almost any kind of plant can therefore be a weed, as long as it exists in a location or situation where it is considered unwanted. It also follows that a certain plant may be a weed in one situation and not a weed in another. For instance, a volunteer maize plant in rice field can rightly be called a weed even though maize is a crop plant. Weeds encompass all types of undesirable plants, trees, broad leaved plants, grasses, sedges, shrubs, vines and aquatic as well as parasitic flowering plants.

Weed management is therefore an important side in crop production systems. It is noted that weeds reduce crop yields and can lead to total crop failure if not controlled. The nature and severity of weed problems, however, vary according to the rice ecosystem. Likewise, weed management practices and the available alternatives are often a function of biophysical and socio-economic factors which, in turn, are determined by the agro ecosystem (Mola and Belachew, 2015).

2.15.1 Cultural weed control

This is a common term used to describe those measures established by farmers to reduce the germination, growth and competitiveness of weeds at harvest time or during the growing period of the crop. Indeed, it is one of the major integrated weed management practices that farmers should consider for their cropping systems to reduce weed problems in the short and long terms. It is, however, the first step to consider in the fight against weeds especially for small holder farmers.

Planting methods

Crop establishment is a key factor in determining the effects of weed–crop interactions and preventive weed management measures. A vigorous rice crop with a closed canopy refuses weeds for space and light, thereby suppressing its growth and reduces the costs associated with weed control (Swanton *et al.*, 2015). Crop establishment, however, involves various steps of land preparation and planting depending on the agro-ecosystem (Rodenburg and Johnson, 2009). In addition to crop establishment, farmers also need to consider the time of planting as an effective way of reducing weed competition. Early planted crop, however, gets the highest sunshine and temperatures and grows before the first emergence of weeds occurred. By the time weeds emerge the crop will have established and are strong competitors against weeds (Ronald *et al.,* 2011).

Crop rotation

Crop rotation is an effective practice for weed management. Traditionally, rain-fed rice farmers in Africa use fallow and rotations to interrupt the build-up of weeds. Rotations with non-cereal crops like cowpea and soybean in the savannah and forest uplands and groundnut, soybean, cassava, potato, or vegetables in the rain-fed lowlands are commonly practiced in subsistence rice-based production systems in Sub Saharan Africa (Rodenburg and Johnson, 2009). However, the effectiveness of a crop rotation in weed suppression may be increased by crops succession that create different patterns of resource competition, chemical hindrance of one plant by another, soil disturbance and mechanical damage to certain species (Ronald *et al.*, 2011). According to Sanyal *et al.* (2008), different planting and harvesting dates among these crops might not only suppress weed competition but also provide more opportunities for producers to prevent either plant establishment or seed production by weeds.

Soil fertility management

Agricultural weeds are high users of soil nutrients and therefore have the potential of reducing available nutrients for crop growth (Arif *et al*., 2006). Timing of fertilizer application may be very important with respect to its influence on the effect of weed competition and also improve the nutrient status of the soil (Bajwa *et al.*, 2014). The common nutrients applied to the soil by rice farmers in Africa are nitrogen (N), phosphorus (P) and potassium (K). Nitrogen supports rapid vegetative growth resulting in increased plant height, tiller number and leaf size, therefore, producing shade that helps to suppress late-germinating weeds. Phosphorus on the other hand strengthens root development and increases rice tillering ability (Ismaila *et al.,* 2013). Vigorous root growth is advantageous especially in below-ground competition with weeds for moisture and nutrients. Weeds are more efficient in nutrient uptake than rice; therefore, it is important to keep the crop field weed free before fertilization.

Mulching

Mulching is a practicable option in upland rice production but not widely practiced in Africa. Mulching with residues from trees or crops has shown to suppress weeds in cereal crops, including rice (Singh *et al*., 2007). Mulching can prevent weed seed germination by shading and in some cases through the release of allelopathic substances that influence the growth, survival, and reproduction of weeds (Singh *et al*., 2003). Furthermore, mulch also helps to recycle plant nutrients back to the soil efficiently (Mohtisham *et al*., 2013). Rice straw has been demonstrated to be an effective mulch material in reducing weed growth and therefore considered as a useful option in increasing crop production (Mohtisham *et al*., 2013). On the other hand, different types of mulches including organic and inorganic have also found to be vital in increasing the growth and yield of rice as these mulches conserve water and reduce weeds infestation in rice fields (Iqbal, 2014).

2.15.2 Mechanical weed control

Mechanical weed control involves the use of machines or mechanical devices driven by human, animal or fossil fuel energy (Ronald *et al.,* 2011). It can be applied as an intervention within the crop, and as a preventive measure as part of pre-season land preparation or as off-season dry-soil tillage. Preventive mechanical weed control options can be differentiated as either off-season soil tillage between harvest and establishment of the next crop or land preparations prior to crop establishment that may include tillage, levelling, and puddling. Off-season dry-soil tillage at sufficient depth may help in breaking and drying subsoil rhizomes of perennial weeds growth (Rodenburg and Johnson, 2009).

2.15.3 Chemical weed control

Herbicides are important weed control methods in the lowlands, and in upland rice production. Herbicides are useful in areas where frequent rainfall may impede physical weeding. They control germinating weeds and thereby make the crop weed free and more competitive during early growth stages. Herbicides are found to have long lasting effect especially on controlling broad leaved weeds and perennial weeds and they are more efficient in controlling weeds on erodible soils where tillage may accelerate soil and water erosion (Ismaila *et al.,* 2013). Furthermore, the use of herbicides is economically attractive as it requires less overall weeding time and it enables the farmer to use time and labour-saving planting methods such as direct (broadcast) seeding (Riches *et al*., 2005). With all the numerous benefits derived from herbicides use, the adoption of herbicide technology by small holder farmers in Africa has been low. Some of the factors that lead to the low adoption of herbicides in Africa include lack of technical knowledge on herbicide usage and resources for the purchase of chemicals and associated application devices together with the fear of the toxic nature of these chemicals contribute to this (Muzari *et al*., 2012).

2.15.4 Integrated weed control

Good control of weeds can be achieved through combining various approaches which can work simultaneously to produce a weed suppressing cropping system. This involves the combination of two or more weed management techniques at low cost to obtain the level of weed suppression higher than that usually obtained when one weed management system is used. However, smallholder farmers are often constrained by a lack of finance, information, and inputs for weed control, and therefore are often dependent on traditional methods of weed control such as hand picking and hand hoeing (Ekeleme *et al.,* 2007). Therefore, weed management practices based on cultural and integrated approaches may be more compatible with farmers' resources than single-component technologies requiring high levels of external inputs.

2.15. 5 Manual weed control

This is the use of direct human effort to remove weeds and it is a common method in both the small scale farmers and the commercial sector. In both sectors, it can be used to supplement other weeding methods such as mechanical or cultural methods or both.

Hoe weeding

This is by far the most commonly used weed control method in Africa. Weeds are removed by iron blades attached to wooden handle. However, hoe weeding method is usually slow, labour exhaustive and ineffective such that in most cases timely weed control is hardly achieved. On the other hand, regardless of the major advantages derived from chemical weed control over hoe weeding, hoe removal of weeds still remains the most feasible practice of weed control in many developing countries (Ismaila *et al.*, 2013). As such researchers and extension agents should put in effort to make sure that hoe weeding is combined with other control methods so that the number of weeding routines done on a single crop during the season is reduced. Although back breaking and laborious, hoe weeding is completely effective if employed at the right time. The number of hoe weeding's on a particular crop field depends on the crop and frequency of weed growths as well as the critical period of crop-weed competition. This method of weed control is mostly carried out in upland ecology where the entire surface soil is dug to shallow depths with hand hoes, and weeds are uprooted and removed. It is also found to improve soil physical condition.

Hand weeding

This involves the physical removal of the weeds from the field by hand. This method is often practiced in the low land rice ecology. However, farmers should combine this method with either chemical or cultural weed control practices like flooding. One main advantage of using hand pulling lies in the fact that those weeds that cannot be effectively controlled by herbicide or cultural means can be manually uprooted and thrown away in such a way that they have no chance to re-establish themselves. On the other hand, hand weeding is labour-intensive and time-consuming, requires high drudgery and stress on labour (bending all the time to remove weeds), it is also found to be strenuous especially if the soil surface is not moist and loose as well as the difficulty in identifying and removing certain grassy weeds at early growth stages (Ronald *et al.*, 2011).

3. MATERIALS AND METHODS

3.1 Experimental Site Description

This field experiment was conducted under rainfed conditions at the upland rice experimental field of the Savannah Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR) at Nyankpala between July, 2014 and November, 2014. The site lies around latitude 09° 25”N and longitude 1° 00”W of the equator at an altitude of 183 m above sea level. The study area is located in the Guinea Savannah agro-ecological zone of Ghana. The soil at the site is sandy loam in texture in both the 0–15 cm layer and the 15–30 cm layer. Table 3.1 presents some physico-chemical properties of the soil at the study area prior to starting the experiment.

Table 3.1: Properties of the soil prior to starting the experiment

	Soil Layer	
Soil Properties	0 – 15 (cm)	15 – 30 (cm)
Sand (%)	51.64	47.64
Silt (%)	42.00	46.00
Clay (%)	6.36	6.36
Organic Carbon (%)	0.312	0.273
pH	4.70	4.51
Total N (%)	0.0269	0.0198
Ca (mg/kg)	184.67	187.63
Mg (mg/kg)	63.98	68.27
K (mg/kg)	49.85	55.76
Available P (mg/kg)	3.3125	6.0325
Exchangeable Acidity	1.43	1.27

The mean annual rainfall at Nyankpala is 1000 mm. The average minimum and maximum daily temperatures at Nyankpala range between 19 °C and 41 °C. Weather data for the year 2014 including the experimental period is summarized in Fig. 3.1.

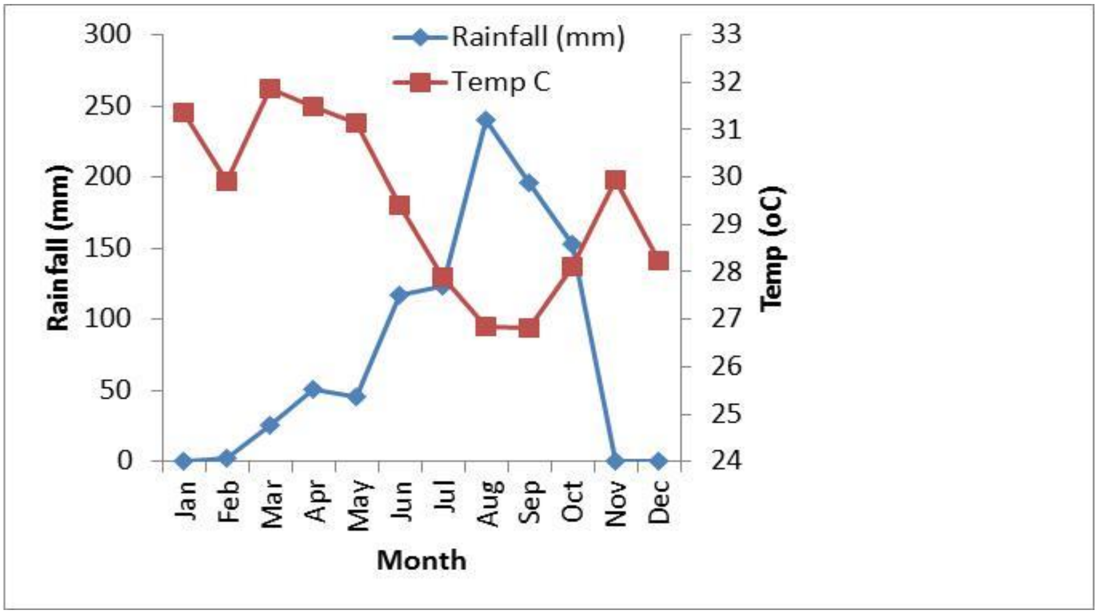

Figure 3.1: Average rainfall and temperature at Nyankpala in 2014

3.2 Experimental Design

The experiment was laid out in a split plot design with tillage as main plots, and weeding frequency as sub-plots. There were three tillage treatments and four weeding frequency treatments. The tillage treatments included disc ploughing only, disc ploughing followed by disc harrowing, and no tillage. The weeding frequencies consisted of weeding with a hand hoe three times, two times, and once. The fourth weeding frequency treatment was no weeding. Each treatment was replicated three times. There was an alley of one metre between plots and two metres between replications. The experimental design layout is presented at figures 3.2 – 3.4.

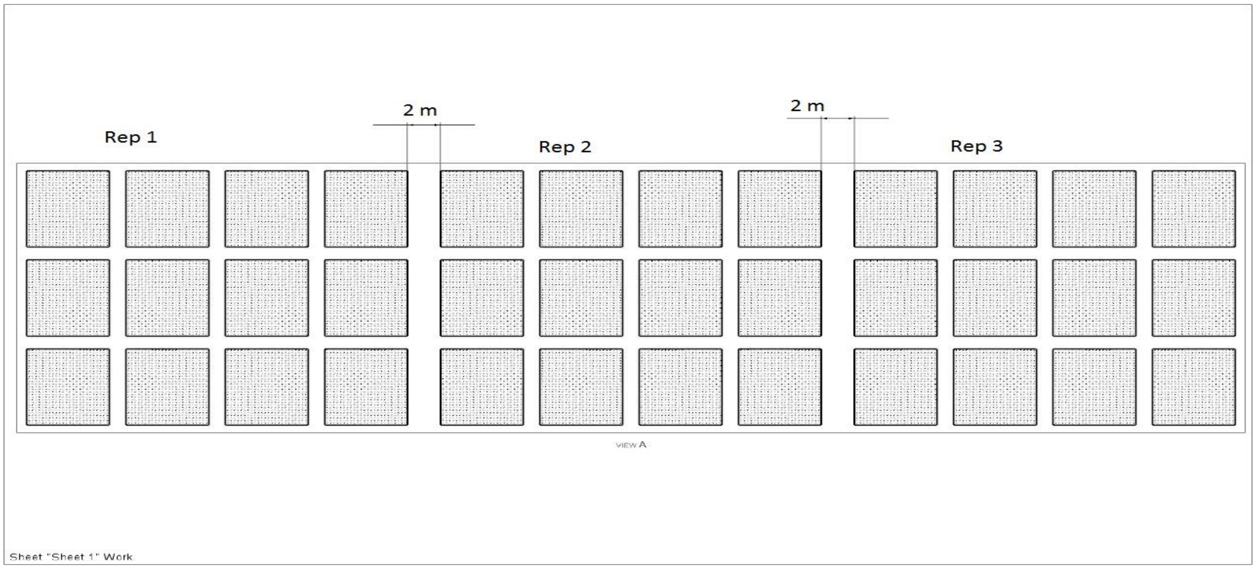

Figure 3.2: Field Layout

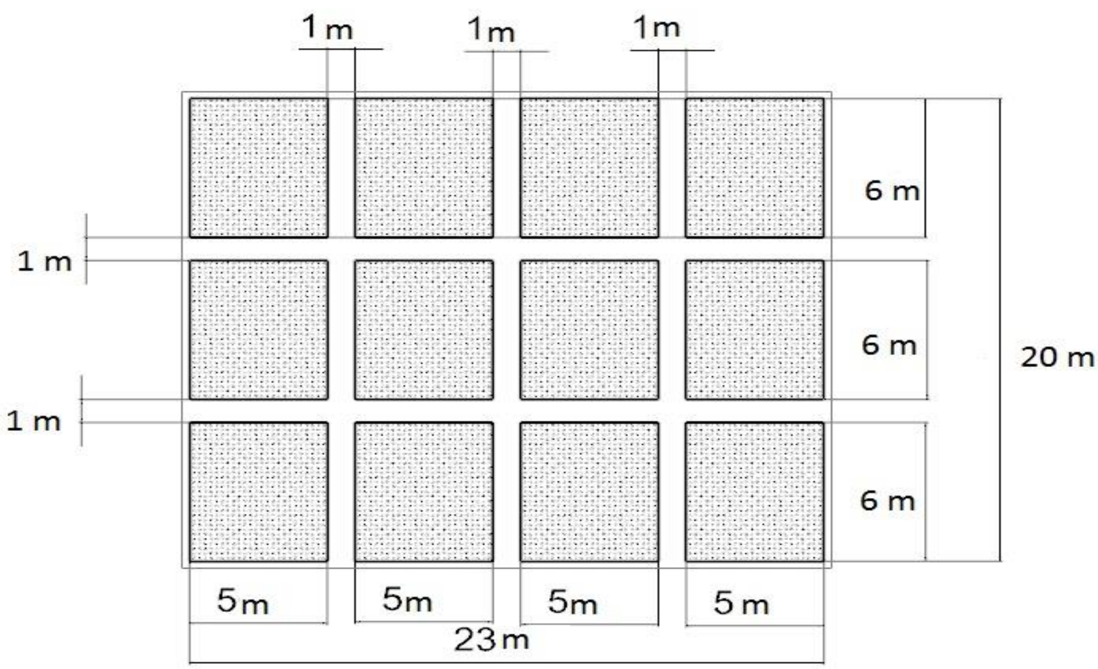

Figure 3.3: **Layout of Replication**

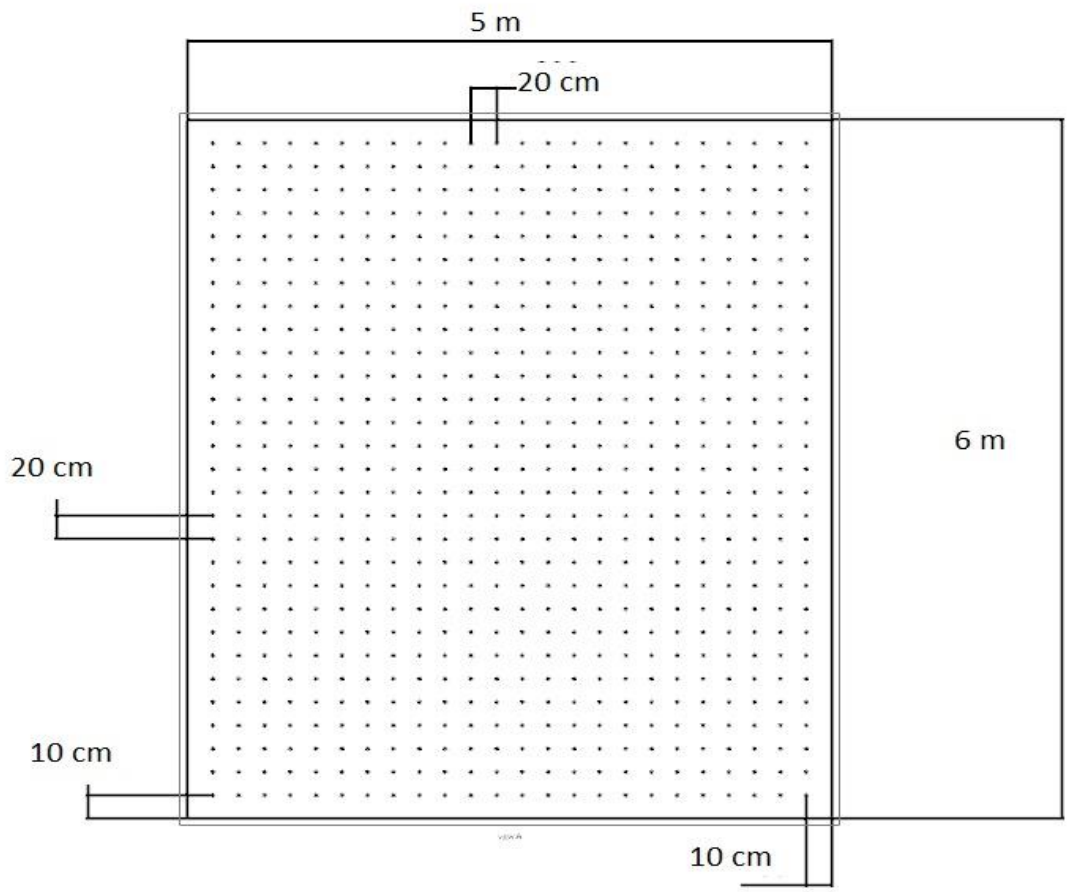

Figure 3.4: Plot Layout

3.3 Land Preparation

The experimental field was sprayed with non-selective systemic herbicides, Glyphader 480, containing 360 g/l Glyphosate at the rate of 2,055ml ha^{-1} with a knapsack sprayer on 15 July, 2014. Disc ploughing was carried out on 18 July, 2014 while disc harrowing was undertaken on 22 July, 2014.

3.4 Sowing and, Weed and Pest Control

NERICA 4 rice variety seeds were obtained from the SARI of CSIR. The crop was sown on 24 July 2014 at four seeds per hill and later thinned to one. Plant spacing of 20 cm by 20 cm was used giving a plant population of 250,000 plants ha^{-1}. Each plot measured 6 m long by 5 m wide. Weed control was carried out at four weeks after planting, six weeks after planting, and eight weeks after planting respectively using hand hoe. Insect pests were controlled with KOMBAT 2.5 EC non-systemic contact Acting Repellent insecticide containing 25g Lambda cyhalothrin per litre using a Knapsack Sprayer at a rate of 684.9ml ha^{-1} at five weeks after planting and eight weeks after planting respectively.

3.5 Fertiliser Application

NPK 15-15-15 fertilizer was applied in two split applications at a rate of 90-60-60 kg ha^{-1}. A basal fertilizer (NPK 15-15-15) was applied on 21 August, 2014 (i.e. four weeks after planting) at a rate of 60-60-60 kg ha^{-1} (400 kg ha^{-1}). The rest of the nitrogen was applied on 7 September, 2014 (seven weeks after planting) with 46% urea nitrogen as top dressing at a rate of 65.3kg ha^{-1}. The first fertilizer application was basal drilled between the rice plants, whereas the second application was top dressing. The method of applying fertilizer in drills prevents the fertilizer from being eroded by rainfall.

3.6 Data Collection

Data collected included plant height, number of leaves per plant, number of tillers, panicle length, panicle weight, number of spikelets per panicle, number of filled grains per panicle, 1000-grain weight, grain yield, rice dry matter yield, and weed dry matter yield. The soil physical properties collected were dry bulk density, moisture content, air content and total porosity.

3.6.1 Plant height and number of leaves per plant

Ten plants per plot were tagged for plant height and number of leaves determination. Data was collected once a week starting from the fourth week up to the thirteenth week after planting. Plant height was determined from the soil surface up to the apex of the plant using a metre rule, and the average of the 10 plant heights was calculated and recorded. The number of leaves per plant was determined by counting all the leaves on each plant. The mean of the 10 plants was used as the number of leaves per plant.

3.6.2 Number of tillers

The number of tillers was counted at nine and 12 weeks after planting for each plot using the 10 tagged rice plants.

3.6.3 Number of panicles, panicle length, panicle weight and number of spikelets per panicle

The number of panicles from the 10 tagged rice plants in each plot was counted and recorded before harvesting at 109 days after planting. The length of each panicle of the 10 plants was measured from the node to the uppermost panicle after harvest. The average panicle length of the 10 plants was calculated and recorded. Panicle weight was determined by measuring the mass of the ten panicles using an electronic balance. The average of the panicle weight was noted. The number of spikelet's for each panicle of the 10 plants was counted and their average was recorded.

3.6.4 Number of filled grains per panicle, 1000-grain weight and grain yield

The number of filled grains per panicle in each of the ten plants was counted and their average was recorded. The weight of 1000-grains from the ten tagged plants per plot was determined using an electronic balance. The grain yield was determined by measuring the total weight of grains obtained from the 10 tagged plants per plot after threshing and sun drying for three days. Grain yield was measured in grammes per plot, and then converted to kilogrammes per hectare.

3.6.5 Rice dry matter yield

Rice dry matter yield was determined by manually harvesting the 10 tagged rice plants per plot after harvesting the panicles. The plants were cleaned to remove traces of soil and placed in brown envelopes before oven drying them at 70 °C for 48 hours. The dry matter was taken using an electronic balance.

3.6.6 Weed samples and weed dry matter yield

Samples of types of weeds present at the experimental site were taken before ploughing for identification. At 25 days after planting, a one metre square quadrat was used on each plot and marked out. The weeds were carefully pulled out from the one metre square quadrat and separated into grass and broadleaf weeds in each plot. The samples were placed in brown envelopes and oven dried at 70 °C for 48 hours. The weed dry matter per plot was determined using an electronic balance.

3.6.7 Soil dry bulk density

A cylindrical soil core sampler of height 15 cm and 2 cm in diameter was used to take soil samples. Four core samples were collected at random from each of the 36 plots at the 0–15 cm and 15–30 cm soil layers before tillage, at flowering and after harvest respectively. The collected soil cores were weighed before oven drying them at 105 ^{o}C for 24 hours. Afterwards, the mass of oven dry soil was measured using an electronic balance. Soil dry bulk density was calculated by dividing the oven dry mass by the core volume of soil sample.

3.6.8 Soil moisture content

Four soil samples were taken at random locations in each plot from the 0–15 cm and 15–30 cm soil layers with a soil core sampler 15 cm long and 2 cm in diameter before ploughing, at flowering, and after harvest. Samples were oven–dried at 105 °C for 24 hours to determine the soil moisture content gravimetrically (ASABE Standards, 2008). The gravimetric moisture content was calculated as the mass of moisture in the soil sample divided by the mass of the dry soil multiplied by 100.

3.6.9 Soil air content

The air content of the soil in the 0–15 cm and 15–30 cm soil layers was calculated from the values of the total porosity and moisture content.

3.6.10 Soil total porosity

According to Chancellor (1994), total soil porosity can be calculated using the following equation:

$$Porosity = \left(1 - \frac{\rho_b}{\rho_p}\right)$$

where,

ρ_b = Dry bulk density (Mg m^{-3})

ρ_p = Particle density (Mg m^{-3}) = 2.65 Mg m^{-3} (Assumed)

Therefore, the total porosity of the soil in the 0–15 cm and 15–30 cm layers were calculated from the values of the dry bulk and particle densities.

3.7 Statistical Analyses

All crop and soil data collected were subjected to Analysis of Variance using the MINITAB Statistical software Release 15 (MINITAB Inc., 2007). Significant difference between treatments was determined using the Least Significant Difference test at level of 0.05.

4. RESULTS AND DISCUSSION

4.1 Introduction

The main objective of the study was to evaluate the effects of tillage and weeding frequency on NERICA 4 rice performance and soil physical properties. In this chapter, the results of the field study are presented and salient features discussed.

4.2 Effect of tillage and weeding frequency on rice growth and yield

4.2.1 Effect of tillage on plant height

Plant height is an important parameter that determines the growth of rice plant. The effect of different tillage treatments on plant height is presented in Fig. 4.1. At 13 weeks after planting, the results showed no significant difference in NERICA 4 rice plant height among the different tillage treatments.

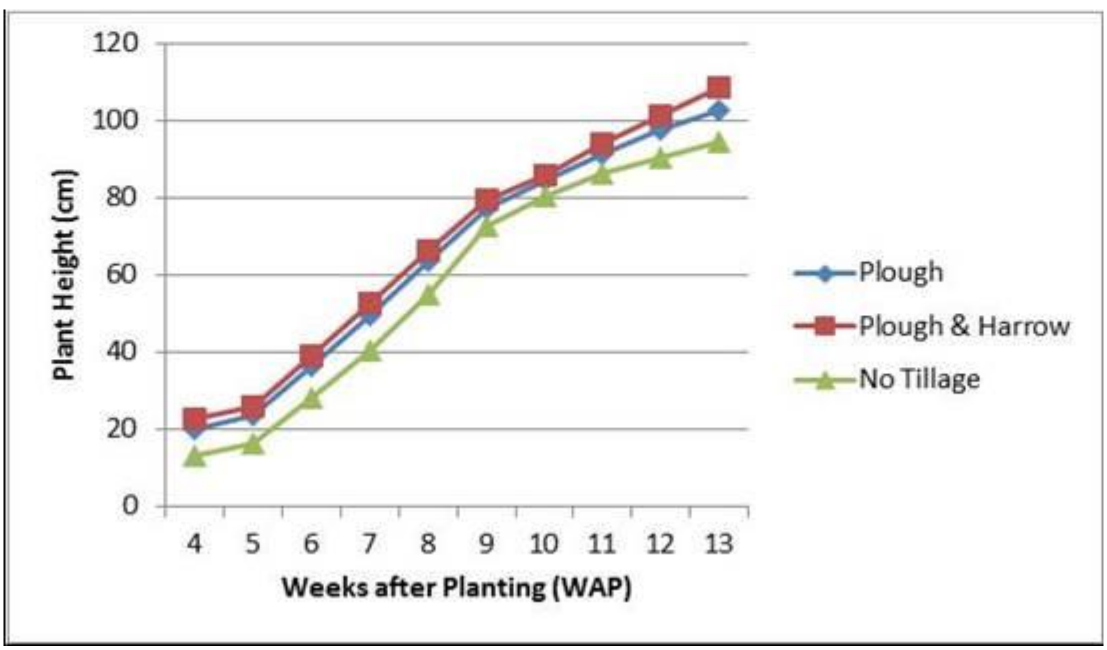

Figure 4.1: Effect of tillage on plant height

The tallest plant (108.8 cm) was observed in the disc ploughing followed by disc harrowing plots while the shortest plant (94.4 cm) was recorded in the no tillage plots. This result is similar to that of Zein El-Din *et al.* (2008) who recorded the tallest rice plants under conventional tillage in comparison with that under minimum tillage on sandy clay loam soil at the Agriculture Research Experimental Station, Faculty of Agriculture, Alexandria University, Egypt. However, Ujoh and Ujoh (2014) in contrast reported tallest rice plants in no tillage plots in comparison with that of disc ploughing followed by disc harrowing and disc ploughing only treatments on Acrisol soils, Yandev, in Central Nigeria.

4.2.2 Effect of weeding frequency on plant height

The effect of weeding frequency on plant height is illustrated in Fig. 4.2. At 13 weeks after planting, plant height was significantly affected by the weeding frequency treatments.

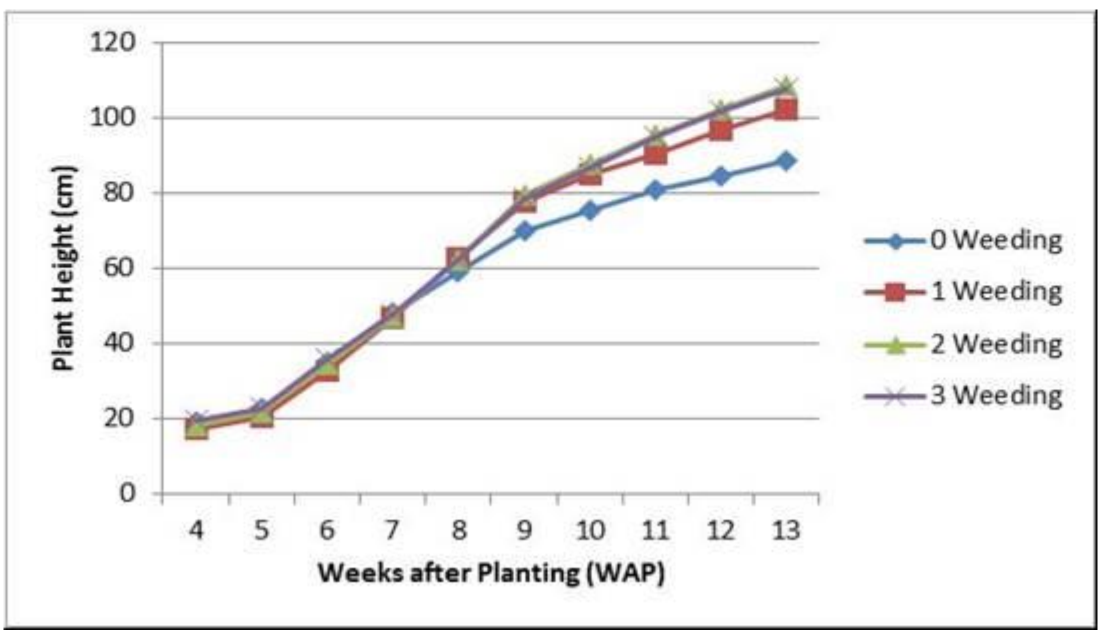

Figure 4.2: Effect of weeding frequency on plant height

Weeding twice produced the tallest plant (108.8 cm). Weeding three times resulted in plant height of (107.9 cm) while the no weeding treatment presented the shortest plant (88.8). There was no significant difference in plant height between the two times weeded plots and that of the three times weeded plots. The no weeding treatment gave plant height significantly smaller than that of weeding twice or thrice.

4.2.3 Effect of tillage on number of leaves per plant

Fig. 4.3 presents the effect of tillage on number of leaves per plant. At 13 weeks after planting, tillage did not show statistical significant difference in the number of leaves per plant between the different tillage treatments.

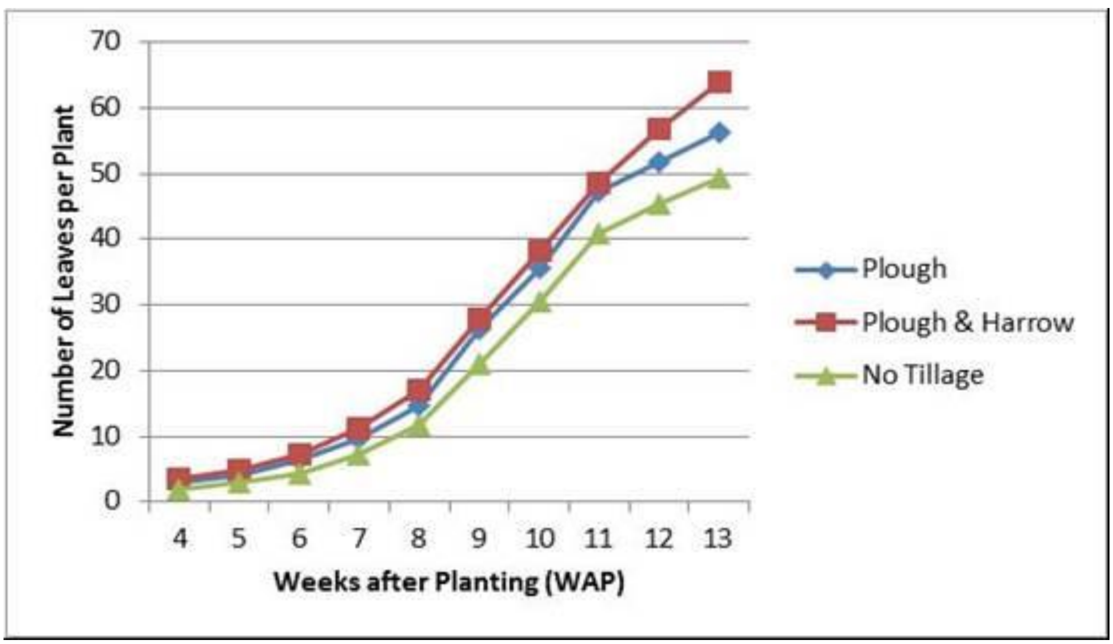

Figure 4.3: Effect of tillage on number of leaves per plant

The disc ploughing followed by disc harrowing treatment presented the highest number of leaves per plant (64.0). This was followed by disc ploughing only (56.2) while the lowest number of leaves per plant (49.4) was recorded in the no tillage plots. A similar result was reported by Anjum *et al.* (2014) under maize at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan.

4.2.4 Effect of weeding frequency on number of leaves per plant

Fig. 4.4 shows the effects of weeding frequency on number of leaves per plant. There was significant difference in number of leaves per plant between the different weeding frequencies. At 13 weeks after planting, the highest number of leaves per plant (80.0) was produced by weeding three times. This was followed by weeding two times with number of leaves per plant of 78.6, and weeding once (47.3). The lowest number of leaves per plant (20.2) was found in the no weeding plots.

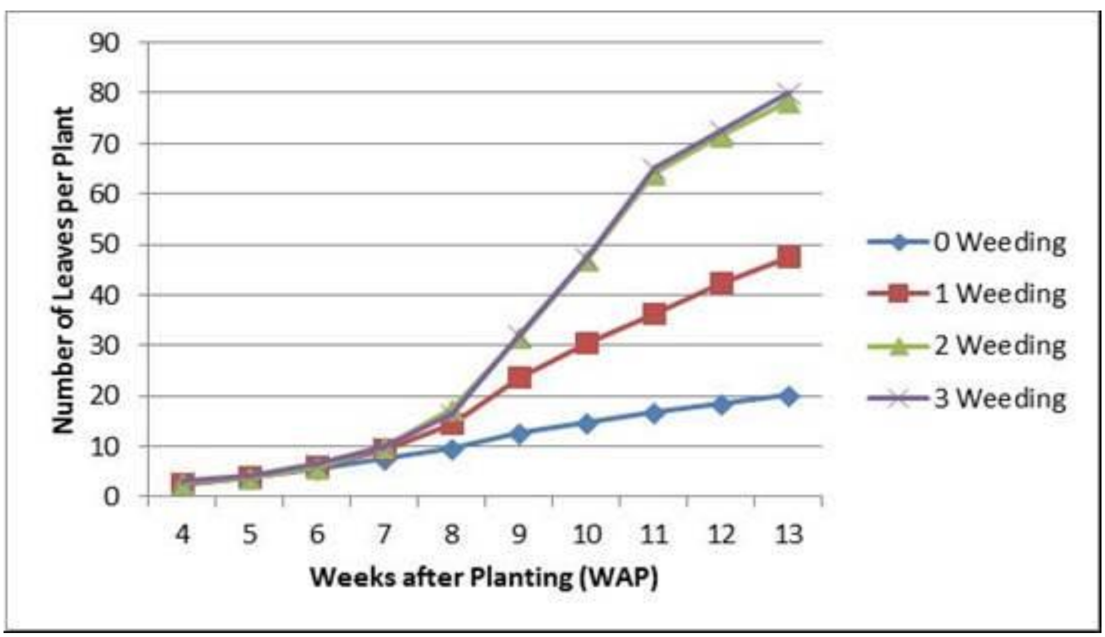

Figure 4.4: Effect of weeding frequency on number of leaves per plant

There was no difference in number of leaves per plant between weeding two and three times. Weeding three times was found to increase the number of leaves per plant of NERICA 4 rice. This might be due to lesser nutrient and moisture competition between the crop and weeds per unit area and the availability of more space to rice plant.

4.2.5 Effect of tillage on number of tillers per plant

Table 4.2 presents the effect of tillage on the number of tillers. Tillage treatments significantly influenced the number of tillers per plant of NERICA 4 rice. At nine weeks after planting, the disc ploughing followed by disc harrowing treatment recorded the highest number of tillers per plant (10.3) and this was statistically similar to that of the disc ploughing treatment (8.7). The no tillage treatment produced number of tillers (7.1) per plant statistically smaller than that of the other tillage treatments.

Table 4.2: Effect of tillage on number of tillers at nine and 12 weeks after planting

	Number of tillers/plant	
Tillage Treatment	9 WAP	12 WAP
Disc Plough	8.7	12.8
Disc Plough + Harrow	10.3	14.0
No Tillage	7.1	9.9
Average	8.7	12.2
LSD ($p < 0.05$)	1.65	2.49

Similarly, at 12 weeks after planting, the highest number of tillers per plant (14.0) was located in the disc ploughing followed by disc harrowing plots. This result was not statistically different from that of the disc ploughing treatment (12.8). The no tillage treatment resulted in the lowest number of tillers per plant (9.9) and this was statistically smaller than those of the other tillage treatments. A similar result was reported by Ujoh and Ujoh (2014) for rice in Yandev, in Central Nigeria.

4.2.6 Effect of weeding frequency on number of tillers

The effect of weeding frequency on number of tillers of NERICA 4 rice plant is presented in Table 4.3. Weeding frequency had significant effect on number of tillers per plant both at nine weeks and 12 weeks after planting. At nine weeks after planting, weeding three times presented the highest number of tillers per plant (11.9). This was closely followed by weeding two times (11.1). The lowest number of tillers per plant (3.9) was found in the no weeding plots significantly smaller than those of the other weeding treatments. Similarly, at 12 weeks after planting, the highest number of tillers per plant (18.4) was obtained in the weeding three times plots and this was statistically higher compared with those of the other weeding treatments. The lowest number of tillers per plant (4.9) was found in the no weeding plots. This result is similar to that of Hassan *et al.* (2010) who reported higher number of rice tillers in three weeding plots in Patuakhali Science and Technology University, Bangladesh.

Table 4.3: Effect of weeding frequency on number of tillers

Weeding Frequency Treatment	Number of tillers/plant	
	9 WAP	12 WAP
0 Weeding	3.9	4.9
1 Weeding	7.9	9.9
2 Weeding	11.1	15.7
3 Weeding	11.9	18.4
Average	8.7	12.2
LSD ($p < 0.05$)	1.47	1.88

4.2.7 Effect of tillage on number of panicles, panicle length, panicle weight and number of spikelet's per panicle

Table 4.4 sums up the effect of tillage on number of panicles, panicle length, panicle weight and number of spikelets per panicle. Tillage significantly influenced the number of panicles, panicle length, panicle weight and number of spikelets per panicle at 109 days after planting. For all the tillage treatments, the significance was in the order: disc ploughing followed by disc harrowing > disc ploughing only > no tillage.

Table 4.4: Number of panicles, panicle length, panicle weight and number of spikelets per panicle

Tillage Treatment	Number of Panicles	Panicle Length (cm)	Panicle Weight (g)	Number of Spikelets/Panicle
Disc Plough	3.6	24.88	3.6	12.5
Disc Plough + Harrow	4.4	25.92	4.0	13.4
No Tillage	3.0	22.76	2.7	10.6
Average	3.7	24.52	3.5	12.2
LSD ($p < 0.05$)	0.32	0.507	0.19	0.46

The highest number of panicles (4.4) was noted in the disc ploughing followed by disc harrowing plots. The no tillage resulted in the lowest number of panicles (3.0). Disc ploughing followed by disc harrowing gave the longest panicle (25.92 cm) while the shortest panicle (22.76 cm) was located in the no tillage plots. The disc ploughing followed by disc harrowing treatment produced the highest panicle weight (4.0 g). The smallest panicle weight (2.7 g) was recorded in the no tillage plots. Similarly, the disc ploughing followed by disc harrowing presented the highest number of spikelets per panicle (13.4) significantly higher than those of the other tillage treatments while the no tillage produced the lowest (10.6) number of spikelets per panicle. These results are similar to that of Zein El-Din *et al.* (2008) who reported higher rice panicle length, panicle weight and number of spikelets per panicle in conventional tillage plots in comparison with that of conservation tillage plots on sandy clay loam soil in Alexandria University, Egypt.

4.2.8 Effect of weeding frequency on number of panicles, panicle length, panicle weight and number of spikelets per panicle

Table 4.5 depicts the influence of weeding frequency on number of panicles, panicle length, panicle weight and number of spikelets per panicle at 109 days after planting. Weeding frequency statistically significantly affected the number of panicles, panicle length, panicle weight and number of spikelets per panicle of NERICA 4 rice. Weeding three times presented the highest number of panicles per plant (5.2), significantly higher than those of the other weeding treatments. The no weeding plots gave the lowest number of panicles (2.4).

Table 4.5: Number of panicles, panicle length, panicle weight and number of spikelets per panicle

Weeding Frequency Treatment	Number of Panicles	Panicle Length (cm)	Panicle Weight (g)	Number of Spikelets/Panicle
0 Weeding	2.4	22.77	2.6	9.9
1 Weeding	3.0	23.67	3.2	11.4
2 Weeding	4.0	25.30	3.8	13.2
3 Weeding	5.2	26.34	4.3	14.1
Average	3.7	24.52	3.5	12.2
LSD ($p < 0.05$)	0.32	0.4998	0.13	0.51

Weeding three times presented the longest panicle (26.3 cm). The shortest panicle (22.8 cm) was located in the no weeding plots. Weeding thrice gave the highest panicle weight (4.3 g) significantly greater than those of the other weeding frequency treatments. The no weeding treatment resulted in the smallest panicle weight (2.6 g). This result shows similar trend with that of Hassan *et al.* (2010). The highest number of spikelets per panicle (14.1) was noted in the weeding three times plots while the lowest number of spikelets per panicle (9.9) was found in the no weeding plots.

4.2.9 Effect of tillage on number of grains per panicle, 1000-grain weight and grain yield

The number of filled grains per panicle, 1000-grain weight and grain yield as affected by tillage at 109 days after planting are presented in Table 4.6. The number of filled grains per panicle, 1000-grain weight and grain yield were significantly influenced by tillage treatments. The disc ploughing followed by disc harrowing treatment gave the highest number of filled grains per panicle and 1000-grain weight was significantly higher than those of the no tillage treatment. There was no significant difference in number of filled grains per panicle and 1000-grain weight between the disc ploughing followed by disc harrowing treatment and that of the disc ploughing only treatment. The disc ploughing only treatment also resulted in number of filled grains per panicle and 1000-grain weight significantly higher than those of the no tillage treatment. This result is similar to that of Aikins *et al.* (2012) who observed higher 1000-grain weight under maize (*Zea mays* .L) in the disc ploughing followed by disc harrowing plots on sandy loam soil in Kumasi which is located in the semi-deciduous agro-ecological zone of Ghana. Zein El-Din *et al.* (2008) reported higher number of grains per panicle and 1000-grain weight under rice in conventional tillage as compared with those under conservation tillage on sandy clay loam soil in Alexandria University, Egypt.

Table 4.6: Number of filled grains per panicle, 1000 grain weight and grain yield

Tillage Treatment	Number of Filled Grains/Panicle	1000-Grain Weight (g)	Grain Yield (kg ha^{-1})
Disc Plough	130.0	24.9	3060
Disc Plough + Harrow	134.0	25.8	4073
No Tillage	110.7	22.6	2051
Average	124.8	24.4	3061
LSD ($p < 0.05$)	4.37	1.10	255

The results also show that the highest grain yield (4073 kg ha^{-1}) was recorded in the disc ploughing followed by disc harrowing plots while the lowest grain yield (2051 kg ha^{-1}) was observed in the no tillage plots. For all the tillage treatments, the significance in grain yield was in the order: disc ploughing followed by disc harrowing > disc ploughing only > no tillage. A similar result was reported by Ujoh and Ujoh (2014) who recorded higher rice yield in disc ploughing followed by disc harrowing plots compared with that under disc ploughing only and no tillage treatments on Acrisol in Yandev, Central Nigeria. Videnović *et al*. (2011) reported higher maize yield in conventional tillage plots in comparison with that of the no tillage plots on the chernozem soil type in Zemun Polje, Serbia.

4.2.10 Effect of weeding frequency on number of filled grains per panicle, 1000 grain weight and grain yield

Table 4.7 summarizes the effect of weeding frequency on number of filled grains per panicle, 1000-grain weight and grain yield at 109 days after planting. Weeding frequency significantly influenced the number of filled grains per panicle, 1000-grain weight and grain yield.

Table 4.7: Number of filled grain per panicle, 1000 grain weight and grain yield

Weeding Frequency Treatment	Number of Grains/Panicle	1000-Grain Weight (g)	Grain Yield (kg ha^{-1})
0 Weeding	99.3	22.0	1357
1 Weeding	117.0	23.8	2144
2 Weeding	137.6	25.2	3545
3 Weeding	145.7	26.6	5199
Average	124.9	24.4	3061
LSD ($p < 0.05$)	3.87	0.76	217

Weeding three times presented the maximum number of grains per panicle (145.7). The lowest number of grains per panicle (99.3) was recorded for the no weeding treatment. Weeding thrice resulted in the highest 1000-grain weight (26.6 g). The no weeding treatment produced the lowest 1000-grain weight of 22.0 g. Weeding three times produced the highest grain yield (5199 kg ha^{-1}). The lowest grain yield (1357 kg ha^{-1}) was recorded in the no weeding plots. Similar results were reported by Hassan *et al.* (2010) who recorded higher grain yield and 1000-grain weight under rice in the three weeding plots in comparison with those in the weeding twice and once plots. The increase in the number of grains per panicle, 1000-grain weight and grain yield of NERICA 4 rice under the three times weeding treatment over the other weeding treatments might be due to less nutrients, moisture, light and space competition between crop and weeds.

4.2.11 Effect of tillage on dry matter yield

NERICA 4 rice dry matter yield as affected by tillage at 109 days after planting is shown in Table 4.8. There was significant difference in dry matter yield between the three different tillage treatments. The disc ploughing followed by disc harrowing treatment had the highest dry matter yield (7187 kg ha^{-1}) while the no tillage treatment had the smallest dry matter yield (5007 kg ha^{-1}) which was below the average dry matter yield of 6195kg ha^{-1}.

Table 4.8: Effect of tillage on dry matter yield at 109 days after planting

Tillage Treatment	Dry Matter Yield (kg ha^{-1})
Disc Plough	6391
Disc Plough + Harrow	7187
No Tillage	5007
Average	6195
LSD ($p < 0.05$)	707.7

4.2.12 Effect of weeding frequency on dry matter yield

Table 4.9 depicts the effect of weeding frequency treatments on NERICA 4 rice dry matter yield at 109 days after planting. Weeding frequency significantly influenced the dry matter yield of NERICA 4 rice. Weeding three times produced the highest dry matter yield (10,117 kg ha^{-1}). This was followed by weeding two times (8,400 kg ha^{-1}). The smallest dry matter yield of 1,872 kg ha^{-1} was obtained in the no weeding plots. Hassan *et al.* (2010) reported similar result under rice in Bangladesh.

Table 4.9: Effect of weeding frequency on dry matter yield at 109 days after planting

Weeding Frequency Treatment	Dry Matter Yield (kg ha^{-1})
0 Weeding	1872
1 Weeding	4392
2 Weeding	8400
3 Weeding	10,117
Average	6195
LSD ($p < 0.05$)	423.1

4.2.13 Interaction effect of tillage and weeding frequency on plant height and number of leaves

The interaction effect of tillage and weeding frequency on plant height and number of leaves at 13 weeks after planting is presented in Table 4.10. There was no statistically significant difference in interaction effect on plant height between the tillage and weeding frequency treatments. The tallest plant (118.49 cm) was noted in the disc ploughing followed by disc harrowing, and weeding three times plots while the shortest plant (80.64 cm) was found in the no tillage and no weeding plots. Similarly, the highest number of leaves per plant (94.3) was produced by the disc ploughing followed by disc harrowing and weeding three times treatment while the smallest number of leaves per plant (19.8) was located in the no tillage and no weeding plots.

Table 4.10: Interaction effect of tillage and weeding frequency on plant height and number of leaves per plant

Tillage x Weeding Frequency	Plant Height (cm) at 13 WAP	Number of Leaves/ Plant at 13 WAP
Disc Plough x 0 Weeding	95.54	19.9
Disc Plough x 1 Weeding	100.73	43.7
Disc Plough x 2 Weeding	108.60	79.0
Disc Plough x 3 Weeding	106.04	82.1
Disc Plough + Harrow x 0 Weeding	90.19	21.0
Disc Plough + Harrow x 1 Weeding	113.33	53.6
Disc Plough + Harrow x 2 Weeding	113.30	87.1
Disc Plough + Harrow x 3 Weeding	118.49	94.3
No Tillage x 0 Weeding	80.64	19.8
No Tillage x 1 Weeding	93.31	44.6
No Tillage x 2 Weeding	104.50	69.6
No Tillage x 3 Weeding	99.08	63.7
Average	101.98	56.5
LSD ($p > 0.05$)	NS	NS

4.2.14 Interaction effect of tillage and weeding frequency on number of tillers

Table 4.11 presents the interaction effect of tillage and weeding frequency on number of tillers per plant at nine weeks and 12 weeks after planting. Analysis of variance showed no statistically significant difference in number of tillers per plant between tillage and weeding frequency. At nine weeks after planting, the disc ploughing followed by disc harrowing and weeding three times treatment presented the highest number of tillers per plant (14.0) while the smallest number of tillers per plant (3.4) was found in the disc ploughing and no weeding plots. Similarly, at 12 weeks after planting, the highest number of tillers per plant (20.8) resulted from disc ploughing followed by disc harrowing and weeding three times treatment while the lowest (4.3) was produced by the no tillage and no weeding treatment.

Table 4.11: Interaction effect of tillage and weeding frequency on number of tillers

Tillage x Weeding Frequency	Number of tillers/Plant	
	9 WAP	12 WAP
Disc Plough x 0 Weeding	3.4	4.7
Disc Plough x 1 Weeding	7.0	9.3
Disc Plough x 2 Weeding	12.1	17.4
Disc Plough x 3 Weeding	12.2	19.7
Disc Plough + Harrow x 0 Weeding	4.6	5.8
Disc Plough + Harrow x 1 Weeding	10.3	11.5
Disc Plough + Harrow x 2 Weeding	12.4	17.7
Disc Plough + Harrow x 3 Weeding	14.0	20.8
No Tillage x 0 Weeding	3.5	4.3
No Tillage x 1 Weeding	6.5	9.0
No Tillage x 2 Weeding	8.9	11.9
No Tillage x 3 Weeding	9.7	14.6
Average	8.7	12.2
LSD ($p > 0.05$)	NS	NS

4.2.15 Interaction effect of tillage and weeding frequency on number of panicles, panicle length, panicle weight and number of spikelets per panicle

The interaction effect of tillage and weeding frequency on number of panicles, panicle length, panicle weight and number of spikelets per panicle at 109 days after planting is given in Table 4.12. Analysis of variance showed statistically significant difference in number of panicles, panicle length and panicle weight between the different tillage and weeding frequency interactions except for the number of spikelets per panicle. The disc ploughing followed by disc harrowing, and weeding three times treatment produced the highest number of panicles per plant (6.8) while the no tillage and no weeding treatment presented the smallest number of panicles per plant (2.1). The disc ploughing followed by disc harrowing, and weeding three times interaction also gave the longest panicle (27.53 cm), highest panicle weight (4.7 g) and highest number of spikelets per panicle (15.7). The shortest panicle (21.5 cm), smallest panicle weight (4.7 g) and smallest number of spikelets per panicle (8.3) were obtained from the interaction of no tillage and no weeding treatment.

Table 4.12: Interaction effect of tillage and weeding frequency on number of panicles, panicle length, panicle weight and number of spikelets per panicle

Tillage x Weeding Frequency	Number of Panicles	Panicle Length (cm)	Panicle Weight (g)	No. of Spikelets/Panicle
Disc Plough x 0 Weeding	2.6	23.20	2.8	10.3
Disc Plough x 1 Weeding	2.9	23.67	3.4	12.3
Disc Plough x 2 Weeding	4.0	25.83	3.9	13.3
Disc Plough x 3 Weeding	4.7	26.83	4.5	14.0
Disc Plough + Harrow x 0 Weeding	2.6	23.60	3.1	11.0
Disc Plough + Harrow x 1 Weeding	3.5	25.20	3.7	12.3
Disc Plough + Harrow x 2 Weeding	4.7	27.33	4.5	14.7
Disc Plough + Harrow x 3 Weeding	6.8	27.53	4.7	15.7
No Tillage x 0 Weeding	2.1	21.50	1.9	8.3
No Tillage x 1 Weeding	2.7	22.13	2.4	9.7
No Tillage x 2 Weeding	3.2	22.73	2.9	11.7
No Tillage x 3 Weeding	4.0	24.67	3.6	12.7
Average	3.7	24.52	3.5	12.2
LSD ($p \geq 0.05$)	0.53	0.8314	0.24	NS

4.2.16 Interaction effect of tillage and weeding frequency on number of filled grains per panicle, 1000-grain weight and grain yield

Table 4.13 shows the interaction effect of tillage and weeding frequency on number of filled grains per panicle, 1000-grain weight and grain yield at 109 days after planting. Apart from grain yield, there was no significant interaction effect on number of filled grains per panicle and 1000-grain weight. The highest number of grains per panicle (153.3), highest 1000-grain weight (28.0 g) and highest grain yield (7252 kg ha^{-1}) were observed in the disc ploughing followed by disc harrowing, and weeding three times plots. The no tillage and no weeding interaction gave the lowest number of grains per panicle (87.7), lowest 1000-grain weight (20.3 g) and lowest grain yield (923 kg ha^{-1}).

Table 4.13: Interaction effect of tillage and weeding frequency on number of filled grains per panicle, 1000-grain weight and grain yield

Tillage x Weeding Frequency	Number of Grain/Panicle	1000-Grain Weight (g)	Grain Yield (kg ha^{-1})
Disc Plough x 0 Weeding	102.7	22.4	1475
Disc Plough x 1 Weeding	121.7	24.3	2137
Disc Plough x 2 Weeding	144.0	25.7	3735
Disc Plough x 3 Weeding	151.7	27.4	4893
Disc Plough + Harrow x 0 Weeding	107.7	23.3	1672
Disc Plough + Harrow x 1 Weeding	127.7	25.0	2762
Disc Plough + Harrow x 2 Weeding	147.3	26.6	4608
Disc Plough + Harrow x 3 Weeding	153.3	28.0	7252
No Tillage x 0 Weeding	87.7	20.3	923
No Tillage x 1 Weeding	101.7	22.2	1533
No Tillage x 2 Weeding	121.3	23.4	2293
No Tillage x 3 Weeding	132.0	24.5	3453
Average	124.9	24.4	3061
LSD ($p \geq 0.05$)	NS	NS	374

NS = Not Significant

4.2.17 Interaction effect of tillage and weeding frequency on dry matter yield

The interaction effect of tillage and weeding frequency on dry matter yield at 109 days after planting is shown in Table 4.14. The dry matter yield of NERICA 4 rice was significantly affected by the interaction between tillage and weeding frequency. The highest dry matter yield (11,722 kg ha^{-1}) was obtained from the interaction between disc ploughing followed by disc harrowing, and weeding thrice. The lowest dry matter yield (1,345 kg ha^{-1}) was obtained from the interaction between no tillage and no weeding, which was smaller than the average dry matter yield (6,195 kg ha^{-1}) for all the interactions between tillage and weeding frequency.

Table 4.14: Interaction effect of tillage and weeding frequency on dry matter yield

Tillage x Weeding Frequency	Dry Matter Yield (kg ha^{-1})
Disc Plough x 0 Weeding	1995
Disc Plough x 1 Weeding	4712
Disc Plough x 2 Weeding	8425
Disc Plough x 3 Weeding	10432
Disc Plough + Harrow x 0 Weeding	2276
Disc Plough + Harrow x 1 Weeding	4908
Disc Plough + Harrow x 2 Weeding	9844
Disc Plough + Harrow x 3 Weeding	11722
No Tillage x 0 Weeding	1345
No Tillage x 1 Weeding	3557
No Tillage x 2 Weeding	6930
No Tillage x 3 Weeding	8198
Average	6195
LSD ($p < 0.05$)	837.5

4.3 Weeds identified in the study area and weed dry matter weight

Table 4.15 exhibits the weeds identified in the study area together with their families. Ten different species of weeds were identified. They included *Ageratum conyzoides Linn*, *Celosia laxa Schum. and Thonn*, *Phyllanthu amarus Schum and Thonn, Hyptis suaveolens (L). Poit*, *Spermacoce ruelliae Linn*, *Setaria pumila Roemer and Schulles*, *Digitaria sanguinalis Scop*, *Cynodon dactylon*, *Rottboellia cochinchinensis* and *Cyperus rotundus*.

Table 4.15: Weeds present at the experimental site

No.	**Species**	**Family**
1.	*Ageratum conyzoides Linn*	Asteraceae
2.	*Celosia laxa Schum. and Thonn*	Amarantheceae
3.	*Phyllanthu amarus Schum and Thonn*	Euphorbiaceae
4.	*Hyptis suaveolens (L). Poit*	Labiatae
5.	*Spermacoce ruelliae Linn*	Rubiaceae
6.	*Setaria pumila Roemer and Schulles*	Gramineae
7.	*Digitaria sanguinalis Scop*	Gramineae
8.	*Cynodon dactylon*	Gramineae
9.	*Rottboellia cochinchinensis*	Gramineae
10.	*Cyperus rotundus*	Cyperaceae

Table 4.16 presents the effect of tillage on weed dry matter yield at 25 days after planting. The data shows significant difference in weed dry matter yield between the three different tillage treatments. The highest weed dry matter yield for grasses, broadleaf, and both grasses and broadleaf was obtained from the no tillage plots. This was followed by the disc ploughing only plots. The lowest dry matter yield was presented by the disc ploughing followed by disc harrowing treatment. The low weed dry matter yield from the disc ploughing followed by disc harrowing treatment is probably the result of disturbance of the weeds due to the intense mechanical disturbance from disc ploughing followed by disc harrowing. Sornpoon and Jayasuriya (2013), and Prameela and George (2013) also observed similar trends. They found increased weed population and weed dry matter yield in zero tillage compared with minimum and conventional tillage systems.

Table 4.16: Effects of tillage on weed dry matter yield (kg ha^{-1}) at 25 days after planting

Tillage Treatment	Grasses	Broadleaf	Grasses and Broadleaf
Disc Plough	239.6	135.8	187.7
Disc Plough + Harrow	183.3	82.3	132.8
No Tillage	552.3	237.1	394.7
Average	325.1	151.7	238.4
LSD ($p < 0.05$)	180.4	54.6	

4.4 Effect of tillage and weeding frequency on soil physical properties

4.4.1 Effect of tillage on soil dry bulk density

Soil dry bulk density as influenced by tillage for the 0–15 cm and 15–30 cm soil layers before tillage (17 July, 2014), at flowering (6 October, 2014), and after harvest (10 Nov 2014) is presented in Table 4.17. Soil dry bulk density was not significantly affected by tillage treatments over the course of the study. The no tillage plots consistently had the lowest soil dry bulk density. In general, the disc ploughing only treatment resulted in the highest soil dry bulk density before tillage and at harvest. After harvest, the disc ploughing followed by disc harrowing treatment resulted in the highest soil dry bulk density. A similar result was reported by Alam *et al.* (2014) who observed the lowest soil dry bulk density for grey terrace soil under wheat-mungbean-rice cropping system in the zero tillage plots in comparison with that in the conventional tillage plots in the sub-tropical climatic conditions in Bangladesh. The results are in contrast to that of Aikins and Afuakwa (2012) who reported the lowest soil dry bulk density for sandy loam under cowpea (*Vigna unguiculata* (L) Walp) in the disc ploughing followed by disc harrowing plots in Kumasi located in the semi-deciduous agro-ecological zone of Ghana.

Table 4 17: Effect of tillage on Soil Dry Bulk Density (Mg m^{-3})

	Before Ploughing		At Flowering		After Harvest	
Tillage Treatment	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer
Disc Plough	1.39	1.53	1.41	1.53	1.31	1.43
Disc Plough+ Harrow	1.34	1.46	1.43	1.47	1.34	1.44
No Tillage	1.34	1.42	1.39	1.46	1.31	1.41
Average	1.36	1.47	1.41	1.49	1.32	1.43
LSD ($p > 0.05$)	NS	NS	NS	NS	NS	NS

4.4.2 Effect of weeding frequency on soil dry bulk density

The effect of weeding frequency on soil dry bulk density for the 0 – 15 cm and 15 – 30 cm soil layers is given in Table 4.18. The results indicate that there was no significant difference in soil dry bulk density before tillage (17 July, 2014), at flowering (6 October, 2014), and after harvest (10 Nov 2014) between the weeding frequency treatments. Soil dry bulk density before tillage in the no weeding plots was the highest for the 0–15 cm soil layer. However, soil dry bulk density after harvest in the no weeding plots was the lowest among the weeding frequency treatments. On the other hand, soil dry bulk density in the weeding twice and weeding thrice plots before tillage were smaller than that of the no weeding plots, they were higher compared with that in the no weeding plots after harvest.

Table 4.18: Effect of weeding frequency on soil dry bulk density (Mg m^{-3})

Weeding Frequency	Before Ploughing		At Flowering		After Harvest	
	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer
0 Weeding	1.42	1.47	1.45	1.49	1.28	1.41
1 Weeding	1.35	1.47	1.40	1.47	1.33	1.41
2 Weeding	1.32	1.49	1.37	1.51	1.33	1.44
3 Weeding	1.34	1.44	1.41	1.48	1.36	1.45
Average	1.36	1.47	1.41	1.49	1.32	1.43
LSD ($p > 0.05$)	NS	NS	NS	NS	NS	NS

NS = Not Significant

4.4.3 Effect of tillage on soil moisture content

The results of the effect of tillage on soil moisture content before tillage (17 July, 2014), at flowering (6 October, 2014), and after harvest (10 Nov 2014) in the 0 – 15 cm and 15 – 30 cm soil layers are given in Table 4.19. Tillage did not have significant effect on soil moisture content in both the 0–15 cm and 15–30 cm soil layers over the course of the experimental period.

Table 4.19: Effect of tillage on soil moisture content (%)

Tillage Treatment	Before Ploughing		At Flowering		After Harvest	
	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer
Disc Plough	9.35	8.76	10.12	10.24	8.01	10.02
Disc Plough+ Harrow	9.56	8.58	10.35	9.76	8.55	10.68
No Tillage	10.10	8.66	11.19	10.23	8.16	9.77
Average	9.67	8.67	10.56	10.08	8.24	10.16
LSD ($p > 0.05$)	NS	NS	NS	NS	NS	NS

NS = Not Significant

The moisture content in no tillage plots was the highest among the tillage treatments in the 0–15 cm soil layer before ploughing. However, after harvest, the moisture content in no tillage plots was lowest among the tillage treatments in the 15 – 30 cm soil layer. On the other hand, the moisture content in disc ploughing followed by disc harrowing plots was the second highest among the tillage treatments in the 0–15 cm soil layer before ploughing. However, after harvest, the moisture content in the disc ploughing followed by disc harrowing plots was highest among the tillage treatments in both the 0–15 cm and 15 – 30 cm soil layers. This result is similar to that of Aikins and Afuakwa (2012) who reported higher soil moisture content in disc ploughing followed disc harrowing plots in comparison with those of disc ploughing only and no tillage treatments for sandy loam soil under cowpea (*Vigna unguiculata* (L) Walp) in Kumasi located in the semi-deciduous agro-ecological zone of Ghana.

4.4.4 Effect of weeding frequency on soil moisture content

The response of soil moisture content to weeding frequency is presented in Table 4.20. There was no significant difference in moisture content between the different weeding frequencies before ploughing. The no weeding treatment and weeding twice treatments had the highest and lowest soil moisture content before ploughing respectively in the 0 – 15 cm soil layer. Again, the no weeding treatment plots had the highest moisture content before ploughing in the 15 – 30 cm soil layer while the weeding thrice plots had the second highest moisture content before ploughing in the 15 – 30 cm soil layer.

Table 4.20: Effect of weeding frequency on soil moisture content (%)

Weeding Frequency	Before Ploughing		At Flowering		After Harvest	
	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer
0 Weeding	9.89	9.07	10.95	11.34	7.78	9.30
1 Weeding	9.85	8.24	10.93	9.61	7.89	9.92
2 Weeding	9.04	8.48	9.87	9.35	8.86	10.35
3 Weeding	9.89	8.89	10.47	10.01	8.43	11.05
Average	9.67	8.67	10.56	10.08	8.24	10.16
LSD ($p > 0.05$)	NS	NS	NS	1.103	0.830	0.913

NS = Not Significant

The result showed significant difference in soil moisture content at flowering only in the 15 – 30 cm soil layer. Furthermore, analysis of variance showed significant difference in moisture content between the different weeding frequencies after harvest in both the 0 – 15 cm and 15 – 30 cm soil layers. At flowering, the no weeding treatment presented the highest moisture content in both the 0 – 15 cm and 15 – 30 cm soil layers while the lowest moisture content was located in the weeding two times plots. After harvest, the weeding twice treatment presented the highest soil moisture content while the no weeding treatment gave the lowest soil moisture content in the 0 – 15 cm soil layer. Similarly, the no weeding treatment resulted in the lowest soil moisture content while the weeding thrice treatment resulted in the highest moisture content in the 15 – 30 cm soil layer.

4.4.5 Effect of tillage on soil air content

The results of statistical analysis of soil air content in the 0–15 cm and 15–30 cm soil layers as affected by tillage before ploughing (17 July, 2014), at flowering (6 October, 2014), and after harvest (10 Nov 2014) are summarized in Table 4.21. Analysis of variance did not show significant difference in air content between the different tillage treatments over the course of the study.

Table 4.21: Effect of tillage on soil air content (%)

Tillage Treatment	Before Ploughing		At Flowering		After Harvest	
	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer
Disc Plough	34.59	28.81	32.22	26.54	40.02	31.86
Disc Plough+ Harrow	36.49	32.48	31.37	29.97	38.07	30.04
No Tillage	36.05	33.98	31.96	29.91	39.82	32.98
Average	35.71	31.76	31.85	28.81	39.30	31.63
LSD ($p > 0.05$)	NS	NS	NS	NS	NS	NS

NS = Not Significant

4.4.6 Effect of weeding frequency on soil air content

The effect of weeding frequency on soil air content in the 0 – 15 cm and 15 – 30 cm soil layers before ploughing (17 July, 2014), at flowering (6 October, 2014), and after harvest (10 Nov 2014) is shown in Table 4.22. Different weeding frequency treatments had no significant effect on soil air content over the course of the study.

Table 4.22: Effect of weeding frequency on soil air content (%)

Weeding Frequency	Before Ploughing		At Flowering		After Harvest	
	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer
0 Weeding	32.91	31.21	29.25	26.86	41.98	33.79
1 Weeding	35.78	32.32	31.76	30.19	39.04	32.65
2 Weeding	38.07	31.04	34.59	28.70	38.25	30.92
3 Weeding	36.09	32.44	31.80	29.46	37.94	29.15
Average	35.71	31.75	31.85	28.80	39.30	31.63
LSD ($p > 0.05$)	NS	NS	NS	NS	NS	NS

NS = Not Significant

4.4.7 Effect of tillage on soil total porosity

The mean values of total porosity obtained in the 0 – 15 cm and 15 – 30 cm soil layers under the three different tillage treatments over the period of study are presented in Table 4.23.

Table 4.23: Effect of tillage on soil total porosity (%)

Tillage Treatment	Before Ploughing		At Flowering		After Harvest	
	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer
Disc Plough	47.68	42.31	46.63	42.26	50.53	46.11
Disc Plough+ Harrow	49.39	45.03	46.23	44.38	49.50	45.50
No Tillage	49.33	46.36	47.53	44.90	50.54	46.79
Average	48.80	44.57	46.80	43.85	50.19	46.13
LSD ($p > 0.05$)	NS	NS	NS	NS	NS	NS

NS = Not Significant

Tillage did not have significant effect on soil porosity before ploughing (17 July, 2014), at flowering (6 October, 2014), and after harvest (10 Nov 2014). The no tillage plots consistently had the highest soil total porosity over the course of the study except for the 0 – 15 cm soil layer before ploughing. This result is similar to that of Alam *et al.* (2014) who reported highest soil total porosity for grey terrace soil under wheat-mungbean-rice cropping system in the zero tillage plots compared with that in the conventional tillage and minimum tillage plots in the subtropical climatic conditions in Bangladesh.

4.4.8 Effect of weeding frequency on soil total porosity

The effect of weeding frequency on total porosity in the 0–15 cm and 15–30 cm soil layers before ploughing (17 July, 2014), at flowering (6 October, 2014), and after harvest (10 Nov 2014) is presented in Table 4.24. Weeding frequency did not result in significant difference in soil porosity between the different weeding frequency treatments over the study period.

Table 4.24: Effect of weeding frequency on soil total porosity (%)

Weeding Frequency	Before Ploughing		At Flowering		After Harvest	
	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer	0–15 cm Layer	15–30 cm Layer
0 Weeding	46.43	44.54	45.16	43.76	51.87	46.91
1 Weeding	49.07	44.47	47.10	44.40	49.59	46.66
2 Weeding	50.19	43.76	48.25	42.91	50.00	45.80
3 Weeding	49.51	45.48	46.69	44.32	49.30	45.16
Average	48.80	44.56	46.80	43.85	50.19	46.13
LSD ($p > 0.05$)	NS	NS	NS	NS	NS	NS

NS = Not Significant

4.5 Interaction effect of tillage and weeding frequency on soil properties in the 0-15 cm layer (Before Ploughing - 17 July, 2014)

Table 4.25 summarizes the interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, air content and total porosity in the 0–15 cm soil depth before tillage (17 July 2014). Analysis of variance showed no significant difference in the mean values of soil dry bulk density, moisture content, air content and total porosity between tillage and weeding frequency. The maximum dry bulk density (1.48 Mgm^{-3}) was recorded by the no tillage and no weeding interaction while the minimum dry bulk density (1.27 Mgm^{-3}) was found in the no tillage and weeding thrice interaction plots. The highest soil moisture content (10.75%) was noted in the no tillage and weeding once interaction plots while the lowest soil moisture content (8.22%) was found in the no tillage and weeding twice interaction plots. The no tillage and weeding twice presented the maximum soil air content (40.92%) while the minimum soil air content (30.28%) was noted in the no tillage and no weeding plots. The maximum soil total porosity (52.18%) was recorded under the no tillage and weeding thrice treatment while the minimum total porosity (44.29%) was recorded under the no tillage and no weeding treatment.

Table 4.25: Interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, total porosity and air content in the 0–15 cm layer on 17 July, 2014

Tillage x Weeding Frequency	Dry Bulk Density (Mgm^{-3})	Moisture Content (%)	Air Content (%)	Total Porosity (%)
Disc Plough x 0 Weeding	1.38	9.85	34.25	47.93
Disc Plough x 1 Weeding	1.40	8.87	34.66	47.13
Disc Plough x 2 Weeding	1.38	9.44	34.40	47.77
Disc Plough x 3 Weeding	1.38	9.23	35.07	47.89
Disc Plough + Harrow x 0 Weeding	1.40	9.09	34.21	47.07
Disc Plough + Harrow x 1 Weeding	1.31	9.92	37.88	50.79
Disc Plough + Harrow x 2 Weeding	1.29	9.45	38.89	51.23
Disc Plough + Harrow x 3 Weeding	1.36	9.77	35.00	48.46
No Tillage x 0 Weeding	1.48	10.73	30.28	44.29
No Tillage x 1 Weeding	1.34	10.75	34.79	49.29
No Tillage x 2 Weeding	1.28	8.22	40.92	51.57
No Tillage x 3 Weeding	1.27	10.68	38.21	52.18
Average	1.36	9.67	35.71	48.80
LSD ($p > 0.05$)	NS	NS	NS	NS

4.6 Interaction effect of tillage and weeding frequency on soil properties in the 0-15 cm layer on 6 October, 2014

The interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, air content and total porosity in the 0–15 cm soil layer at flowering (6 October 2014) is presented in Table 4.26. There was no significant interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, air content and total porosity. The disc ploughing followed by disc harrowing and no weeding interaction presented the highest dry bulk density (1.49 Mgm^{-3}) while the lowest dry bulk density (1.32 Mgm^{-3}) was recorded by the no tillage and weeding twice interaction. The highest soil moisture content (11.73%) was found in the no tillage and weeding once plots while the lowest soil moisture content (9.07%) was presented by the disc ploughing followed by disc harrowing and weeding twice interaction treatments. The highest air content (36.59%) was located in the no tillage and weeding twice interaction plots while the lowest air content (27.58%) was recorded in the no tillage and no weeding interaction plots. The highest total porosity (50.16%) was found in the no tillage and weeding twice interaction plots while the lowest total porosity (43.83%) was obtained under the disc ploughing followed by disc harrowing and no weeding interaction plots.

Table 4.26: Interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, total porosity and air content in the 0–15 cm layer on 6 October, 2014

Tillage x Weeding Frequency	Dry Bulk Density (Mgm^{-3})	Moisture Content (%)	Air Content (%)	Total Porosity (%)
Disc Plough x 0 Weeding	1.40	10.46	32.33	47.01
Disc Plough x 1 Weeding	1.39	9.85	33.85	47.57
Disc Plough x 2 Weeding	1.43	10.28	31.01	46.03
Disc Plough x 3 Weeding	1.43	9.90	31.70	45.93
Disc Plough + Harrow x 0 Weeding	1.49	10.72	27.82	43.83
Disc Plough + Harrow x 1 Weeding	1.41	11.21	30.82	46.71
Disc Plough + Harrow x 2 Weeding	1.36	9.07	36.17	48.57
Disc Plough + Harrow x 3 Weeding	1.43	10.40	30.65	45.84
No Tillage x 0 Weeding	1.47	11.66	27.58	44.63
No Tillage x 1 Weeding	1.40	11.73	30.60	47.02
No Tillage x 2 Weeding	1.32	10.27	36.59	50.16
No Tillage x 3 Weeding	1.37	11.12	33.05	48.32
Average	1.41	10.56	31.85	46.80
LSD ($p > 0.05$)	NS	NS	NS	NS

4.7 Interaction effect of tillage and weeding frequency on soil properties in the 0-15 cm layer on 10 November, 2014

Table 4.27 displays the interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, air content and total porosity in the 0–15 cm soil layer after harvest (10 November 2014). The results showed no significant interaction effect of tillage and weeding frequency on dry bulk density, moisture content, air content and total porosity. The interaction effect of disc ploughing followed by disc harrowing and weeding thrice gave the highest bulk density, highest moisture content, lowest air content and lowest total porosity. The interaction effect of no tillage and no weeding presented the lowest dry bulk density, highest air content and highest total porosity. The interaction effect of disc ploughing and no weeding resulted in the lowest moisture content.

Table 4.27: Interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, total porosity and air content in the 0–15 cm layer on 10 November, 2014

Tillage x Weeding Frequency	Dry Bulk Density (Mgm^{-3})	Moisture Content (%)	Air Content (%)	Total Porosity (%)
Disc Plough x 0 Weeding	1.31	7.08	41.26	50.62
Disc Plough x 1 Weeding	1.35	7.70	38.77	49.14
Disc Plough x 2 Weeding	1.31	8.72	39.10	50.54
Disc Plough x 3 Weeding	1.28	8.53	40.93	51.81
Disc Plough + Harrow x 0 Weeding	1.31	7.83	40.51	50.64
Disc Plough + Harrow x 1 Weeding	1.31	8.40	39.65	50.64
Disc Plough + Harrow x 2 Weeding	1.36	8.59	37.15	48.80
Disc Plough + Harrow x 3 Weeding	1.38	9.37	34.98	47.93
No Tillage x 0 Weeding	1.21	8.41	44.17	54.36
No Tillage x 1 Weeding	1.35	7.58	38.71	48.99
No Tillage x 2 Weeding	1.31	9.27	38.50	50.66
No Tillage x 3 Weeding	1.38	7.37	37.91	48.16
Average	1.32	8.24	39.30	50.19
LSD ($p > 0.05$)	NS	NS	NS	NS

4.8 Interaction effect of tillage and weeding frequency on soil properties in the 15 - 30 cm layer on 17 July, 2014

Table 4.28 gives the interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, air content and total porosity in the 15 – 30 cm soil layer before ploughing (17 July 2014). Analysis of variance did not show significant interaction effect of tillage and weeding frequency on soil physical properties. The interaction effect of disc ploughing and weeding twice gave the highest dry bulk density, lowest air content, and lowest total porosity. The no tillage and weeding thrice interaction presented the lowest bulk density, highest moisture content and highest total porosity. The no tillage and weeding once gave the lowest moisture content. The disc ploughing followed by disc harrowing and weeding once produced the highest air content.

Table 4.28: Interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, total porosity and air content in the 15 - 30 cm layer on 17 July, 2014

Tillage x Weeding Frequency	Dry Bulk Density (Mgm^{-3})	Moisture Content (%)	Air Content (%)	Total Porosity (%)
Disc Plough x 0 Weeding	1.52	9.17	28.57	42.52
Disc Plough x 1 Weeding	1.53	9.04	28.15	42.06
Disc Plough x 2 Weeding	1.59	8.52	26.10	39.86
Disc Plough x 3 Weeding	1.46	8.31	32.41	44.77
Disc Plough + Harrow x 0 Weeding	1.45	9.09	32.00	45.26
Disc Plough + Harrow x 1 Weeding	1.41	8.20	35.53	47.02
Disc Plough + Harrow x 2 Weeding	1.49	8.16	31.74	43.91
Disc Plough + Harrow x 3 Weeding	1.48	8.87	30.66	43.92
No Tillage x 0 Weeding	1.43	8.93	33.07	45.84
No Tillage x 1 Weeding	1.47	7.46	33.29	44.34
No Tillage x 2 Weeding	1.39	8.75	35.28	47.51
No Tillage x 3 Weeding	1.38	9.51	34.26	47.75
Average	1.47	8.67	31.76	44.56
LSD ($p > 0.05$)	NS	NS	NS	NS

4.9 Interaction effect of tillage and weeding frequency on soil properties in the 15 - 30 cm layer on 6 October, 2014

In Table 4.29, the interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, air content and total porosity in the 15 – 30 cm soil layer at flowering (6 October 2014) is shown. Statistical analysis of variance showed no significant difference in soil physical properties. The disc ploughing and weeding two times interaction produced the highest dry bulk density, lowest air content and lowest total porosity. The disc ploughing followed by disc harrowing and weeding once interaction presented the lowest dry bulk density and highest air content. The no tillage and weeding two times interaction also resulted in the lowest dry bulk density. Additionally, the no tillage and weeding two times interaction resulted in the highest total porosity. The disc ploughing followed by disc harrowing and no weeding interaction gave the highest moisture content.

Table 4.29: Interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, total porosity and air content in the 15 - 30 cm layer on 6 October, 2014

Tillage x Weeding Frequency	Dry Bulk Density (Mgm^{-3})	Moisture Content (%)	Air Content (%)	Total Porosity (%)
Disc Plough x 0 Weeding	1.48	11.35	27.24	44.05
Disc Plough x 1 Weeding	1.54	10.71	25.39	41.89
Disc Plough x 2 Weeding	1.62	9.32	23.76	38.93
Disc Plough x 3 Weeding	1.48	9.58	29.76	44.18
Disc Plough + Harrow x 0 Weeding	1.46	12.01	27.29	44.85
Disc Plough + Harrow x 1 Weeding	1.43	8.74	33.54	46.06
Disc Plough + Harrow x 2 Weeding	1.49	9.05	30.20	43.72
Disc Plough + Harrow x 3 Weeding	1.51	9.25	28.85	42.88
No Tillage x 0 Weeding	1.53	10.66	26.04	42.37
No Tillage x 1 Weeding	1.45	9.37	31.63	45.24
No Tillage x 2 Weeding	1.43	9.69	32.16	46.09
No Tillage x 3 Weeding	1.43	11.21	29.79	45.89
Average	1.49	10.08	28.80	43.85
LSD ($p > 0.05$)	NS	NS	NS	NS

4.10 Interaction effect of tillage and weeding frequency on soil properties in the 15 - 30 cm layer on 10 November, 2014

Table 4.30 summarizes the interaction effect of tillage and weeding frequency on dry bulk density, moisture content, air content and total porosity. Analysis of variance did not show significant effect of tillage and weeding frequency on soil physical properties. The highest dry bulk density, highest moisture content, lowest air content and lowest total porosity were recorded in the disc ploughing followed by disc harrowing and weeding three times interaction plots. The interaction effect of no tillage and no weeding resulted in the lowest dry bulk density, highest air content and highest total porosity. Furthermore, the interaction effect of disc ploughing and no weeding presented the lowest moisture content.

Table 4.30: Interaction effect of tillage and weeding frequency on soil dry bulk density, moisture content, total porosity and air content in the 15 - 30 cm layer on 10 November, 2014

Tillage x Weeding Frequency	Dry Bulk Density (Mgm^{-3})	Moisture Content (%)	Air Content (%)	Total Porosity (%)
Disc Plough x 0 Weeding	1.42	8.61	34.24	46.44
Disc Plough x 1 Weeding	1.41	9.74	33.32	46.97
Disc Plough x 2 Weeding	1.46	10.12	30.12	44.88
Disc Plough x 3 Weeding	1.43	11.61	29.78	46.15
Disc Plough + Harrow x 0 Weeding	1.44	10.13	30.93	45.56
Disc Plough + Harrow x 1 Weeding	1.43	10.28	31.38	46.08
Disc Plough + Harrow x 2 Weeding	1.43	10.51	31.16	46.16
Disc Plough + Harrow x 3 Weeding	1.48	11.80	26.69	44.19
No Tillage x 0 Weeding	1.36	9.18	36.21	48.72
No Tillage x 1 Weeding	1.41	9.73	33.25	46.93
No Tillage x 2 Weeding	1.42	10.43	31.48	46.37
No Tillage x 3 Weeding	1.45	9.73	30.98	45.14
Average	1.43	10.16	31.63	46.13
LSD ($p > 0.05$)	NS	NS	NS	NS

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Effect of tillage and weeding frequency on plant height

There was no significant difference in NERICA 4 rice plant height between the three different tillage treatments at 13 weeks after planting. Disc ploughing followed by disc harrowing produced the tallest plant (108.83 cm). This was followed by the disc ploughing only treatment (102.73 cm). The no tillage treatment presented the shortest plant (94.38 cm). At 13 weeks after planting, analysis of variance showed significant difference in NERICA 4 rice plant height between the four different weeding frequencies. Weeding twice produced the tallest plant (108.80 cm). This was followed by weeding three times (107.87), and weeding once (102.46 cm). The no weeding treatment gave the shortest plant (88.79 cm). The no weeding treatment gave plant height significantly smaller than that of weeding twice or thrice. Weeding two times was statistically similar to that of weeding three times. There was no significant interaction effect of tillage and weeding frequency on plant height. The tallest plant (118.5 cm) was given by the interaction between disc ploughing followed by disc harrowing, and weeding thrice times. The interaction between no tillage and no weeding brought about the shortest plant (80.6 cm).

5.1.2 Effect of tillage and weeding frequency on number of leaves per plant

Tillage increased the number of leaves per plant although there was no significant difference in number of leaves per plant between the tillage treatments at 13 weeks after planting. Disc ploughing followed by disc harrowing presented the highest number of leaves per plant (64). Disc ploughing only produced the second highest number of leaves per plant (56.2) while the no tillage gave the lowest number of leaves per plant (49.4). Analysis of variance showed significant difference in NERICA 4 rice number of leaves per plant between the four different weeding frequencies. Weeding thrice produced the highest number of leaves per plant (80.0). This was followed by weeding two times (78.6), and weeding once (47.3). The no weeding treatment gave the lowest number of leaves per plant (20.2). The no weeding treatment gave plant height significantly smaller than that of the other weeding treatments. Weeding two times was statistically similar to that of weeding three times. The highest number of leaves per plant (94.3) was indicated by the interaction effect of disc ploughing followed by disc harrowing, and weeding three times while the lowest number of leaves per plant (19.8) was given by the interaction effect of no tillage and no weeding.

5.1.3 Effect of tillage and weeding frequency on number of tillers per plant

The results of the study showed significant difference in the number of tillers per plant between tillage treatments, and also, between weeding frequencies. At 12 weeks after planting, the disc ploughing followed by disc harrowing treatment produced the highest number of tillers per plant (14.0), followed by disc ploughing (12.8). The no tillage gave the lowest number of tillers per plant. Weeding three times presented the highest number of tillers per plant (18.4). This was followed by weeding two times (15.7), and weeding once (9.9). No weeding resulted in the lowest number of tillers per plant (4.9). Analysis of variance did not show significant interaction effect of tillage and weeding frequency on number of tillers per plant. The disc ploughing followed by disc harrowing and weeding thrice interaction produced the highest number of tillers per plant (20.8) while no tillage and no weeding interaction presented the lowest number of tillers per plant (4.3).

5.1.4 Effect of tillage and weeding frequency on number of panicles, panicle length, panicle weight and number of spikelets per panicle

The number of panicles, panicle length, panicle weight, and number of spikelets per panicle were significantly influenced by tillage and weeing frequency at 109 days after planting. The highest number of panicles (4.4), longest panicle (25.9 cm), highest panicle weight (4.0 g) and highest number of spikelets per panicle (13.4) were recorded by the disc ploughing followed by disc harrowing treatment. The poorest performance of number of panicles (3.0), panicle length (22.3 cm), panicle weight (2.7 g) and number of spikelets per panicle (10.6) was produced by the no tillage treatment. Weeding thrice recorded the highest of number of panicles (5.2), longest panicle (26.3 cm), highest panicle weight (4.3 g), and highest number of spikelets per panicle (14.1). The no weeding treatment had the lowest number of panicles (2.4), shortest panicle (22.3 cm), lowest panicle weight (2.6 g), and lowest number of spikelets per panicle (9.9).

There was significant interaction effect of tillage and weeding frequency on number of panicles, panicle length and panicle weight. The highest number of panicles (6.8), longest panicle (27.5 cm), and highest panicle weight (4.7 g) was presented by the disc ploughing followed by disc harrowing and weeding thrice interaction. The interaction effect of no tillage and no weeding produced the lowest number of panicles (2.1), shortest panicle (21.5 cm), and smallest panicle weight (1.9 g). There was no significant interaction effect of tillage and weeding frequency on number of spikelets per panicle. While disc ploughing followed by disc harrowing and weeding three times interaction effect resulted in the highest number of spikelets per panicle (15.7), the no tillage and no weeding interaction effect gave the smallest number of spikelets per panicle (8.3).

5.1.5 Effect of tillage and weeding frequency on number of filled grains per panicle, 1000 grain weight and rice grain yield

The number of filled grains per panicle, 1000-grain weight and grain yield were significantly influenced by tillage treatments. Disc ploughing followed by disc harrowing presented the highest number of filled grains per panicle (134.00), highest 1000-grain weight (25.8 g) and highest rice grain yield (4073 kg ha^{-1}). The no tillage treatment had the lowest number of filled grains per panicle (110.7), smallest 1000-grain weight (22.6 g) and smallest rice grain yield (2051 kg ha^{-1}). Weeding frequency also significantly influenced the number of filled grains per panicle, 1000-grain weight and grain yield. Weeding three times resulted in the highest number of filled grains per panicle (145.7), highest 1000-grain weight (26.6 g) and highest grain yield (5199 kg ha^{-1}). The no weeding treatment had the lowest number of filled grains per panicle (99.3), smallest 1000-grain weight (22.0 g) and smallest rice grain yield (1357 kg ha^{-1}).

Tillage and weeding frequency did not have significant interaction effect on number of filled grains per panicle and 1000-grain weight. The interaction effect of disc ploughing followed by disc harrowing, and weeding three times provided the highest number of filled grains per panicle (153.3) and highest 1000-grain weight (28.0). On the other hand, the no tillage and no weeding interaction effect delivered the smallest number of filled grains per panicle (87.7) and smallest 1000-grain weight (20.3). Tillage and weeding frequency significantly produced an interaction effect of 7252 kg ha^{-1} for disc ploughing followed by disc harrowing, and weeding three times, and 923 kg ha^{-1} for no tillage and no weeding.

5.1.6 Effect of tillage and weeding frequency on dry matter yield

Tillage produced statistically significant effect on NERICA 4 rice dry matter yield. The highest dry matter (7,187 kg ha^{-1}) was observed in the disc ploughing followed by disc harrowing plots. The lowest dry matter yield (5,007 kg ha^{-1}) was recorded in the no tillage plots. There was significant difference in NERICA 4 rice dry matter yield between the weeding frequency treatments. The highest NERICA 4 rice dry matter yield (10,117 kg ha^{-1}) was located in the thrice weeded plots while the lowest dry matter yield (1,872 kg ha^{-1}) was found in the no weeding plots. The interaction effect of disc ploughing followed by disc harrowing, and weeding three times, presented the highest NERICA 4 rice dry matter yield (11,722 kg ha^{-1}) while the no tillage and no weeding interaction gave the lowest dry matter yield (1,345 kg ha^{-1}).

5.1.7 Effect of tillage on weed dry matter yield

Different tillage treatments significantly influenced the weed dry matter yield at 25 days after planting. Weed dry matter yield ranged from 187.7 kg ha^{-1} for disc ploughing followed by disc harrowing to 394.675 kg ha^{-1} for no tillage.

5.1.8 Effect of tillage and weeding frequency on soil dry bulk density

There was no significant difference in soil dry bulk density before tillage, at flowering, and after harvest between the tillage treatments. The no tillage plots had the lowest soil dry bulk density over the course of the study. In general, the disc ploughing followed by disc harrowing treatment resulted in the highest soil dry bulk density. Similarly, weeding frequency had no significant effect on soil dry bulk density before ploughing, at flowering, and after harvest. Additionally, there was no interaction effect of tillage and weeding frequency effect on soil dry bulk density.

5.1.9 Effect of tillage and weeding frequency on soil moisture content

Tillage did not have significant effect on soil moisture content in both the 0–15 cm and 15–30 cm soil layers over the course of the experimental period. The no tillage plots had the highest moisture content among the tillage treatments in the 0–15 cm soil layer before ploughing. However, after harvest, the moisture content in the no tillage plots was the lowest among the tillage treatments in both the 0–15 cm and 15 – 30 cm soil layers. The result showed significant difference in soil moisture content at flowering only in the 15 – 30 cm soil layer. Furthermore, analysis of variance showed significant difference in moisture content between the different weeding frequencies after harvest in both the 0 – 15 cm and 15 – 30 cm soil layers. At flowering, the no weeding treatment presented the highest moisture content in the 15 – 30 cm soil layer while the lowest moisture content was located in the plots weeded twice. After harvest, the weeding twice treatment presented the highest soil moisture content while the no weeding treatment gave the lowest soil moisture content in the 0 – 15 cm soil layer. Similarly, the no weeding treatment resulted in the lowest soil moisture content while the weeding thrice treatment resulted in the highest moisture content in the 15 – 30 cm soil layer. There was no interaction effect of tillage and weeding frequency on soil moisture content.

5.1.10 Effect of tillage and weeding frequency on soil air content

There was no significant effect of tillage, weeding frequency or interaction effect on soil air content in both the 0 – 15 cm and 15 – 30 cm soil layers over the course of the study.

5.1.11 Effect of tillage and weeding frequency on soil total porosity

Tillage did not have significant effect on soil porosity in both the 0 – 15 cm and 15 – 30 cm soil layers before ploughing, at flowering, and after harvest. Similarly, weeding frequency had no significant effect on soil porosity before ploughing, at flowering, and after harvest. Additionally, there was no interaction effect of tillage and weeding frequency on soil total porosity.

5.2 Recommendations

Future research should be undertaken to investigate the long term effects of tillage and weeding frequency on NERICA 4 rice growth, yield, and soil physical properties in the Northern Region of Ghana. Economic analysis should also be carried out in order to determine the effects of tillage and weeding frequency on NERICA 4 rice growth, yield, and soil physical properties in the Northern Region of Ghana.

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