LEAD LECTURE https://doi.org/10.58297/KQVA9294

Effects of Alternate Wetting and Drying Water Levels and Planting Methods on Performance of Rice (*Oryza Sativa* L.) and Selected Soil Properties in a Nigerian Sudan Savanna

Abdulkadir A[1*], Lawal HM[1], Ogunsola E[1], Abu ST[1] and Christian AT[2]

[1]Department of Soil Science, Ahmadu Bello University, P.M.B. 1044, Zaria, Nigeria.
[2]Africa Rice, Nigeria Regional office, Kano State, Nigeria
*Corresponding author email: akadir762001@yahoo.com; mobile: +234803 868 8663

Abstract

This study was conducted to determine the effect of changing the depths of water and planting methods on soil properties and rice yields under alternate wetting and drying (AWD) in the Systems of Rice Intensification (SRI). The treatments consisted of four irrigation levels and four planting methods. The irrigation treatments included 4 water drop levels (WDL) in observation well: 6 cm, 10 cm, 14 cm water drop levels below the soil surface and continuous flooding with 5 cm layer of water above soil. Four planting methods included seed drilling, broadcasting, transplanting 12 day-old seedling and transplanting 21 day-old seedlings. Lowland rice (FARO 44) was established in randomized complete block design. Alternate wetting and drying at 6 and 14 cm WDL showed 14.27 % and 11.59 % increase in total porosity respectively, when compared with initial soil total porosity. All plots showed a decrease in bulk density compared with initial soil bulk density. Paddy yield for irrigation treatments ranged between 6.03-9.92 t ha^{-1}, with AWD at 10 cm WDL having highest yield of 9.92 t ha^{-1}, the lowest was observed in the continuously flooded plots (6.03t ha^{-1}). System of rice intensification method of transplanting was observed to yield 10.08 t ha^{-1} of paddy and showed percentage increases in paddy yields by 26.3%, 69.9% and 33.5% over conventional transplanting (21 day seedling), broadcasting and drilling, respectively. This study showed the superiority of using younger seedlings in transplanting and 10cm water drop level in the observation well for increased food security and income.

Keywords: Alternate wetting and drying, planting methods, soil porosity, water drop level, Paddy yield

Introduction

Rice is the most widely consumed staple food for a large part of the world's human population, especially in Asia. It is the agricultural commodity with the third-highest worldwide production (741.5 million tonnes in 2014), after sugarcane (1.9 billion tonnes) and maize (1.0 billion tonnes) (FAOSTAT, 2014). In 2022, world production of paddy rice was 509.99 million MT, led by China (147 million MT) and India (126.5 million MT) with a combined 50% of this total. Other major producers are Bangladesh (35.65 million MT) and Indonesia (34.6 million MT), with Nigeria being the 13th highest rice producer with 5.4 million MT (FAOSTAT 2021; WAP 2022).

Rice is one of the most consumed staples in Nigeria, with consumption per capita of 32 kg. In the past decade, consumption has increased by 4.7%; almost four times the global consumption growth, and reached 6.4 million tonnes in 2017 – accounting for 20% of Africa's consumption. Given the importance of rice as a staple food in Nigeria, boosting its production has been accorded high priority by the government in the past 7 years and significant progress has been recorded.

Rice is produced in Nigeria under both rainfed and irrigated cropping systems and with varieties adapted to different agroecologies across the country. Among the major rice producing states, Kebbi State produces 2.05 million MT in wet season and 1.51 million MT in dry season.

Previously, there was a huge demand – supply gap of around 2 million metric tons of rice annually in Nigeria. Recent policies and peoduction strategies has led to a closing up of this gap. To meet the demand of growing population, intensification of yield from each unit of land cultivated to a crop must be increased. A big challenge in Irrigated lowland rice production is that it consumes more than 50% of total freshwater and irrigated flooded rice requires two or three times more water than other cereal crops, such as wheat and maize (Barker *et al.,* 1998). In addition, rice production is facing increasingly competition with rapid urban and industrial development in terms of freshwater resource (Tuong and Bouman, 2001). The need for “more rice with less water” is crucial for food security and irrigation plays a greater role in meeting the future food needs and is gaining more attention in the recent times (Tuong and Bouman, 2004). One strategy of meeting up this rice demand is through the systems of rice intensification (SRI). The system of rice intensification refers to a set of sustainable cropping strategies that was shown to increase crop yields with less water and reduced greenhouse gases emissions (Uphoff, 2015).

Nigeria is well endowed with water and land resources for irrigation farming; such as the vast irrigation schemes that exists such as the Bakolori Irrigation Scheme in Zamfara State. Utilization of these existing resources can close the demand supply gap of rice in the country. The objective of this research is to test the effect of different planting methods and water application under SRI and conventional practices on rice yields and on selected soil properties.

Materials and methods

Experimental Site and Description

The research work was conducted at in the dry seasons of 2019 at the Bakolori Irrigation Scheme Talata-Mafara, Zamfara State, located on latitude 12^{o} 41. 714’N and longitude 006^{o} 01.079’E in the Sudan Savanna of Nigeria (Fig. 1). According to NiMet (2012), the study area has an elevation of 313 m above sea level and an establishment of rainfall from mid-June, with an error margin of 1 to 6 days, and a cessation at 11^{th} October. The length of growing season is 126 days with an error margin of 2 to 11days. Seasonal rainfall is 615 mm with an error margin of 22 to 94 mm. The average annual temperature is 27.9^{o}C.

Treatments and Experimental Design

The treatments consisted of four irrigation treatments and four planting methods. The irrigation treatments included four water drop levels (WDL) in observation tube-well: 6 cm, 10 cm, 14 cm water drop levels below the soil surface and continuous flooding with 5 cm layer of water above the soil surface. The four planting methods included direct seed drilling, direct seed broadcasting, System of Rice Intensification (SRI) method of transplanting 12 days old seedlings after sowing and Conventional method of transplanting 21 days old seedling. This comprised of 16 treatments combination laid out in a randomized complete block design in a split plot arrangement. The main plots consisted of irrigation treatments while planting methods was assigned to the sub-plots. The plots were prepared in a plot size of 2.5 m x 2.5 m ($6.25\ m^2$), with a bund spacing of 0.5 m between sub-plots and 1 m between main plots.

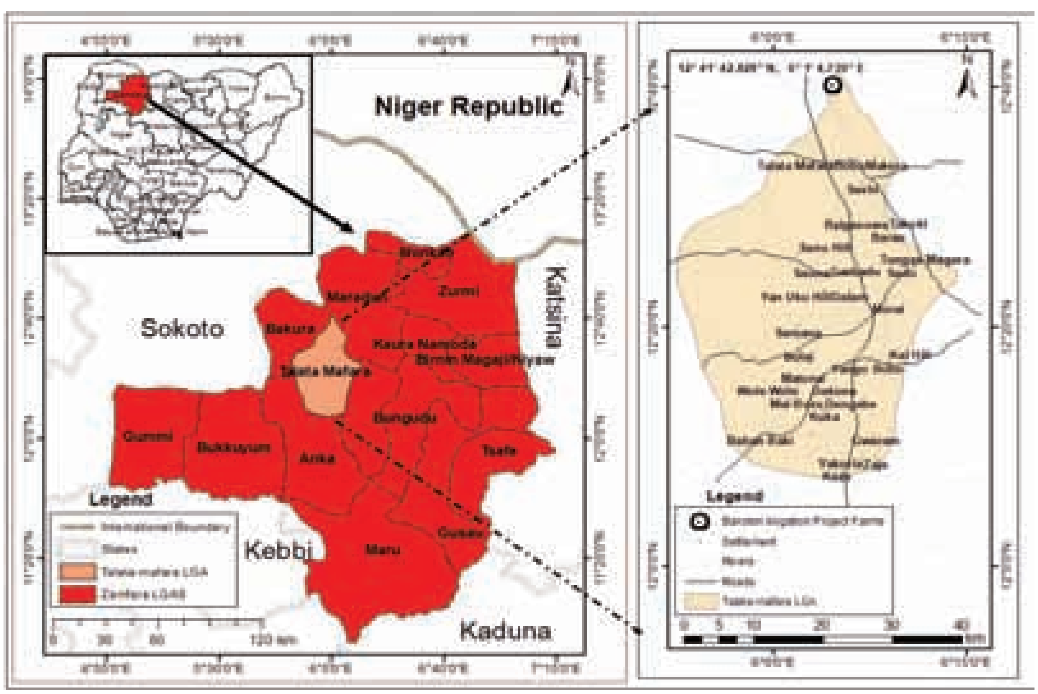

Fig. 1: Map of the study Area in Zamfara State, Nigeria

Soil Sampling

Soil samples were randomly collected from the field both before and after land preparation. At land preparation stage, disturbed soil samples were collected at 0-15 cm and 15-30 cm depths using auger for routine analysis of soil. A composite sample was formed from each depth. After harvest, disturbed soil samples were also collected from each experimental plot to determine effect of the treatments on chemical properties of the soil. Post-harvest, undisturbed bulk samples were taken at 13 points in a W-shaped pattern at 4 depths (0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm) to determine selected soil physical properties viz. total porosity and bulk density.

Results and Discussion

Effects of Irrigation Treatments and Planting Methods on Soil Bulk Density and Total Porosity

The mean bulk density for plots under the various irrigation treatments ranged between 1.43-1.49 Mg m^{-3} **(Table 1),** with AWD treatment plot where re-irrigation was done at 10 cm water drop level recording the highest (1.49 Mg m^{-3}). This showed a 4.48 % decrease in bulk density when compared with initial soil bulk density and was significantly different from bulk density at 6 cm, 14 cm and continuous flooding treatments. The relatively higher bulk density in plots where re-irrigation was at a 10 cm water drop level might be due to a higher stand planting density, which suggests a direct effect of planting density on soil compaction (Duan *et al.*, 2019). It could also be attributed to the increased activities of aerobic soil organisms which led to the collapse of small soil aggregates. Collapsed soil aggregates are deposited in spaces within the soil groupings, which causes the formation of semi-compressed layers and increased soil bulk density (Abdul and Sinan, 2008; Al-Wazan, 2009).

Plots where rice was established by broadcasting and conventional method of transplanting recorded the highest mean bulk density (1.46 Mg m^{-3}), which showed a 6.41 % decrease in bulk density when compared with initial soil bulk density. This was statistically similar with bulk densities for plots established by drilling and SRI the method of transplanting. The interaction effect of the irrigation regime and planting method on bulk density was significant ($p<0.05$).

Table 1: Effect of Irrigation Treatments and Planting Methods on Bulk Density and Total Porosity

Treatments	Bulk Density (Mg m^{-3})	Total Porosity (%)
Irrigation Treatments (IT)		
6 cm AWD WDL	1.43c	42.10a
10 cm AWD WDL	1.49a	40.73b
14 cm AWD WDL	1.43c	41.11a
Flooding	1.46b	41.06ab
SE±	0.008	0.353
Planting Methods (PM)		
Broadcasting	1.46	41.46
Drilling	1.45	41.68
SRI	1.44	41.51
Conventional TP	1.46	41.22
SE±	0.008	0.353
IT*PM	*	NS

Means followed by the same letters within a treatment column are not significant at 5% level of probability. Ns: not significant; *: significant at 0.05 level; **: significant at 0.01 level. AWD: alternate wetting and drying; WDL: water drop level; SE: standard error

Broadcasting method combined with continuous flooding had similar effect on bulk density, as combination of conventional transplanting method and re-irrigation at 6 cm water drop level under AWD did.

Mean total porosity for irrigation treatments was observed to range between 40.73-42.10 %, with AWD at 6 and 14 cm WDL having the highest total porosity (42.10 and 41.11 % respectively). Both were statistically at par, but significantly different from total porosity when AWD was applied at 10 cm WDL. Alternate wetting and drying at 6 and 14 cm WDL showed 14.27 % and 11.59 %

increase in total porosity respectively, when compared with initial soil total porosity. Increased total porosity in AWD might be due to increased activities of plant roots and soil organisms when AWD was applied at both 6 and 14 cm WDL.

With respect to the planting methods, mean total porosity of plots ranged from 41.22 to 41.68 %, with plots established by drilling method and those transplanted using SRI practices giving the highest values of 41.68

and 41.51 % respectively) values; but statistically at par with the porosity of plots established by broadcasting and conventional method of transplanting. Drilling and SRI method of transplanting were observed to show 13.14 % and 12.68 % increase in total porosity respectively, when compared with initial soil total porosity. This might be due to increased tillering in drilling and SRI, which increased plant population and root activities. There was no significant difference observed in total porosity when irrigation regimes interacted with planting methods.

Effects of Irrigation Treatments and Planting Methods on Paddy Yield and Some of the Yield Components

Table 2 presents the effects of irrigation treatments and planting methods on rice yield and some yield components. Mean number of tillers in irrigation treatments ranged from 39 to 48.

Table 2: Effect of Irrigation Treatments and Planting Methods on Paddy Yield Parameters

Treatments	Number of Tillers/hill	Number of Productive Tillers/hill	Straw yield (t/ha)	Paddy yield (t/ha)	Total biomass (t/ha)
Irrigation Treatments (IT)					
6 cm AWD WDL	39.34c	38.35c	27.10b	6.95c	34.05c
10 cm AWD WDL	48.43a	47.17a	30.73a	9.92a	40.65a
14 cm AWD WDL	45.03b	43.58b	28.35ab	8.64b	36.99b
Flooding	40.98c	40.15c	24.60c	6.03d	30.63d
SE±	0.648	0.648	0.871	0.197	0.971
Planting Methods (PM)					
Broadcasting	34.36d	33.28d	24.73b	5.93c	30.66c
Drilling	40.90c	39.54c	26.51b	7.55b	34.06b
SRI	52.50a	51.30a	29.58a	10.08a	39.66a
Conventional TP	46.03b	45.13b	29.95a	7.98b	37.93a
SE±	0.648	0.648	0.871	0.197	0.971
Interactions					
IT*PM	***	***	**	**	**

Means followed by the same letters within a treatment column are not significant at 5% level of probability. NS: not significant; *: significant at 0.05 level; **: significant at 0.01 level; ***: significant at 0.001 level. AWD: alternate wetting and drying; WDL: water drop level; SE: standard error.

with AWD at 10 cm WDL giving the highest mean of 48.43; which was attributed to better vegetative growth observed when AWD was applied at 10 cm WDL. Alternate wetting and drying at 10 cm WDL showed percentage increase in number of tillers by 23.1%, 7.5% and 18.1% over AWD at 6 cm WDL, 14 cm WDL and continuous flooding respectively. Mean number of tillers in planting method treatments were observed to range from 34.36 to 52.50, with SRI and conventional transplanting having highest mean of 52.50 and 46.03 respectively.

Plots established by system of rice intensification were observed to show a percentage increase in number of tillers by 14%, 28.3% and 52.7% over conventional transplanting, drilling and broadcasting respectively. Wider spacing in SRI method of transplanting, improved the crops' effective utilization of available resources such as space, nutrient area for the root system, better root spread, more light interception etc resulting in an enhanced tiller production (Thavapraprakash *et al.,* 2008; Singh *et al.*, 2015). Interaction between irrigation treatments and planting methods for number of tillers at harvest was observed to be significant ($P<0.001$). Alternate wetting and drying at 10 cm WDL water drop level combined with SRI method of transplanting was observed to have highest number of tillers from the interaction figure (not shown).

Paddy yield for irrigation treatments ranged from 6.03-9.92 t/ha, with AWD at 10 cm WDL having highest yield of 9.92 t/ha, which statistically differ from yield at 6 cm and 14 cm AWD WDL; as well as continuous flooding. This may be because wetting and drying process at this depth provides a suitable soil-plant relationship that allows plant roots better access to water, nutrient adsorption and air; when compared to continuous flooding and other irrigation depths (Lhendup, 2008). Paddy yield was observed to range from 5.93-10.08 t/ha for planting method treatments, with SRI method of transplanting yielding the highest value of 10.08 t/ha, which was significantly different from means of conventional transplanting, drilling and broadcasting. System of rice intensification method of transplanting was observed to have percentage increase in paddy yield by 26.3%, 69.9% and 33.5% over conventional transplanting, broadcasting and drilling respectively.

Perhaps this could be due to efficient utilization of externally applied nutrients in SRI and more foraging area of root volume in SRI plots as shown in several studies. Alternate wetting and drying at 10 cm WDL combined with system of rice intensification method of transplanting was observed to have highest paddy yield, which was significantly different from all treatment combinations (**Figure 2**).

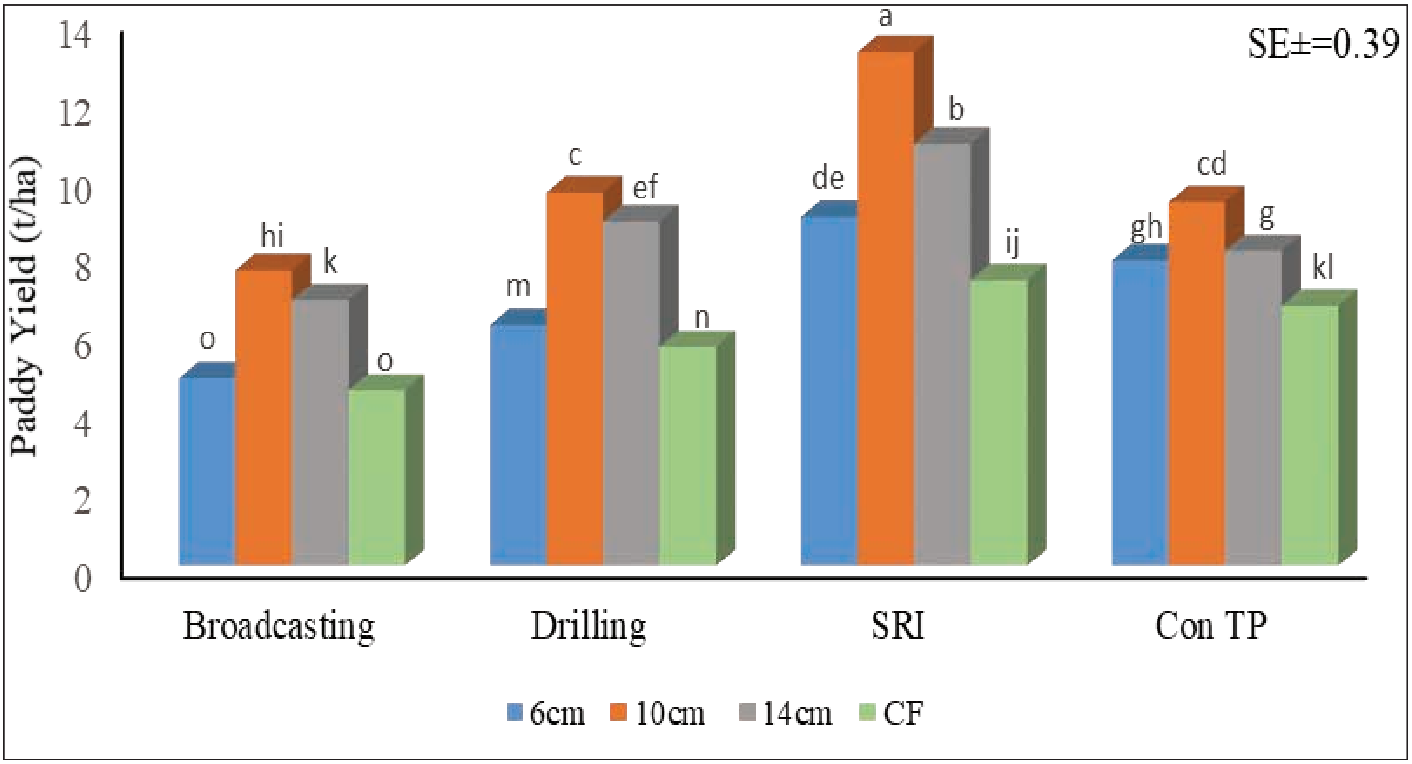

Figure 2: Interaction of Irrigation Treatment and Planting Methods on Paddy Yield

Conclusion

Alternate wetting and drying at 10 cm WDL recorded highest soil bulk density of 1.49 Mg m^{-3} which showed a 4.48 % decrease in soil bulk density when compared with initial soil bulk density. Alternate wetting and drying at 10 cm WDL combined with system of rice intensification method of transplanting was observed to have highest number of tillers which translated to higher paddy yields than all treatment combinations. This is consistent with previous findings that show the superiority of SRI methods of rice production over conventional methods.

Acknowledgements

The authors duly acknowledge the financial support of conducting this MSc research through The World Bank funded SRI-TRIMING project. The support of the farmer at Bakolori Irrigation Scheme, field and laboratory staff of Soil Science Department of Ahmadu Bello University, Zaria, Nigeria, is also duly appreciated.

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