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Effects of Tillage, Soil Amendment and Weed Management Regime on Performance of Lowland Rice (*Oryza sativa* L.) in the Guinea Savannah

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ABSTRACT

Field experiment was carried out during the 2015 and 2016 cropping seasons at Integrated Water and Agricultural Development Limited (IWAD) in the Mamprugu Moaduri district of Northern region. The objectives of the study were to evaluate tillage system, soil amendment and weed management regime on the growth and yield of rice under lowland conditions. The experiment was laid out in split-split-plot design in three replications with tillage, soil amendment and weed management which constituted the main-plot, sub-plot and sub-sub-plot factors respectively. Tillage, soil amendment and weed management, each at three levels, were respectively made-up of zero tillage (ZT), minimum tillage (MT) and conventional tillage (CT); 2.5 tons/ha organic manure, 2 tons/ha biochar and 250 kg NPK/ha; and hand weeding at 3 and 6 weeks after planting (WAP), pre-emergence herbicide, and post-emergence herbicide. Post-emergence herbicide application supported earliest flower initiation (80-85 days) compared to manual weeding (82-92 days) and pre-emergence herbicides (83-90 days). The combination of zero tillage and pre-emergence herbicide weed management gave the highest number of tillers of 34.3 per hill and maximized grain yield (6661 kg/ha). Longest rice root length was 34 cm in zero tillage with compost amendments and pre-emergence herbicide treatments. Soil carbon stock below 40 cm soil depth was highest in zero tillage (0.89% C) compared to minimum tillage (0.65% C) and conventional tillage (0.55 % C). Results gave good indication of best land preparation, soil amendment and weed management practice that could promote sustainable cropping in sandy-loam textured lowland soils.

INTRODUCTION

Rice (*Oryza sativa* L.) is the second most important cereal after maize in Ghana and is fast becoming a cash crop for many farmers (MiDA, 2010). Beyond providing sustenance through income generation and human consumption, rice plays an integral, but important cultural role in many rural communities of Ghana (Gangwar *et al*., 2008). Annual per capita consumption of rice grew rapidly, from 17.5 kg in 1999 – 2001 to 22.4 kg in 2002–2004 and 24 kg in 2010 – 2011 (MOFA, 2013), whilst rice demand is projected to grow at a compound annual growth rate of 11.8 % in the medium term (MiDA, 2010).

Many industry players including government have intervened to improve on the output of the rice sector. Despite the interventions, the national average yield has remained low, between 2.5 t ha^{-1} (MoFA, 2013), and 2.2 t ha^{-1} (CRI/SARI/IFPI, 2013) below the national yield potential of 6.5 Mt/ha (MoFA 2011). Henceforth, Ghana is unable to meet local demand but relies on external sources.

Sustainable rice production by small holder farmers is very crucial in addressing the yawning gap of 38 % in production and consumption but this is hampered by several factors (Huang et al., 1998) such as poor land preparation, low soil fertility and early and heavy weed competition and allelopathy. These factors account for high cost of rice production. It is estimated that tillage cost accounted for about 20 % of the total cost of rice production (Bandara, et al., 2008). The inadequacy of tractors for land preparation has particularly, resulted in delays in rice crop cultivation in Ghana. Indeed, continuous tillage of land has been identified as a major source of development of soil hardpan, and soil erosion (Tilakaratne and Tilakeratne 2003).

Therefore, finding ways and means to cut down the tillage cost is important in reducing the expendicture in rice production. The adoption of alternative tillage rather than conventional method in rice production systems in rainfed lowland and upland rice production in Asia and sub-Saharan Africa is very limited despite reported cases of the benefits of successful adoption in other parts of the world. Crop establishment with zero-tillage is used widely for many crops around the world. It has the potential to save time, energy, water and labour during crop establishment (Piggin et al*.,* 2001). However, little research has been conducted on zero-tillage establishments in lowland rice cultivation in Ghana. One major constraint of the application of minimum or zero tillage in rice production is weed infestation. Weed management is synonymous with rice production. Rice at the seedling stage and indeed throughout its growth and developmental stages is very vulnerable to weed competition and allelopathy (Dzomeku et al*.,* 2015, in press). Weeds are at present the major biotic constraint to increased rice production worldwide. The importance of their management has been emphasized in the past by various authors (De Datta and Baltazar, 1996; Labrada, 1996; Ze-Pu Zhang, 1996). Application of pre=plant and preemeergence herbicides could suppress early weed growth in minimum and zero tillage practices in rice production. Although herbicide usage has increased productivity, there are several weed problems that remain unsolved by the use of herbicides commonly applied in rice cultivation. Research on new emerging herbicides need to be widely tested to prove their efficacy in weed management in the face of dwindling labour and heavy weed infestation.

The evaluation of soil tillage practices, soil amendments and weed management regimes for rice production in lowland areas in the region would provide information that could enhance adoption of farmers as cost of production might be reduced and productivity improved. Adoption of zero-tillage technique could minimize manual labour need and save cost of land preparation. The best possible combination of tillage, soil management and weed management could offer multiple advantages in rice production. The objectives of the study were to evaluate the synergy of tillage system, soil amendment and herbicide weed management regime on the growth and yield of rice under lowland conditions.

MATERIALS AND METHODS

Experimental Site

Field experiment was carried out during the 2015 and 2016 cropping seasons at Integrated Water and Agricultural Development Ltd, (IWAD) in the Mamprugu Moaduri district of the Northern region. The experimental field specifically was located at an elevation of 143 meters above sea level with the following coordinates; 10°16'60" N and 1°16'0" W. The study area is characterized with unimodal annual rainfall.

Experimental Design and Treatments

The experiment was laid out in split-split plot design with tillage, soil amendment and weeding regime each at three levels, and constituted the main-plot, sub-plot and sub-sub-plot factors respectively with 3 replications. Tillage was made-up of zero tillage (ZT), minimum tillage (MT) and conventional tillage (CT), whilst soil amendment comprised of application of 2.5 tons/ha organic manure (F1), 2 tons/ha biochar (F2) and 250 kg NPK/ha (F3). Weed management regime comprised of hand weeding at 3 and 6 weeks after planting (WAP, W1), pre-emergence herbicide applied immediately after sowing (W2) and post-emergence herbicide applied 4WAP (W3). The sub-sub-plot measured 5 m by 5 m with 1 m as alley and 2 m alley between plots and replications respectively.

Soil Water Infiltration Rate Test

This was conducted in the experimental plots with a view of establishing the rate of flow of water in the study site. Infiltration measurements were done on three spots per treatment. A double-ring infiltrometer with an inner ring diameter of 28 cm and outer ring diameter of 54 cm was used to conduct the infiltration test in situ. For the same surface area, the rate of infiltration was determined as the amount of water which penetrated the soil per unit time. The measurements exclusively took place in the inner ring through which the water runs vertically. The analysis of the infiltration test was based on Kostiakov (1932), which showed a decreasing infiltration rate with time. The equation by Kostiakov (1932) was used to compare the measured parameters with published literature values. The Kostiakov's equation has been found to fit field measured infiltration data especially over relatively short periods; that is, in the range of a few hours. The Kostiakov equation is described as follows:

$$i = c\,(t)a \quad (1)$$

Where, i = depth of infiltration (cm), t = time of infiltration (min), c and a = empirical constants.
This equation assumed that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time (Bedient and Huber, 1992). From the measured data on the field, the infiltration rate (mm/h) versus time (hour) was plotted, from which the Kostiakov's equation was determined for all the curves.

Agronomic Practices

Plots of ZT and MT were sprayed with glyphosate at the rate of 4 litres per ha, 2 weeks before the crop establishment. The MT was ripped prior to sowing whilst conventional tillage plots were prepared by ploughing to a depth of 15-20 cm using a tractor, followed by harrowing and levelling before crop establishment.
Compost at a rate of 2.5 tons/ha and biochar at 2.0 tons/ha were uniformly spread on the soil and incorporated prior to planting of rice. Sowing at crop spacing of 20 cm x 20 cm was done on the same day for all treatments. NPK (15-15-15) was applied at 250 kg/ha as basal application at 3 WAP and 50 kg N/ha of sulphate of ammonia as top dressing at 5WAP. Manual weeding using a hoe was done twice at 3 and 6 WAP on manual weed control treatments. The pre-emergence herbicide was applied immediately after sowing with one supplementary weeding whilst the post-emergence herbicide with once hand supplementary weeding was also applied.

Data Collection

Data was collected on the following parameters: soil physical and chemical properties, soil water infiltration, and soil carbon sequestration were taken before and after the experiment. Crop growth characters such number of seedlings emergence percentage, number of plants established per plot, number of leaves per plant, plant height at 21, 63 days after sowing (DAS) and at harvest were taken. Data on number of tillers per hill at 21, 63 DAS and at harvest, leaf area index at maximum tiller, canopy cover at maximum tiller, days to 50 % flowering and root length and root biomass after harvest were taken. Yield and yield component data included length of panicle, number of fertile spikelets per panicle, number of sterile spikelets per panicle, 1000 seed weight , grain yield, straw yield, biological yield and harvest index were collected.
Economics of production (cost benefit ratio and unquantifiable inputs) data were taken. Data on the cost of production as against the yield realized was gathered and analyzed.

Data Analysis

Data gathered for the two years was pooled together due to similarity and analyzed using analysis of variance (ANOVA) technique with the split-split-plot model in GENSTAT and the mean differences determined by LSD at 5% probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSIONS

Days to 50 % Flowering of Rice

Days to 50 % flowering was significantly ($p<0.05$) affected such that the earliest flowering was supported by zero tillage (82 days) with inorganic fertilizer and post-emergence herbicide application (Fig 1). Days to fifty percent flowering in rice is very important as it could offer opportunities to escape potential terminal drought and other environmental stresses. Zero tillage practices might have aided in overcoming edaphic constraints by reducing soil structure destsruction, soil erosion, loss of soil nutrients and soil organic matter. These together aided the rapid release of nutrients from the soil amendment and with the less competition from weeds due to the application of post-mergence herbicides, which perhaps provided conducive environment for plant growth and flower initiation.

According to Khairul Alarm et al, (2014) similar studies reported continuous tillage of soils affected the soil-water-plant ecosystem which impacted negatively on crop yield. In the face of rain unpredictability especially with terminal drought, the promotion of zero tillage, soil amendments (inorganic fertilizer) and post-emergence herbicide application could help farmers reduce the risk of delayed flowering in rice and hence better adaptation to climate change.

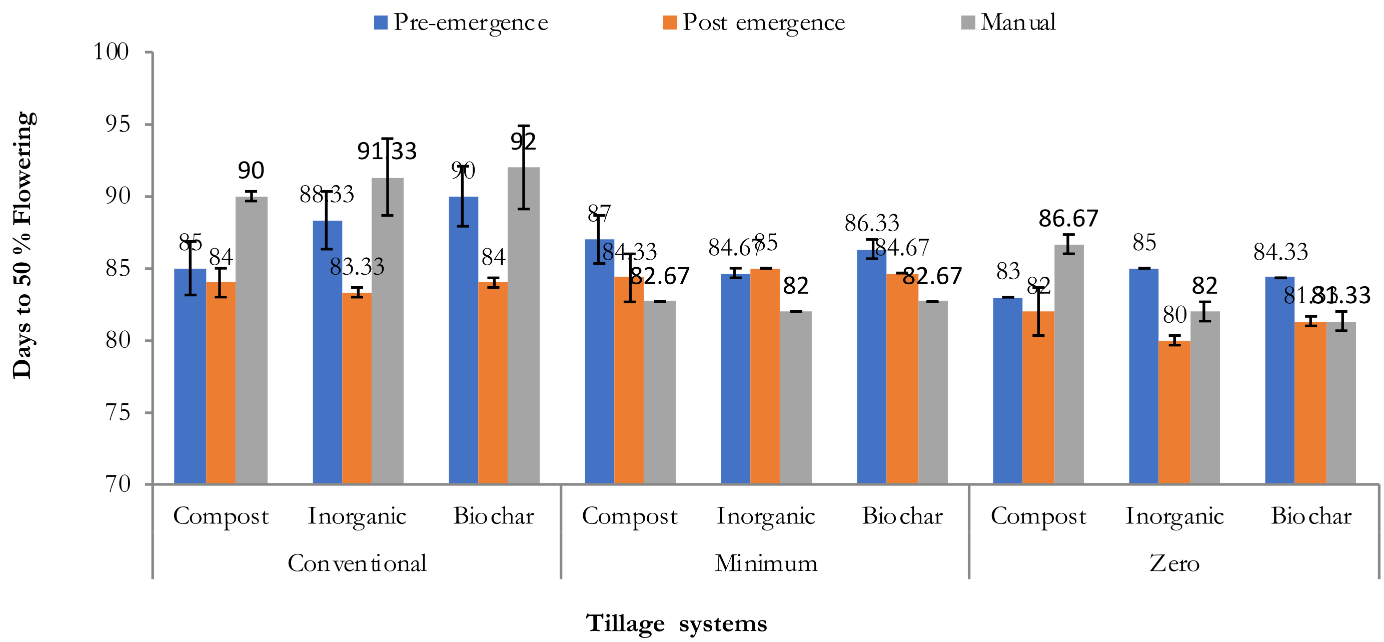

Figure 1: Days to 50% Flowering as Influenced by Tillage Type, Soil Amendment and Weed Management Regime. Bars Represents Standard Error.

Effective Tillering in Rice

Effective tiller count varied significantly among treatments with the combination of tillage system and weed management regimes significantly ($p<0.05$) affecting effective tiller count per hill such that zero tillage with pre-emergence herbicide application maximised the parameter with 38 tillers per hill (Fig. 2). It could be argued that the observation was due to ZT tends to stabilize soil structure, promote effective root development that absorbs nutrients better. The pre-emergence application of herbicides ensured that there was negligible weed interference and hence enhanced tillering, growth and development. The observation is similar to that of Zhao *et al.* (2009) that indicated tiller count in rice were more effective in conservational tillage fields compared with other tillage systems. The number of effective tiller count correlated with grain yield (Table 1) and the possible relationship between effective tiller count and yield is speculated by this study.

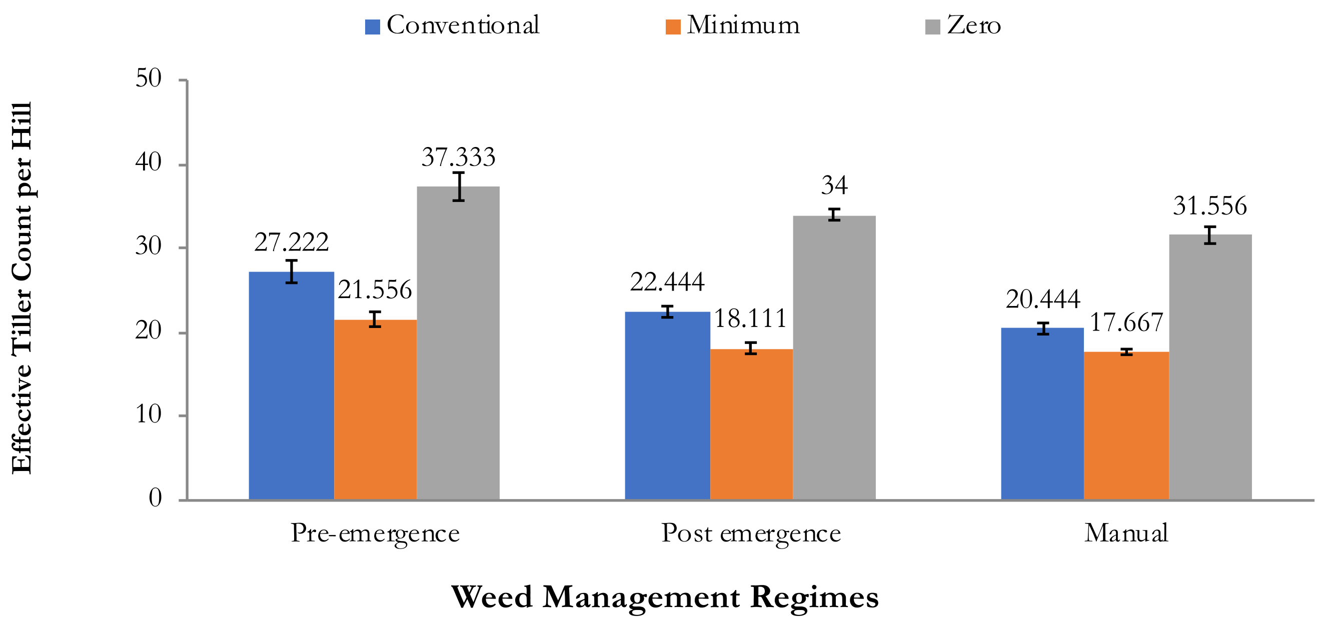

Figure 2: Tillering as Affected by Tillage and Weed Management Options. Bars Represents Standard Error.

Grain Yield of Rice

Grain yield was significantly ($p<0.05$) influenced by the combined effect of tillage system and weed management regime such that zero tillage and pre-emergence herbicide application gave highest grain yield of 6,661 kg/ha, whilst the least was achieved on minimum tillage and manual weed control (4,086 kg/ha) (Fig 3).

The difference in yield reflects the different adaptive capacity of the tillage system and effectiveness of the weed management regime. The effect of tillage on crop growth is mainly through the influence on soil moisture retention influenced by stability in soil structure. Zero tillage promoted extensive root development which aided the absorption of water and nutrients. These findings confirmed earlier studies by Rashidi and Keshavarzpour, (2007) that indicated conventional tillage practices caused destruction in soil structure and bulk density, reduction in soil moisture content; whilst conservation and no-tillage methods stabilizes soil natural status. This difference resulted in a change of characteristics of the pores network. The number, size, and distribution of pores again controlled the ability of soil to store and diffuse air, water, and agricultural chemicals and, thus, in turn, regulated erosion, runoff, and crop performance, (Khan, et al, 2001). Khairul Alarm et al, (2014)) found that percent organic matter (OM) content decreased in continuous tillage fields but gradually deposited in the soils no or minimum disturbance after four cropping cycles. A similar result was reported by Chan and Heenan (2005) in different tillage practices. Zero tillage with organic matter and crop residues in cropping systems was reported to increase soil organic matter significantly in the 0–25 cm soil layer compared to direct tillage (DT) after 4 years. Zhu *et al*. (1999) also observed a similar result where ZT had 4.3 % OM more in the 0–30 cm soil layer compared to traditional tillage in 4 years. In addition, improvements of crop yields have been documented where conservation tillage was practiced. Ma and Tong, (2007) reported the crop yield in conservation tillage was 10–20% higher than the conventional tillage in Shandong, northern China.

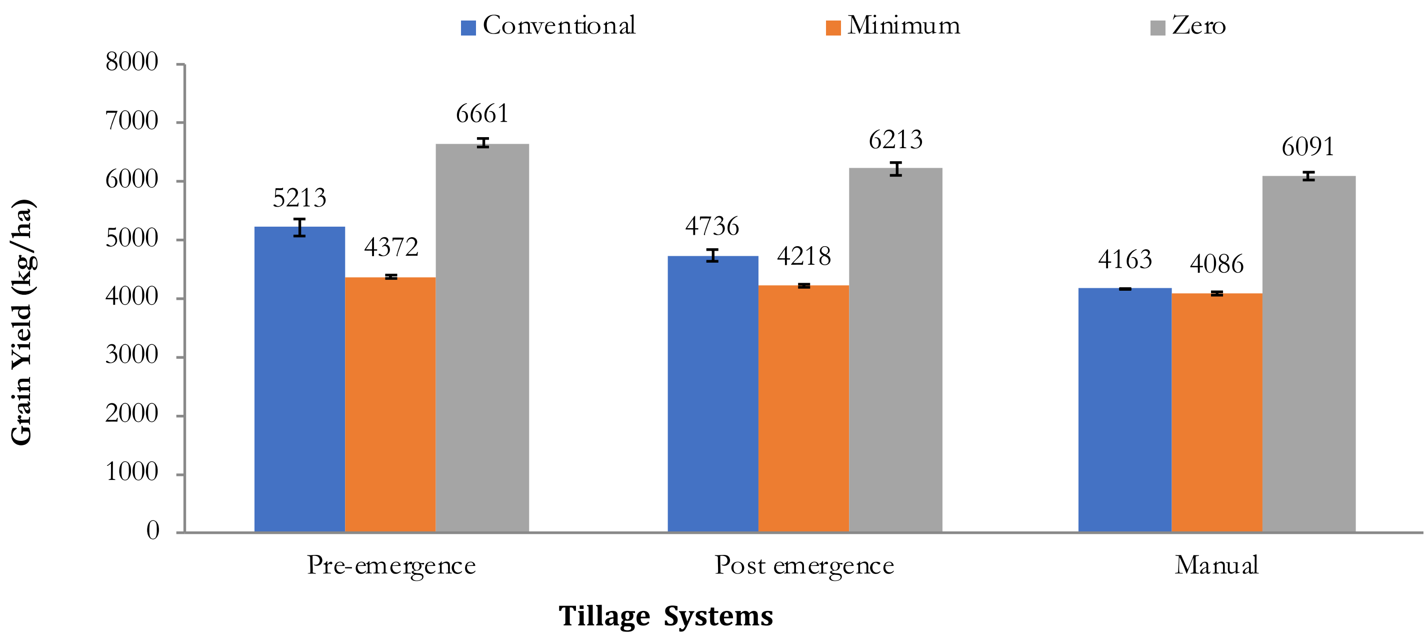

Figure 4: Response of Grain Yield of Rice to Tillage Methods under Various Weed Management Options. Bars Represents Standard Error.

Root Length Formation in Rice

Zero tillage system with compost amendments and pre-emergence herbicide favoured the longest root growth of 34 cm (Fig 4). The adoption of ZT system in combination with compost amendment which is believed to play a role in decrease of bulk density of the soil play important role in root development and distribution in the soil. The application of compost might have also promoted the improvement of other soil physical properties resulting in better root elongation. Songmuang et al. (1990) suggested that organic fertilizer might decrease soil bulk density and alleviate soil compaction. Accordinbg to Khairul Alarm, (2014), root extension might be obstructed by the dense or compact layer of the soil profile. Similar results were found by Parker and Lear, (1996) and Alam and Matin, (2002) in crops maize and wheat respectively

There was a positive correlation between growth in root length and grain yield (Table 1). Longer and healthy roots with consequential larger surface area could better trap nutrients and water for use by rice resulting in better formation of spikelets and grains.

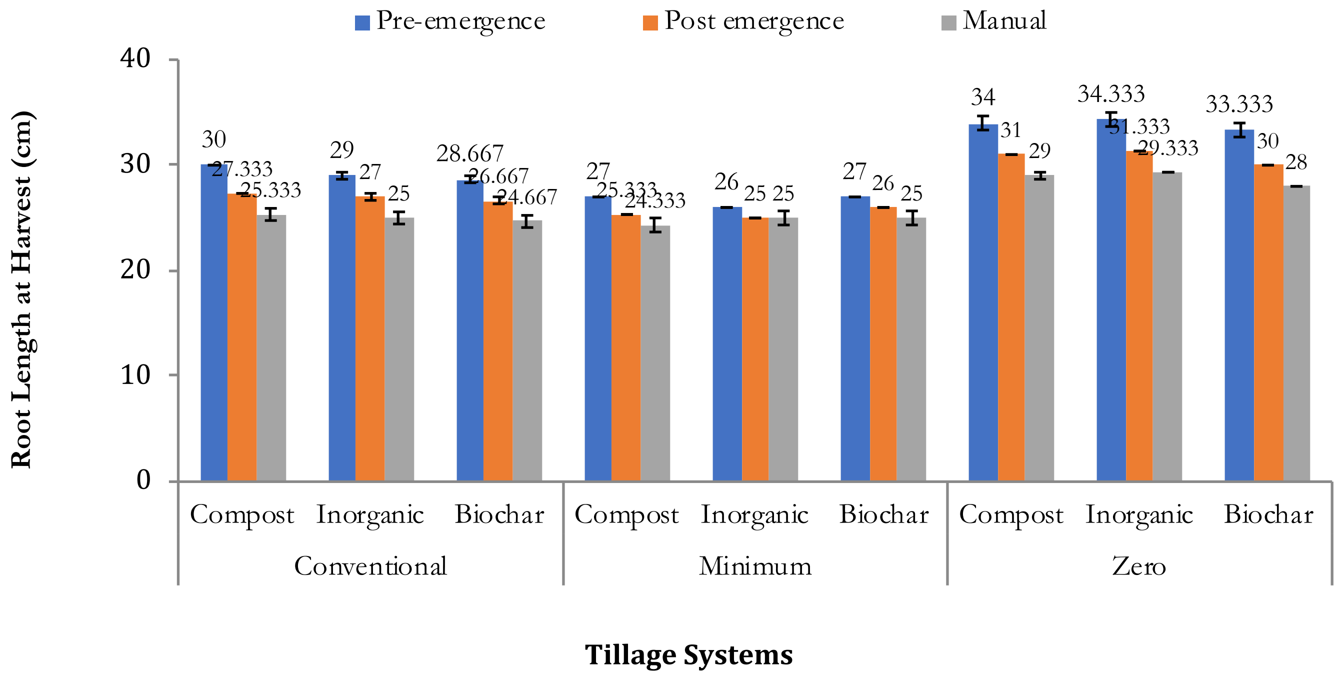

Figure 3: Root Length Growth in Rice as Influenced by Tillage and Weed Management Methods. Bars Represents Standard Error.

Straw Yield

The data revealed significant ($p<0.05$) difference in straw weight by the interaction effect of tillage system and weed management regime such that highest straw weight (19,983 kg/ha) was obtained under zero tillage, and pre-emergence herbicide, followed by zero tillage and post-emergence herbicide (18,640 kg/ha), followed by zero tillage and manual weeding (18,273 kg/ha) (Fig. 5).

Straw yield indicate the potential to accumulate dry matter in vegetative parts by the crop and it is due to the combined effects of all growth parameters such as tillering and plant height. Vigorous growth in rice plant during the vegetative stage supported by the treatments increased the production and output of straw produced. Spearman correlation conducted by the study (Table 1) showed a positive correlation (r = 0.58**) of straw weight with grain yield of rice.

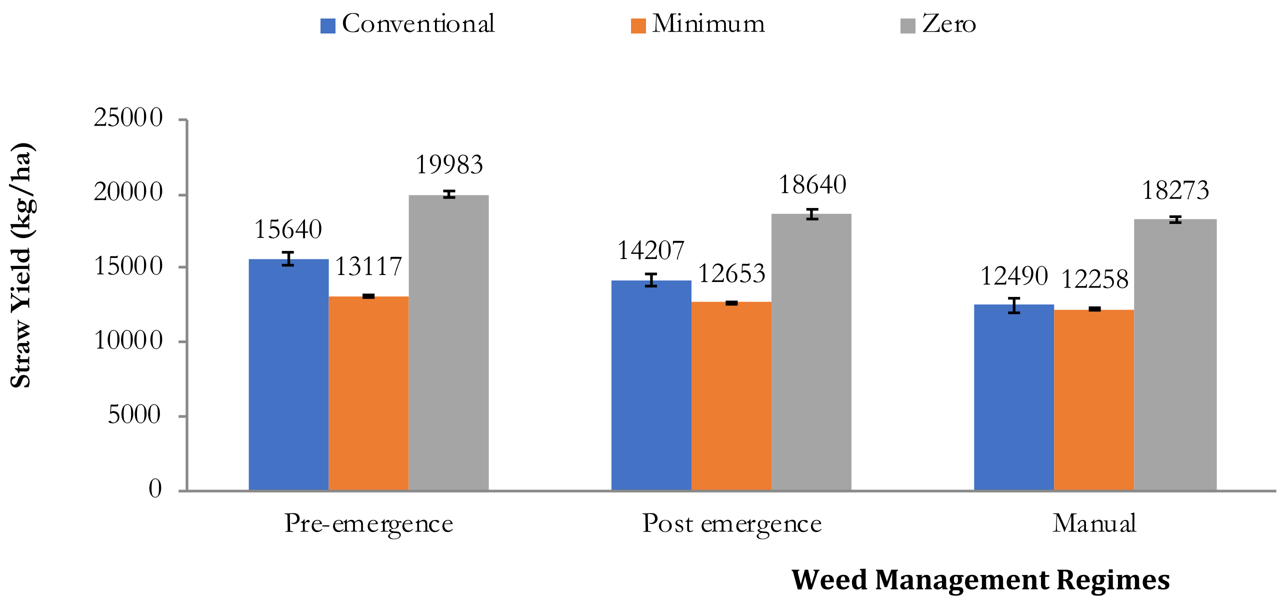

Figure 5: Straw Yield as Affected by Tillage and Weed Management Methods. Bars Represents Standard Error.

Correlation Analysis of Growth Parameters of Rice

Correlation analysis for growth paramters of rice was done and a number of these parameters correlated positively with grain yield. Tiler count, panicle length and fertile spikelets positively correlated with grain yield at significant level of p<0.01 (Table 1).

Table 1: Spearman's Correlation Coefficients (r) for Rice Parameters in 2016 Season

Parameter	GY	LAI	NFGP	PL	PH	SW	TCH	TSW	ETCH	FS
GY	-									
LAI	0.95**	-								
NFGP	0.92**	0.90**	-							
PL	0.91**	0.90**	0.95**	-						
PH	-0.11	-0.05	0.02	0.12	-					
SW	0.58**	0.62	0.36	0.40	-0.20	-				
TC/H	0.96**	0.95**	0.93**	0.92**	-0.03	0.57	-			
TSW	0.66	0.70	0.50	0.53	-0.25	0.86**	0.67	-		
ETCH	0.95**	0.95**	0.94**	0.52	-0.04	0.58**	0.95**	0.69	-	
FS	0.90**	0.93**	0.83**	0.82**	-0.12	0.69	0.90	0.77	0.91**	-

GY = Grain yield, LAI = Leaf area index, NFGP = Number of grain filled per panicle, PL = Panicle length, PH (63 DAP) = Plant height at 63 DAP, SW = Straw weight, TCH = Tiller count per hill, TSW

= 1000 seed weight, ETCH = Effective tiller count at harvest, FS = Fertile spikelets. ** = significant at $p<0.01$.

Soil Water Infiltration Rate

The average initial rate of water infiltration in the field was 159.72 mm/hr. Hence we could conclusively predict that the soil of the fields is sandy-loam. These findings of the pre-study is in line studies conducted by IWAD, (2013) that indicated that most soils in the lowland valleys in the study area are of sandy-loam in nature with high run off. These findings also confirmed the report of Kugbe and Zakaria (2015), that most soils in the study area were high in sand and low in clay content.

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The post experiment soil water infiltration rate was improved under zero tillage (from 224.36 mm/hr to 299.12 mm/hr) whilst CT showed reduced infiltration rate of 220 mm/hr from 224.36 mm/hr. MT had end infiltration rate of 250.01 mm/hr from 240.60 mm/hr (Fig.6).

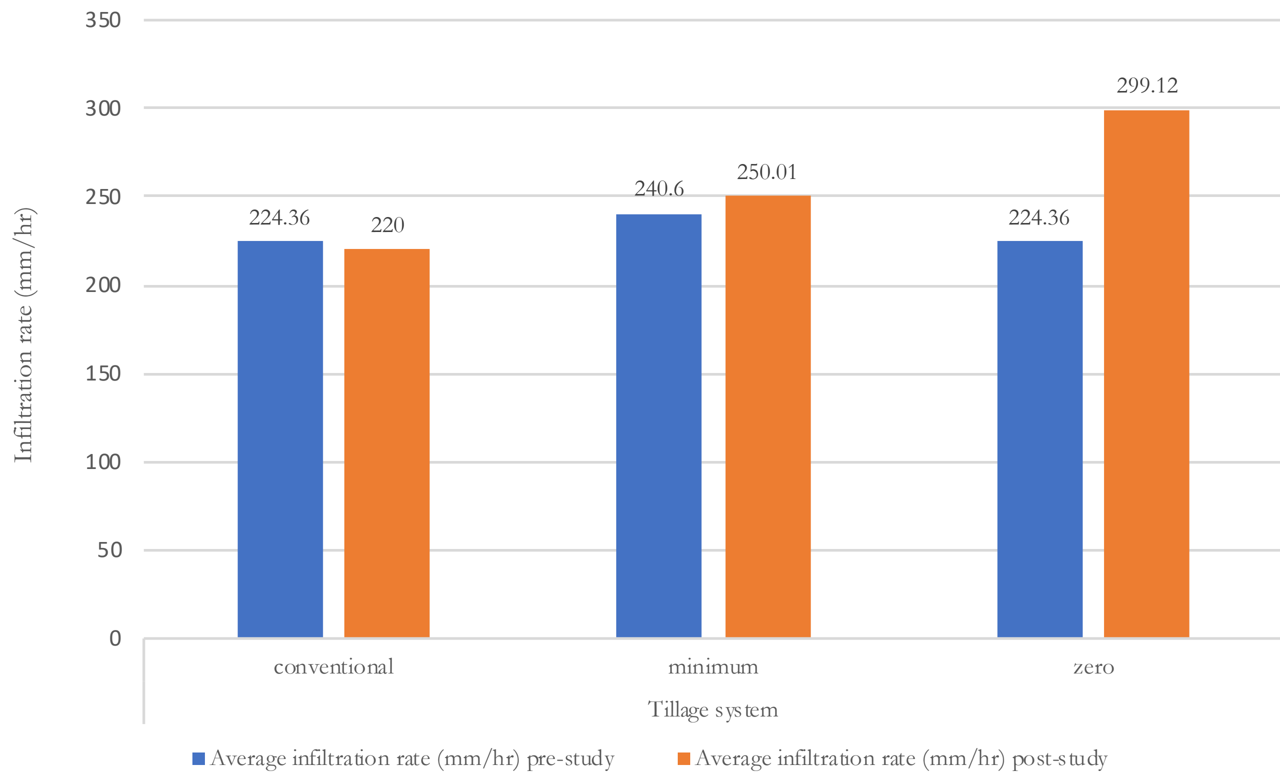

Figure 6: Soil Water Infiltration Rate as Influenced by Tillage Systems. Bars Represents Standard Error.

These findings indicate that zero tillage systems could have beneficial impacts on infiltration in low land valleys. Besides. This could lead to improvement soil structure as rate of decomposition of OM in the soil, resulting in increased water infiltration rate and reduction in runoff. Similar reports have been observed by Biamah et al. (1993); Alabi and Akintunde (2004); Abdalla and Mohamed (2007) and Theodor and Kassam (2009) and Giller et al. (2009). The reports further indicated increased soil water availability for plants as a result of reduced soil evaporation; reduced water run-off; increased water infiltration and reduced soil temperature oscillations. The findings indicated that whereever zero tillage system was adopted varied agronomic beneficial traits were noted.

Carbon Sequestration

Tillage systems affected soil biochemical and physical properties, sucg that soil carbon stock below 40 cm soil depth measured in the laboratory using standard procedure was highest in ZT (0.89% C) compared to MT (0.65% C) and CT (0.55 % C) (Table 2). Liang et al, (2012) reported higher carbon storage in CT treated paddy fields than from ZT paddy fields. However, Nyanadzawo et al., (2008) found that ZT had more soil organic carbon (SOC) than CT. The potential might exist for carbon sequestration under ZT in lowland rice fields. Further research is needed under different ecological systems and sampling depth to understand the sequestration of SOC.

Table 2: Organic Carbon (OC) Storage below 40 cm in Soil.

Pre-Experiment			Post-Experiment		
Treatment	PH	OC (%)	PH	OC (%)	Percentage Change in OC
CT	5.56	0.59	5.57	0.55	-6.7 %
MT	5.55	0.59	5.55	0.65	10.1 %
ZT	5.53	0.59	5.53	0.89	50.8 %

Soil Physical and Chemical Properties

Soil samples of the site were taken and chemical analysis carried out in the laboratory. The results of the analysis showed that tillage system had positive effects on soil properties (Table 3). Bulk and particle densities were decreased due to tillage practice. The highest NPK and S in available forms were recorded in ZT.

Post soil data analysis conducted indicated that chemical properties such as N, K has reduced. The reduced levels of the above nutrients could be due to the explanation provided by Baanante *et al.* (1992) that about two-thirds of the N applied to cereals is accumulated in the grain and is exported during harvest. Much of the remaining N and a greater proportion of K are located in the stover and will not necessarily be cycled back to the soil. However, P, Ca, and Mg recorded appreciable levels of increment.

The result obtained showed that generally the soil nutrients levels are low for sustainable rice production in the low land area. According to Buri et al, (2010), the observed nutrient levels for low land rice fields in Ghana are as follows; Nitrogen (0.88 g kg^{-1}), carbon (9.1 g kg^{-1}), magnesium (2.5mg kg^{-1}), phosphorus (3.2 mg kg^{-1}), potassium (0.3 kg^{-1}), calcium (4.8 kg^{-1}) and pH of 5.2. Zero tillage was found to be suitable for enhancing soil health and achieving optimum yield. These conclusions are similar to observations made by Khairul alarm *et al,* 2014.

Table 3: Soil Analysis of the Study Area Prior and Post Field Study

Post-experiment					Pre-experiment			
Treatment	N (%)	P (Mg/kg)	K (Mg/kg)	Mg (Mg/kg)	N (%)	P (Mg/kg	K	Mg Mg/kg
CT	0.0513	7.00	66.00	58.00	0.0689	6.01	93.11	32.84
MT	0.0515	7.06	67.90	58.02	0.0689	6.01	93.11	32.84
ZT	0.0575	7.16	67.96	58.02	0.0689	6.01	93.11	32.84

CONCLUSION

Results gave good indication of best land preparation by soil amendment and/or weed management practice that could promote sustainable rice cropping in lowland valleys especially with sandy-loam soils. Zero tillage was outstanding in combination with inorganic NPK fertilizer and post-emergence herbicide in enhancing early flowering in Agra-rice (80 days). ZT in combination with pre-emergence herbicide weed management maximized effective tiller count (38 per rice hill) and grain yield (6661 kg/ha) and straw biomass (19983 kg/ha). The potential might also exist for carbon sequestration under ZT in lowland rice fields as organic carbon increased by 51% after two years of cropping.

The research revealed that zero tillage systems could have beneficial impacts on rain water infiltration in lowland valleys. The adoption could lead to improvement in soil structure with stable rate of decomposition of OM in the soil, resulting in increased water infiltration rate and reduction in runoff. The study found the tillage systems to have profound effects on soil physical and chemical properties which ultimately affect the growth and yield of rice. In particular the sequestration of carbon was found to be significant in non tilled fields. Further research is needed under different ecological systems and sampling depth to understand the sequestration of SOC.

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