Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

Lowland rice yield responses to variation in water management in a Sudan savannah soil of Nigeria.

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ARTICLE INFO

Article history:
Received September 13, 2020
Received in revised form October 12, 2020
Accepted June November 26, 2020
Available online January 21, 2021

Keywords:
Alternate wetting and drying
Continuous flooding
Yield
Water management practices
Rice
Lowland.

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mobile:

https://doi.org/10.36265.njss.2021.310115

ISSN Online: 2736-1411

Print: 2736-142X

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ABSTRACT

This study investigates the applicability of reduced water management (alternate wetting and drying AWD) practice alongside continuous flooding (CF) which is the traditional water management practice of lowland rice production in Sudan savanna ecological zone of Nigeria. Rice growth component variables from each of the management practice were compared to identify the best in terms of reduced number of irrigations, productivity, yield quality and profitability. The study was carried out at the Irrigation field of the Teaching and research farm of Faculty of Agriculture, Federal University Dutse. To achieve the said objective, the research experiment was laid out in a Randomized Complete Block Design RCBD arrangement. Two types of irrigation management; AWD and CF were assigned in the plot. The consequent treatment combinations were replicated 3 times and as such a total of 6 plots each with a dimension of 18m x 3m ($54m^2$) were utilized in the experiment. The individual plots and blocks were separated by a discard of 1m and 2m respectively. Soil samples at 0-20cm depth were collected before land preparations from three random spots within each plot, thoroughly mixed to form composite sample per plots for routine analysis. The result showed that AWD had 55, 15 and 25% increase in yield, percentage filled grains and thousand grains weight relative to CF. In the same vein, other attributes such as Mean number of tillers/hill (65.533), panicles/hill (61.522) and panicle length (30.611) of AWD plots also had an increment of 12, 10 and 40% respectively more than the CF method. These findings, clearly demonstrate that AWD is a promising water management practice that has the potentials of reducing the cost of lowland rice production without necessarily and significantly reducing productivity, yield quality and profitability of the crop.

1.0 Introduction

Rice is an important staple food for about 70 per cent of Asian and Sub Saharan African countries population (FAO, 2016). In West Africa, it forms a major dietary source of energy occupying the third most important food in the region (Daudu *et al*., 2018). It is predicted that in 30 years, the earth's population maybe 8 billion people and the number of people depending on rice for food may equal 5 billion. Feeding them will require a massive increase in global rice production (He, 2010; Rahman and Bulbul, 2015). More than 75% of the rice supply of these regions comes from 79 million hectares of irrigated land under intensive cultivation. This makes the crop the greatest consumer of water among all crops, using about 80% of the total irrigated freshwater resources (Ndiiri *et al*., 2013).

Nigeria is the African leading consumer and a major importer of rice (FAO, 2017). About 6.7 million Mg of rice paddy, that is the grain before dehulling, was produced from 3300,000 ha in 2014 (FAOSTAT, 2016). Most of the rice production is in central and northern Nigeria (Daudu *et* *al*., 2018).

Paddy production under a large and continuous supply of water constitutes the major form of production with only a little accounting for rainfed production (Becker and Johnson, 1999; He, 2010). This form of waterlogging system of production is associated with the production of a harmful and toxic product (hydrogen sulphide, acetic acid and butyric acid) that can have a negative influence on the plant for several weeks after flooding (Ponnamperuma, 1972; Koch and Mendelssohn, 1989; Lynch, 2006). As such, prolonged waterlogging can have lasting impacts on plant yield (Islam *et al*., 2016). The average paddy yield has been only 3.0 to 3.5 Mg ha^{-1} in the irrigated lowlands of Nigeria (Diagne *et al*., 2013; Nwilene *et al*., 2008). Increased in rainfall variability due to changing climate is likely to exacerbate water availability in the future. About 1000-2000mm of water is the average standard required for a field rice production (Bouman and Tuong, 2001). Evapotranspiration, surface runoff, seepage, and deep percolation account for the major losses of water during rice production system (Guerra, 1998). Water limitations are therefore becoming a more serious constraint on rice production than is the availability of suitable land.

Thus, changes need to be made in our present rice production methods to get 'more crop per drop' because present rice-growing practices are becoming unsustainable. The System of shallow ponding, intermittent irrigation or Alternate wetting and drying has been introduced in the world as an opportunity to reduce water requirements while at the same time increasing the yields of rice (Setiawan *et al*., 2013). This practice is defined by the periodic drying and re-flooding of the rice field thereby combining beneficial aspects of both aerobic and anaerobic cultivation. Alternate wetting and drying are widely accepted as the most promising practice for reducing GHG emissions from irrigated rice. Zhang *et al*. (2008) and Lampanyang *et al*. (2015) in their studies reported the potentials of AWD in reducing crop water requirements while maintaining or even increasing the yield as compared to the conventional flooded system. Positive results, getting higher productivity of irrigation water by reducing water applications in conventionally -managed paddy fields, are reported in many literatures (Li and Barker 2004; Moya *et al*. 2004; and Phengphaengsy and Okudaira,2008).

However, despite the recent attention received by System of Alternate wetting and drying in its ability to increase yields while using less water, yet, there has been little research especially on an African Soil into this system of water management, and how they compare to those from conventional flooded-rice production techniques. Thus, this study aims to find rice sustainable irrigation systems by comparing yield and yield component from continuous flooding and Alternate wetting and drying water management practices in Sudan Savanna ecological zones of Nigeria.

2.0 Materials and methods

2.1 Experimental Site

The field experiment was conducted during the 2018 dry season at the irrigation research farm of Federal University Dutse, (Latitude 11° 46'39" N and Longitude 009° 20'30"E) at an altitude of 444m above sea level in the Sudan savanna ecological zone of Nigeria (Ifabiyi and Ojoye, 2013). The study area falls in the arid and semi-arid areas characterised with low rainfall and less vegetation cover. The Average daily sunlight duration is 9 hours while mean annual rainfall is 720mm which comes between June to October (Usman *et al*., 2013). The average annual temperature at the site is 26.5^0C with a mean minimum of 23^0C in January and a mean maximum of 34^0C in April (Ojoye, 2008). The mean relative humidity for the area is 97%. Rice is grown during two seasons, dry (March–June) and wet (July–October) seasons. These two growing seasons have different irrigation needs due to differences in rainfall and evaporative demands.

The soil of the study area is characterised as fairly deep soils often covered by a sheet of laterite that has resulted from the weathering of Pre-Cambrian Basement Complex rocks formed by granites, schists and gneisses.

2.2 Soil Sampling and Analysis

The soil samples of 0 to 20 cm depth were collected and analysed at the Soil Science Department of Ahmadu Bello University in Zaria. Particle size distribution was assessed by Bouyoucos hydrometer method (Gee and Bauder, 1986), soil pH by glass electrode pH meter (Meter-Toledo Delta 320 pH meter) in water and 0.01 mol L^{-1} $CaCl_2$ using a soil-solution ratio of 1:2.5 (McLean, 1982), electrical conductivity was determined using an EC meter with the same soil solution ratio of 1:2.5, organic C by Walkley-Black (Nelson and Sommers 1982), ammonium acetate extraction methods (Chapman, 1965) was employed for exchangeable bases and cation exchange capacity determination, while P was determined using AAS after extraction with Bray-1 extraction method (Table 1).

2.3 Experimental Design

Treatments in the main plot consisted of two systems of water management; AWD and CF. These were replicated three times in a Randomized Complete Block Design (RCBD) arrangement. Each treatment plot was $54m^2$ (18m x 3m) in area. The individual plots and blocks were separated by a discard of 1m and 2 m respectively.

The field preparation and nursery set up were based on System of Rice Intensification (SRI) as described by Zotoglo (2011). Transplanting was at 12 days after sowing when having only two leaves with one seedling per hill. The seedlings were transplanted carefully and quickly with some soil attached to the roots to minimize seedlings damage. Weeding was done manually with hand pulling supplement at 12-days Intervals.

2.3.1 Water management

Two methods of irrigation were adopted to monitor their differences. The SRI method (Alternate wetting and drying) and Common practices (continuous Flooding).

Alternate wetting and drying (AWD) conditions were maintained through the limited water supply. For proper monitoring, a PVC pipe with perforations up to 15cm from its base was inserted in control plots and irrigation was provided when the water level goes below 15 cm from the surface. The first alternating wetting and drying cycle was deployed 15 days after transplanting and continued until the commencement of flowering. During the flowering period, water head 2-3 cm was maintained above the ground. The wetting/drying cycle consists of flooding the field followed by dry to 15 cm below the soil surface (as when observed in the PVC pipe or when the soil starts cracking). The field was then re-flooded to 2 cm above soil surface before the next drying cycle begins.

For the continuous flooding, 10cm water was maintained throughout the plant growth period.

2.4 Observation and Data Collections

Three plant stands were randomly selected from each plot to measure plant height and number of tillers during each development stage. Harvesting was done when the mature rice panicle ripened to a golden-brown colour. Rice was harvested manually by cutting with sickles from a net plot of $54m^2$ and threshed. The threshed paddies were left in the field for 3 days for sun drying.

2.5 Data Analysis

The data on rice yield and yield parameters obtained were subjected to Analysis of Variance (ANOVA) using Statistical Analysis Software as described by Steel and Torrie (1987). The treatment means were separated using Duncan Multiple Range Test (DMRT) at 5% level of significance. All statistical analysis was conducted using SAS software (version 9.3, 2011).

3.0 Results and Discussion

Table 1 shows the result of soil properties of the experimental research area as determined before the land preparation. Soil reaction was found to be moderately acidic in water and strongly acidic in $CaCl_2$ with values ranging from 5.92 and 4.77 respectively. The organic carbon (OC) content and the Total Nitrogen (TN) were low with values of 0.61g kg^{-1} and 0.12g kg^{-1} in all the fields respectively. Exchangeable bases were also low. Low OC contents of soils of the Nigerian savanna have been reported by Jones and Wild, (1975) who attributed this to continuous crop production on the same piece of land with poor sustainable management practices such as removal of crop residue and low addition of organic matter to the soils. . Balasubramanian *et al.* (1984) and Esu (1991) also reported that soils of the Northern Savanna of Nigeria are low in fertility status.

Table 1: Soil physicochemical properties of the study area

Soil Properties	**Mean Value**
pH (water)	5.92
pH ($CaCl_2$)	4.77
OC (gkg^{-1})	0.61
TN (gkg^{-1})	0.12
AP (ppm)	3.93
K (cmol/kg)	0.69
CEC (cmol/kg)	7.49
Sand (%)	62.50
Silt (%)	22.72
Clay (%)	14.78
Texture	Sandy loamy

OC-organic carbon, TN-total nitrogen, AP-available phosphorus, K-potassium, CEC-cation exchange capacity.

Figure 1 and 2 show the result of the growth parameters analyses, which showed that water management practices had significant ($p<0.001$) influence on the yield component of rice (yield). Generally, high crop yield components were recorded in AWD plots compared to the CF plots. Average value of 100.050 cm plant height at 12WAS was recorded in AWD plot which is 8% more than in the CF plot. Mean number of tillers/hill (65.533), panicles/hill (61.522) and panicle length (30.611), were also higher than the CF plots with 12%, 10% and 40% increment respectively. AWD also recorded a higher average number of grains filled (15%) relative to the CF as illustrated in Figure 1. Adoption of AWD in some plots compared to CF resulted in consequent 25% increase in 1000-grain weight, because of 55 % (kg/ha) more paddy yield in the system.

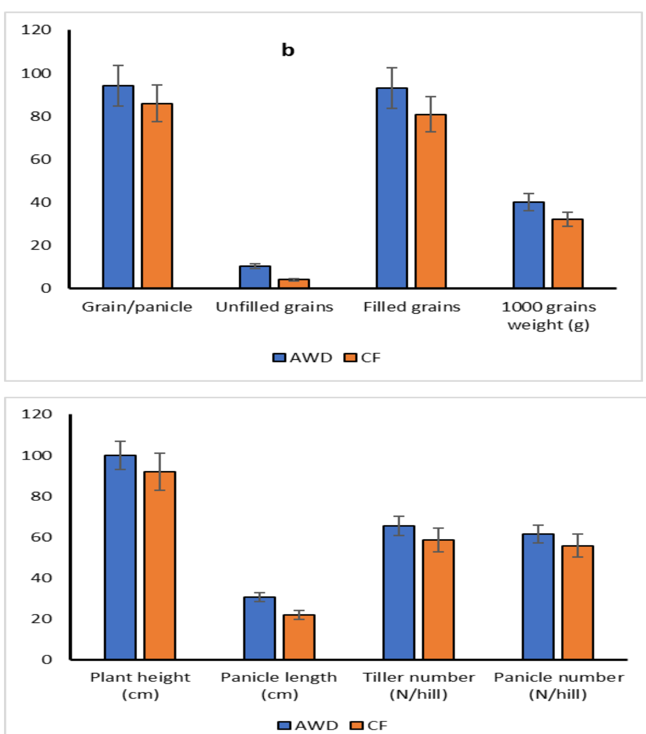

Figure 1: Means (±standard error) for (a) plant height, Panicle Length, Number of tillers/hill and Number of Panicle/hills and (b) Number of Grains/panicles, unfilled grains, filled grains and thousand grain weight as influenced by irrigation systems.

The presence of taller plants in the AWD plots (Figure 1a) compared to the CF plots continues to support the findings of many authors (Zhang *et al*., 2010; Kima *et al*., 2014), who detailed that rice does not need to be continuously submerged to produce high yields if adequate water is provided at critical growth stages. However, some researchers (Sariam and Anuar, 2010; Chowdhury *et al.,* 2014; Mote *et al*., 2017) reported the emergence of taller plants in the CF plots than the AWD. They claimed that any water stress imposed at any stage of rice growth before antheses could seriously affect the plant height. Increased in soil fertility resulting from accelerated immobilisation of organic matter induced by more oxygen available to the roots during the drying and rewetting cycle may also be linked to favouring of rice growth in the AWD than the CF plot as opined by Bouma, (2007); Dong *et al*. (2012) and Tan *et al*. (2013).

Quick adoption of osmotic adjustment resulting from early recovery potentials of young seedlings transplanted in the AWD plots can be linked to the production of more panicles / hill as observed in Figure 1a. The findings of Mishra *et al*., (2006) and Mishra and Slokhe (2010) also supported this claim. The synergetic effect of young seedlings in the formation of panicle and grain filling is also reported by Omwenga *et al*. (2014). However, Pascual and Wang, (2016) reported no significant difference in panicle weight, grain number per panicle and 1000-grain weight between AWD and CF.

Enhancement in the exchange of air between soil and atmosphere during the dry and rewetting of the soil in the AWD is believed to have a positive influence on the production of tillers/hill during the panicle initiation (Pascual and Wang, 2016). This could also be linked to the fact that the AWD plots were transplanted with early seedlings thereby inducing higher development of tillers at an early stage than the CF plots (Omwenga *et al.*, 2014). A delay in the transplanting of the seedling is reported to have resulted in the delay of tiller development, consequently resulting in low yield compared to early transplanting of seedlings by Estela (2004).

The greater significant ($p<0.01$) yield observed in AWD plots (Figure 2) when nutrients are considered to be limiting may be attributed to the fast remobilization of carbon and root enlargement of the plant for maximum nutrient and water uptake induced by short soil drying during the grain filling stage. This mechanism of increased yield under AWD was also reported by Yang *et al*. (2001); Yang and Zhang (2006) and Li *et al*. (2016). Another reason that may be attributed to the high yield observed in AWD plots compared to CF could be attributed to the wider spacing, avoiding root injury and transplanting shock and planting of seedling before third leaf emergence leading to quicker tiller initiation as rightly observed by Barison and Uphoff, (2011). Low yield observed in CF plots of this studies could be attributed to reduced oxygen supply and root respiration, root growth and elongation as well as reduced nutrient and water uptake arising due to excessive wetness of such soil (Grable and Siemer, 1968).

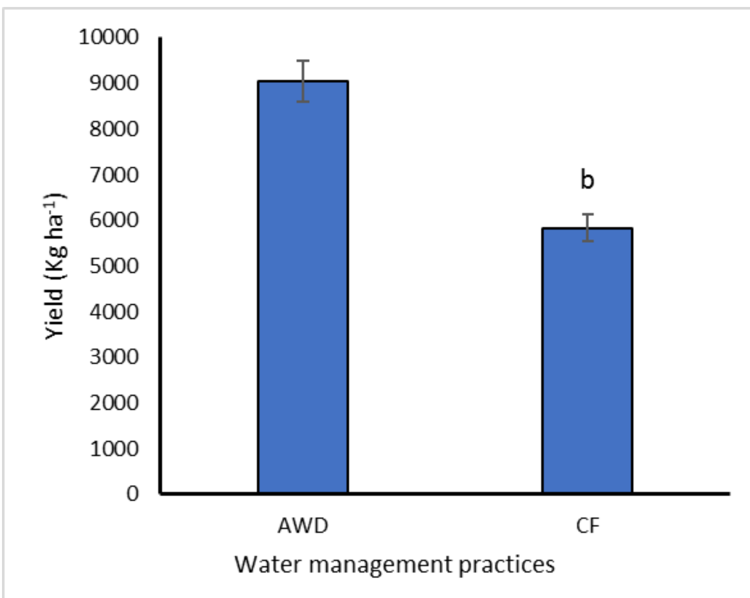

Figure 2: Means (±standard error) of Paddy Yield (kg per hectare) as influenced by irrigation systems. Means with same letters are not significantly different from one another at 5% level of significance.

4.0 Conclusion

The result from this study continues to prove that AWD compared to the traditional continuous flooding is an extremely effective water saving irrigation technology in the context of reduction in the number of irrigations with a statistically significant increase in yields and profits of lowland rice production. This implies an increased in harvest indexes such as increased in grain yield, increased percentage of filled grains, increased 1000 grain weight, number of tillers/hill, panicles/ hill and panicle length in the AWD than those recorded in CF. While water savings and increase in lowland rice production are achieved through AWD, it is possible that these could be further improved by paying extra attention in avoiding water stress conditions that can occur from allowing the soil to dry too much or as result of the delay in the rewetting cycle due to either undersized wells, irrigation system failure or human error particularly during the critical stage of plant growth as this could seriously affect crop productivity and yield quality. The use of an extra-early maturing variety of lowland rice is also encouraging with this system. Finally, the findings of these study demonstrate that AWD is a promising water management practice that has the potentials of reducing the cost of lowland rice production without necessarily and significantly reducing productivity, yield quality and profitability of the crop.

Acknowledgement

This research was supported by 2016 Tertiary Education Trust Fund Institutional Based Research (TETfund IBR 2016) awarded to Abubakar Halilu Girei and Abba Nabayi of the Department of Soil Science, Faculty of Agriculture, Federal University Dutse.

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