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Evapotranspiration, Soil and Water Quality Implications on Upland Rice Production

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ABSTRACT

In light of plausible impacts of climate change with respect to food insecurity due to growing shortage of water, an attempt was made to establish direct relationship between crop yield, irrigation and evapotranspiration. This is with respect of determining 'safe' consumptive water use for upland rice in Nigeria. Also, effect of two very important factors, soil and water qualities on rice production were considered in relation to rice productivity. Some parameters common to the two factors analyzed included, the pH, Sodium, Iron, Potassium, Copper, Manganese and Zinc while the remaining water and soil properties were investigated using standard procedures. The relationships between crop yield and Evapotranspiration (ET) as well as yield and applied irrigation water was $R^2 = 0.97$. The result of ANOVA showed significant differences in grain yield and crop ET between treatments ($p<0.05$). Majority of the soil and water parameters considered were within permissible limits for rice production in Nigeria. Traceable quantities of pollution were noticed in both soil and water samples but were insufficient to prevent promotion of optimum rice crop growth under existing conditions. Good soil and water qualities with proper irrigation scheduling could sufficiently result in rice grain yield increase under standard environmental conditions.

Key words: Evapotranspiration, yield, upland rice, soil, water, productivity

INTRODUCTION

Rice constitutes one of the most important staple foods of over half of the world's population. Globally, it ranks third after wheat and maize in terms of production (Akinbile and Sangodoyin, 2009). In Nigeria, its cultivation is indigenous and has been in existence since over three centuries ago. Rice could be cultivated in about 4.6-4.9 million ha of land in Nigeria, but the actual area under cultivation is only 1 million ha representing 22% of the total potential available area (Kehinde, 1997). The milestone used for measuring the success of any agricultural production is yield which quantifies in measurable terms the most important part of the crop. Increasing yields of most agricultural crops require many factors, including water which is essential for rice cultivation and its supply in adequate quantity is one of the most important factors in rice production (Akinbile, 2011). Irrigated agriculture is the dominant use of water, accounting for about 80% of global and 86% of developing countries water consumption as at 1995 (Bouman and Tuong, 2001). Different yields have been achieved in different ecological zones especially in Africa and West Africa sub region with an all time highest yield achieved in Egypt of 9.1 tons ha^{-1}

in 2001 chiefly due to the profitable use of soil and water (Mondonedo, 2008). Rice production is totally under irrigation in north Africa while in sub-Saharan African upland rice production has been dominant as average yields in most countries are still less than 2.5 tons ha^{-1}. In other parts of the World however, yields have been fluctuating with Philippines attempting to increase its rice yield to 4 tons ha^{-1}, planting twice a year and attain a 20% rice self-sufficiency by 2011 in only 1,300 hectares of land (Duwayri *et al.*, 2000). Asia is the World's biggest rice producer accounting for over 90% of production and consumption. China and India, which accounts for more than one-third global population supply over half of the world's rice. Brazil is the most important non-Asian producer, followed by the United States and Italy ranks first in terms of rice production in Europe (Duwayri *et al.*, 2000). The demand for rice, especially fragrant and jasmine rice had increased in recent years, hence global increase in production became inevitable while optimizing some production factors, such as water which was increased (Bounphanousay *et al.*, 2008).

About 250 million ha, representing 17% of global agricultural land, is irrigated worldwide today, nearly five times more than at the beginning of the 20th century. This contributes about 40% of the global production of cereal crops (Barker *et al.*, 2000). By 2025, global population will likely increase to 7.9 billion, more than 80% of whom will live in developing countries and 58% in rapidly growing urban areas (Bouman, 2009). Irrigated rice was responsible for about 75% of the world's total rice production. Irrigation has helped boost agricultural yields and outputs, stabilize food production and prices (Akinbile *et al.*, 2011). Increased rice production consistently could be achieved by increasing area under irrigation, increasing cropping intensity and maximizing one major factor of production, which is water (Akinbile, 2010a). Soil and water are very important factors considered for growth of any crop before the advent of hydroponic systems in the emerging science of the 21st century. Soil is the medium which holds the root of crops firmly in place while water is needed to dissolve nutrients' for plant uptake also through the root system. While soil store nutrients for crop development, water makes the nutrients available to plants for uptake and to promote chlorophyll formation for photosynthesis (Olaleye *et al.*, 2004). Several studies have reported the effects of contaminated soil and water on the environment and humans and therefore, quality of these parameters with respect to productivity is a factor that cannot be underestimated. The objective of the study therefore were to assess the effect of irrigation on crop yield and also consider the implications of soil and water qualities on upland rice production in Ibadan, Nigeria. This was to ascertain the degree of influence such qualities will have on the crop growth and development with respect to the grain yield.

MATERIALS AND METHODS

Detailed explanation on experimental design, treatments and replicates and other methods adopted from November 2005 and March 2006 and November 2006 to March 2007 were reported in Akinbile (2010a). The experimental design was a Randomized Complete Block Design (RCBD) with four treatments. NERICA 2 and 4 was planted on all the plots and irrigation water was delivered through an overhead sprinkler systems. There were four treatments based on the level of irrigation water application were: full irrigation (100% ET), plot A received water seven times continuously in one week, medium level irrigation (75% ET), plot B received water six times a week. The third treatment (moderate level irrigation) (50% ET) received water five times a week (plot C) and the fourth treatment (low level irrigation) (25% ET) received water four times a week (plot D). The crop's responses to differential water application have been reported in Akinbile *et al.* (2007) and Akinbile (2010a) while the agronomic responses under different water schedules have also been reported by Akinbile (2010b). Water administered to the field by irrigation was measured using catch-data cans over the entire growing season period. A set of relationships were established between the crop yields reported by Akinbile (2010b) and irrigation water and evapotranspiration respectively. This was to establish an existence of a direct relationship between rice crop yield and the water-related parameters for proper irrigation scheduling and also to estimate ET in absolute terms. Similarly, soil and water analyses were carried out to ascertain the effects of their qualities on upland rice production. The parameters considered for analysis in soil samples included particle size, bulk and particle densities, organic matter and percentage composition of Nitrogen, Calcium, Phosphorous and Manganese. Other soil parameters that were also determined included, the pH, potassium, field capacity, wilting points, percentage composition of sand, clay and silt as well as the textural class using standard procedures. As for the water analysis, water samples were taken and analyzed using AOAC (1990) standard procedures at the IITA water laboratory. This was to ascertain the water quality for irrigation purposes.

Description of the study area: For the qualitative analyses, soil and water samples were also collected from the study Area, International Institute of Topical Agriculture (IITA), Ibadan, the Oyo State capital, Nigeria. Located between latitude 3°54'E and 7°30'N, at elevation of 200 m above the mean sea level, it has an annual rainfall range of between 1300 and 2000 mm while its rainfall distribution pattern is bimodal. The annual mean temperature is 27.2°C during dry season and 25.6°C during the rainy season. The soil class is oxic paleustaff which belongs to Egbeda Series as Alfisol (Apomu Sandy loam). The vegetation is humid rain forest with an average relative humidity of between 56 and 59% during the dry season and 51-82% during the wet season (IITA, 2002).

Associated computation and measurements: Other associated issues of the study was the validation of five Evapotranspiration (ET) models to determine which model was best suited for determining potential ET in the study area. This was to determine the best model that compared favourably with Penman-Monteith (PM), which is the universally accepted equation for determining reference Evapotranspiration ET_o. The findings from this have been reported by Akinbile and Sangodoyin (2009). Another important aspect was the computation of crop coefficient (K_c) for the three growth stages of rice namely; the vegetative, mid-season and maturity stages. The K_c was used together with potential ET in determining the crop ET or consumptive water use of the crop throughout the growing seasons. This has also been reported by Akinbile and Sangodoyin (2010).

Statistical analyses: All measurements taken from six Weeks after Planting (WAP) and other results were subjected to statistical analyses using ANOVA 't' test procedure on Excel spreadsheet considered at 95% level of significance ($p<0.05$).

RESULTS AND DISCUSSION

Water application: The average total irrigation water applied to all the treatments during the entire growing season of upland rice were as shown in Fig. 1.

From the Fig. 1, average irrigation water applied during the vegetative stage (i.e., 1 to 6 Weeks After Planting (WAP) ranged from 10 to 23 mm in all the treatments. Crop water use at this stage was low due to the water demand by the crop. The emergence of rice in the early vegetative stage

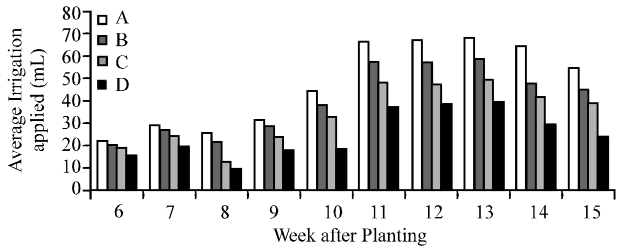

Fig. 1: Average weekly water applied versus Weeks after Planting (WAP) on all the four treatment plots based on water application

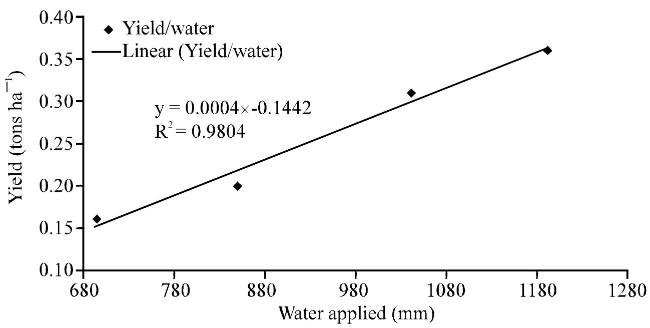

Fig. 2: Relationship between total irrigation water applied and yield

required less water for metabolic activities, hence the low water use. This was similar to the findings of Bouman (2009). During the mid season stage, from 7 to 14 WAP, a steady but gradual increase in water applied was observed. It ranged from 25 to 63 mm in treatment A while the values ranged between 12 and 37 mm in D, the treatment with least water application. The highest water use was experienced at this stage due to increased metabolic activities. At this stage, flowering, dough, booty and panicle development took place. Shortage of water at this stage significantly affected the yield. Akinbile and Yusoff (2011b) remarked that increased water use at the mid season stage prompted chlorophyll formation thereby enhancing photosynthesis process. This agreed with the findings of Carriger and Vallee (2007). From 15 WAP, gradual reduction in water application and it was expected as the crop had reached maturity stage, a phase where increased water application does not result in increased yield but waste. At this stage, heavy water loss in form of surface runoff, increased infiltration and percolation would result if irrigation water was not reduced. This observation was supported by Bouman (2009) and Droogers and Allen (2002).

Relationship of rice yield with applied irrigation water : The relationship between the grain yield and amount of irrigation water was as shown in Fig. 2. It was observed that grain yield increased linearly with increasing amount of irrigation. This is an indication that a linear relationship existed between grain yield and applied irrigation water. However, continuous increase in irrigation water does not imply corresponding increase in yield. This increase was not indefinite as there was a stage where further increase in irrigation did not result in further increase in biomass and grain yield. For this study, increase in applied irrigation water beyond 3100 mm, the grain yield remained static hence further application of water will result in waste. The result highlighted greater potential in saving irrigation water while maintaining grain yields at reasonably high levels. Figure 2 indicated the linear relationship was best suited for an optimum grain yield and irrigation with R^2 value of 0.98. Although yield response to irrigation could be described using the quadratic equation on average, yield response to irrigation varied considerably due to differences in seasonal rainfall amount and distribution as well as pre planting available soil water between the seasons. The crop used less stored soil water when the amount of irrigation was increased. This was due to availability of applied irrigation water in excess of crop water requirement. At this point, water loss due to percolation and evaporation would be at the maximum. Therefore, the rainfall during the cropgrowing season and the stored soil water at pre-planting needed to be considered when irrigation scheduling was made. This observation was supported by Guerra *et al.* (1998) in a similar study.

Relationship between crop yield and evapotranspiration: Nwadukwe and Chude (1998) established that there was a direct relationship between rice yield and crop evapotranspiration (ET) under standard environmental conditions for rice production. The relationship of crop production functions without considering the time of water deficit may be modified by replacing the amount of irrigation water with seasonal ET. This showed a direct but inverse relationship between ET and yield and confirmed the observations of Lage *et al.* (2003) in his study. Figure 3 showed the variation in grain yield with Total ET which decreased with increase in the grain yield. Therefore, the relationship of crop yield and Total ET would be inversely linear. In other words, increased crop water use resulted in decrease grain yield. It could be deduced that the reduction in crop yield was caused by water stress, which may be expressed as plant water deficit. This resulted in increased consumptive water use which may be due to insufficient water application and other weather factors such as increased incidences of sun rays and sunshine hours, daytime temperature, extraterrestrial radiation and other associated components (Akinbile, 2010b). Relating crop yield with seasonal Evapotranspiration without considering the time of water deficit, the linear function ($R^2 = 0.98$) best represented the relationship (Fig. 3) which is a clear indication of strong inversely co-variability between grain yield and total ET within the given circumstance. In other words, a well-watered situation that will give rise to less water stress, resulting in lesser consumptive water use would be ideal for optimum grain yield. In this study, reference ET of between 87 and 107 mm was required to produce minimum grain yield while a range of between 237 and 311 mm was required to produce the maximum grain yield under a limited water supply. Lafitte *et al.* (2005) reported that ET values ranging from 200 to 480 mm was sufficient for rice production in northern part of Senegal. This was an indication that the findings of this research in a tropical rain forest zone of Nigeria were adequate in producing optimum rice yield without wasting water. However, this was different from Pereira *et al.* (2002) and Lage *et al.* (2003) positions and may be due to their locations.

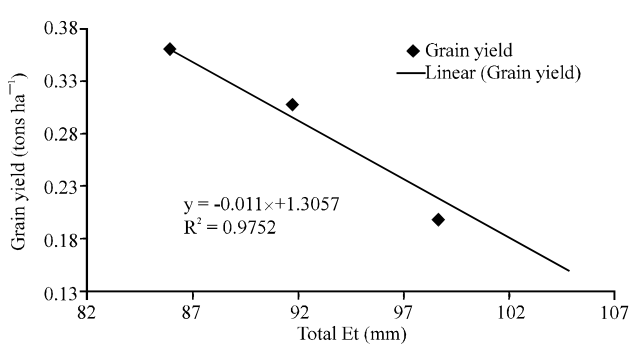

Fig. 3: Grain yield versus total evapotranspiration (ET)

Soil characteristics: The physical and chemical properties of the soil at the experimental site were determined and shown on Table 1. The soil class was found to be Sandy loam on the USDA textural triangle from 74% Sand, 14% Clay and 12% Silt. This class suggested that the soil on the site is predominantly sandy and allows quick downward movement of water to the lower layer of soil. This is beneficial to both the deep-rooted and shallow-rooted crops. The sandy loam texture with a good aeration will favour crop growth under the sprinkler or trickle irrigation system while the combined physical and chemical characteristics showed that it was good for upland rice cultivation especially in areas with similar soil properties in the region. The soil pH was 5.5 which is slightly acidic and good residue of plant nutrients for rice cultivation (Lafitte *et al.*, 2007). The bulk density (1.27 g cm^{-3}) and particle density (2.63 g cm^{-3}) were within tolerable limits for crop growth. FAO (1996). Above the critical value of 2.1 g cm^{-3} for bulk density, plant growth would be seriously impeded. All other minerals were present in sufficient quantities (Nitrogen, 0.13%, Carbon, 1.21%, phosphorous, 6.05%, potassium, 0.5%) and fall within tolerable limits suitable for sustaining crop growth. Studies on Soil Carbon (SC) had generated interests due to its importance in sustainable agriculture strategies to increase soil fertility and accelerate C sequestration (Law *et al.*, 2009). The amount of carbon stored in the soil was estimated to be four times greater than the total available in a living vegetation (Law *et al.*, 2009) hence underlying its importance to this study. There was little retention of C and N in the early stage of crop establishment which may be due to land management practices. Soil C may also be affected by climate, soil texture, nutrient status and time since the land management was initiated (Handayani *et al.*, 2008). This agreed with the findings of Handayani *et al.* (2010) and Akinbile and Yusoff (2011a) in their respective studies. The presence of all the minerals in the soil, Iron (138.9 ppm), Manganese (236.44 ppm), Zinc (2.39 ppm) and Copper (1.41 ppm) were well below the maximum permissible level for soil composition which is injurious to crop (FAO, 1996). For Iron, Manganese, Zinc and Copper, their maximum allowable limits were 200 ppm, 200 ppm, 2000 μg L^{-1} and 250 ppm, respectively. Irmak (2009) remarked that toxicity could occur if micronutrients were present is

Table 1: Some selected physical and chemical soil parameters at the study site

Parameters	Measured values	FAO Permissible values
pH (H_2O)	5.50	6.5-8.5
% N	13.00	45-50
% C	1.20	
P (ppm)	6.05	
K (ppm)	0.50	
Exchangeable acidity	0.00	
Fe (ppm)	138.90	200
Mn (ppm)	236.44	
Zn (ppm)	2.39	
Cu (ppm)	1.41	250
Ca (cmol kg^{-1})	2.77	
Mg (cmol kg^{-1})	0.70	200
Na (cmol kg^{-1})	0.10	
% Sand	74.00	-
% Clay	14.00	-
% Silt	12.00	-
Bulk density (g cm^{-3})	1.27	-
Particle density (g cm^{-3})	2.63	-

excess in soils. Other minerals in the soil such as Calcium (2.77 cmol kg^{-1}), Magnesium (0.70 cmol kg^{-1}) and Sodium (0.10 cmol kg^{-1}) were in permissible non-toxic limits in the soil and therefore not harmful for crop growth.

Water quality: The physical and chemical properties of the water from dam are detailed in Table 2. The results showed that the parameters determined fall within the tolerance limits of irrigation water for crop production in the study area as spelt out in the FAO (1996) yearbook. Bouman and Tuong (2001) considered salinity and total dissolved solids as most important parameters for irrigation water because they has the capacity to control the availability of water to plants through osmotic pressure regulating mechanisms. Since these parameters were within the limits recommended for irrigation water, the water from the dam was considered suitable for irrigation purposes.

The irrigation water form IITA Dam was colourless, odourless and had low turbidity value of 0.04 JTU far below the recommended guideline value of 5 JTU. The implication is that the degree of suspended particles present was not high enough as to cause a blockage on any part of pipes or sprinkler nozzles during operations. The low value of electrical conductance 2.4×10^{2} µS cm^{-1}, was also an indication of low salt contents which if present in high quantities will affect growth and yield of the crop. This view was shared by Aimrun *et al.* (2011) as similar result was obtained in his study aimed at characterizing paddy soil's physical and chemical characteristics using apparent electrical conductivity technique for rice precision farming in Selangor, Malaysia. The heavy metals present; Zinc (16.7 ppm), Sodium (60.2 ppm) and Potassium (64.0 ppm) were within tolerable limits permissible for irrigation water. FAO (1996) reported that the maximum allowable limits for Zinc, Sodium and Potassium are 200 ppm and 210 ppm respectively above which the water will be unsuitable for irrigation purposes. Heavy presence of Zinc leads to hardness poisoning while change in colour in plants is caused by higher concentration of Potassium in water

Table 2: Physical and chemical parameters of water from the site

Parameters	Measured values	FAO Permissible values
Odour	Odourless	-
Colour	Colourless	-
Taste	Insipid	-
Turbidity (JTU)	0.04	5-10
Conductivity (µS cm^{-1})	2.4×10^{2}	
pH	5.8	6.5-8.5
Alkalinity	265.4	
Chloride	0.18	
Hardness	6.0	
Nitrate	*ND	
Total solid	19	
Total dissolved solid	0.07	
Zinc	16.7	
Sulphate	*ND	
Iron	*ND	
Sodium	60.2	
Potassium	64.0	
Copper	*ND	
Manganese	*ND	

*ND: Not detected, All parameters are in ppm unless otherwise stated

(Pandey *et al.*, 2006). It was further remarked by Irmak (2009) that though the insufficient content of micronutrient elements in soil and water had negative impact on the development of crops, which in turn affected human health, toxicity could occur when present in excess. The average pH value was 5.8 from the study which was considered good for rice crop since it thrives well on a slightly acidic soil. This was particularly good as this was similar to the observations of Takase *et al.* (2011) in his study of four different water sources for irrigation purposes. The All other parameters, alkalinity and hardness have minimum permissible values in the water from IITA dam hence suitable for irrigation purposes for this study.

CONCLUSION

Sustainable increased rice production in the near future requires substantial improvement in productivity and efficiency. The use of innovative genetic improvement including hybrid rice and possibly transgenic rice could increase the yield ceiling, where yield gaps are nearly closed. It was also reported that a direct relationship existed between the amount of irrigation water and ET with rice yield indicating the dependence of yield improvement or (shortage) on the quantity of irrigation water administered and by extension the crop water use (ET). Therefore, water application, being a dominant factor affecting growth and grain yield of rice needs to be properly scheduled for improved rice production. Similarly, a direct relationship existed between water and soil qualities with respect to crop yield under any given circumstance. This pre-experiment investigation at the International Institute of Tropical Agriculture (IITA) Ibadan, Nigeria attested to this. From the soil samples analyzed, it was evident that the constituents of parameters investigated were within permissible limits as to permit the growth and increased grain yield of rice. Also, from the water samples analyzed, the constituents were well below the maximum allowable concentration for irrigation purposes. The results indicated that although, traceable quantities of pollution were noticed in both soil and water samples, they were insufficient to prevent promotion of good and optimum rice crop growth under existing conditions.

Proper irrigation could guarantee sufficient yield increase in rice production while excellent soil and water qualities could also play significant factor.

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