

# Crop Water Use Responses of Upland Rice to Differential Water Distribution under Sprinkler Irrigation System.

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## ABSTRACT

A two-year dry season experiment was conducted at the research farm of the International Institute of Tropical Agriculture, IITA Ibadan, Nigeria to estimate irrigation water requirements and establish crop water use. Two upland rice varieties (NERICA 2 and NERICA 4) were planted in a randomized complete block design (RCBD). Four treatments based on different water distribution levels were adopted. Total irrigation water applied were 3047 mm, 2656 mm, 2223 mm, and 1789 mm while reference ET were 236.5 mm, 260.6 mm, 283.9 mm, and 310.9mm in treatments A, B, C, and D, respectively, for NERICA 2.

There were no significant differences in these parameters for NERICA 4 variety. Total irrigation water applied were 3054 mm, 2649 mm, 2220 mm, and 1792 mm while total reference ET were 238.6 mm, 258.8 mm, 285.9 mm, and 308.8 mm in A, B, C, and D, respectively.

The total average weekly crop ET used were 31.6 mm, 36.8 mm, 39.9 mm, and 42.9 mm in all the four treatments while the highest weekly crop water use was observed during ripening stage at 8 weeks after planting (WAP) in all the treatments; 3.18 mm/day (A), 3.66 mm/day (B), 3.94 mm/day (C), and 4.24 mm/day (D). The minimum consumptive water use of 1.16mm/day was observed in 13 WAP in A.

The water use efficiency (WUE) decreased in line with water distribution pattern in all the treatments. In NERICA 2, it decreased from 0.0165 t/ha/mm (A), to 0.0152 t/ha/mm (B), to 0.0099 t/ha/mm (C), and 0.0044 t/ha/mm (D). Similar pattern were observed in NERICA 4 variety. 0.0175 t/ha/mm (A), 0.0154 t/ha/mm (B),

0.0110 t/ha/mm (C), and 0.0087 t/ha/mm (D). The behavior of rice crop in extracting water varied with the phenological stages with the highest quantity of water extraction taking place at the mid season/ripening stage during which increased metabolic activities lead to grain formation.

(Keywords: upland rice, water use, sprinkler irrigation, evapotranspiration, agricultural water use)

## INTRODUCTION

Rice (*Oryza sativa* L) 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 {1}. In Nigeria, rice is the sixth major crop in cultivated land area after sorghum, millet, cowpea, cassava, and yam {2, 3}. It is the only crop grown nationwide and in all agro ecological zones from Sahel to the coastal swamps.

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 {4}. The irrigated ecology has very high potential for rice production but contributes only 10-15% of the national production {5}.

Before the oil boom of the 1970s, Nigeria had been largely self sufficient in rice production with negligible imports to take care of the taste of small European populations in the country. The resultant buoyant foreign exchange earnings of the country from the oil boom of 1970-80 raised the general standard of living and taste, which resulted in massive importation of all kinds of manufactured goods and commodities, including

rice. Local rice production was no longer encouraged and therefore national self-sufficiency declined from over 99% to about 23% in 1984 {6}. Rice importation rose from 7,000 tons in the 1960s to 657,000 tons in the 1990s {7}. Nigeria is the World's second largest rice importer, spending over US\$300 million on rice imports annually. It imported 1.7 and 1.5 million tons in 2001 and 2002, respectively {8}. This created a serious drain on Nigeria's foreign exchange reserve.

Water is essential for rice cultivation and its supply in adequate quantity is one of the most important factors in rice production. Most studies on constraints to high rice yields show that water is the main factor for yield gaps and yield variability from experiment stations to farm {9}. Irrigated agriculture is the dominant use of water, accounting for about 80 % of global and 86% of developing countries water consumption as at 1995 {10}. 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 {11}.

About 250 million ha, representing 17% of global agricultural land, is irrigated worldwide today, nearly five times more than at the beginning of the 20<sup>th</sup> Century. This contributes about 40% of the global production of cereal crops. Irrigated rice was responsible for about 75% of the world's total rice production {12}. Irrigation has helped boost agricultural yields and outputs, stabilize food production and prices.

A sustainable increase in irrigated rice production however faces a number of critical technical and development factors. Land and water resources for irrigated rice production especially in Asia have been increasingly lost to the expansion of urban and industrial sectors. In other continents such as Africa, the high cost of development of irrigation infrastructures is the major constraints to the expansion of irrigated rice production. Inappropriate management of irrigation has contributed, not only to food insecurity but also to environmental problems including excessive water depletion, water quality reduction, water logging and salinization {13}.

During the crop growth period, the amount of water usually applied to the field is often much more than the actual field requirement. Irregular water application often leads to a high amount of surface runoff, seepage and percolation which

accounts for about 50-80% of the total water input into the field {14}. Therefore, the water crisis being experienced today is not about having too little water to satisfy our needs especially in Agriculture but a crisis of proper management {15}. Increased rice production consistently can be achieved by increasing area under irrigation, increasing cropping intensity and maximizing one major factor of production, which is water. Therefore, an attempt was made to determine the consumptive water use pattern of Upland Rice to differential water application using sprinkler irrigation system in Nigeria.

## MATERIALS AND METHODS

This study was carried out at the farmyard of the International Institute of Tropical Agriculture (IITA) Ibadan, the Oyo State capital, Nigeria. It is located between latitude 3° 54'E and 7° 30'N, at elevation of 200m above the mean sea level. It has an annual rainfall range of between 1300mm and 2000mm 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 and is described 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 {16}.

Field experiments were conducted for two dry seasons to ascertain the crop's water use under irrigated conditions, between November 2005 to March 2006 and November 2006 to March 2007. 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. Plot A (first treatment) received water seven times continuously in one week (full ET) and plot B (second treatment) received water six times a week (0.75 ET). The third treatment (plot C) received water five times a week (0.5 ET) and the fourth treatment (plot D) received water four times a week (0.25 ET) (Akinbile, 2009).

Water was pumped into the sprinkler line system and delivered to the field plots through the risers and sprinkler heads. The sprinkler arrangement

was 6x6 m triangular configuration. There was pre-planting irrigation for about two days before planting to allow soil to attain field capacity, promote germination, and easy crop establishment. The specifications of sprinklers heads were 48 mm range by 40 mm sprinkler nozzles. The plot area was leveled as sprinklers placed on 100 cm high and 2.5 cm diameter risers attached to a 3.0 cm diameter quick-coupling portable PVC pipe as supply line. The pressure head difference between the ends of the line was approximately 1% of the inlet pressure and each sprinkler discharged 0.54 l/s, giving a total discharge of 4.32 l/s.

Each plot size was 5mx5 m with 1 m alleyways all round the plots with a total of 4 plots and 2 treatments. All the plots were irrigated as scheduled under low wind conditions (<1 m/s) in the evenings to minimize evaporation losses. During each irrigation, the quantity of water received at every irrigation level plot was measured with catch cans (four cans per plot) scattered randomly over each plot and average applied water determined. Water related measurements such as moisture content, potential, were carried out using gravimetric and digital tensiometer techniques. The reference evapotranspiration (ET<sub>r</sub>) was determined for each day after irrigation using Modified Hargreaves equation and data from IITA meteorological station near the site. Crop water use was thereafter obtained. Results obtained during field experimentation were subjected to statistical analysis using SAS 9.1 version.

## RESULTS AND DISCUSSION

### Moisture Content and Potential Variation during Crop Growth

The variation of soil moisture content during crop growth in all the treatments were as shown in Figure 1. The effect of the four irrigation levels began after the crop had reached the vegetative stage, which was between 35 to 50 days after planting (DAP). At 20 DAP, the soil moisture content storages at 10, 20, 30, and 40 cm depths were within 13, 10, 9, and 7 %, respectively. From 70 to 90 days after planting, the soil water storage at the same depth was almost the same. This may be due to reduced irrigation as the crop grain has been formed and almost getting ready for harvest (maturity). It should be noted that the water requirement of rice is at its highest demand

at reproductive and ripening stages. Vegetative stage is between 0-50 days after planting; reproductive is between 50 –80 days while ripening stages is usually between 80-100 days.

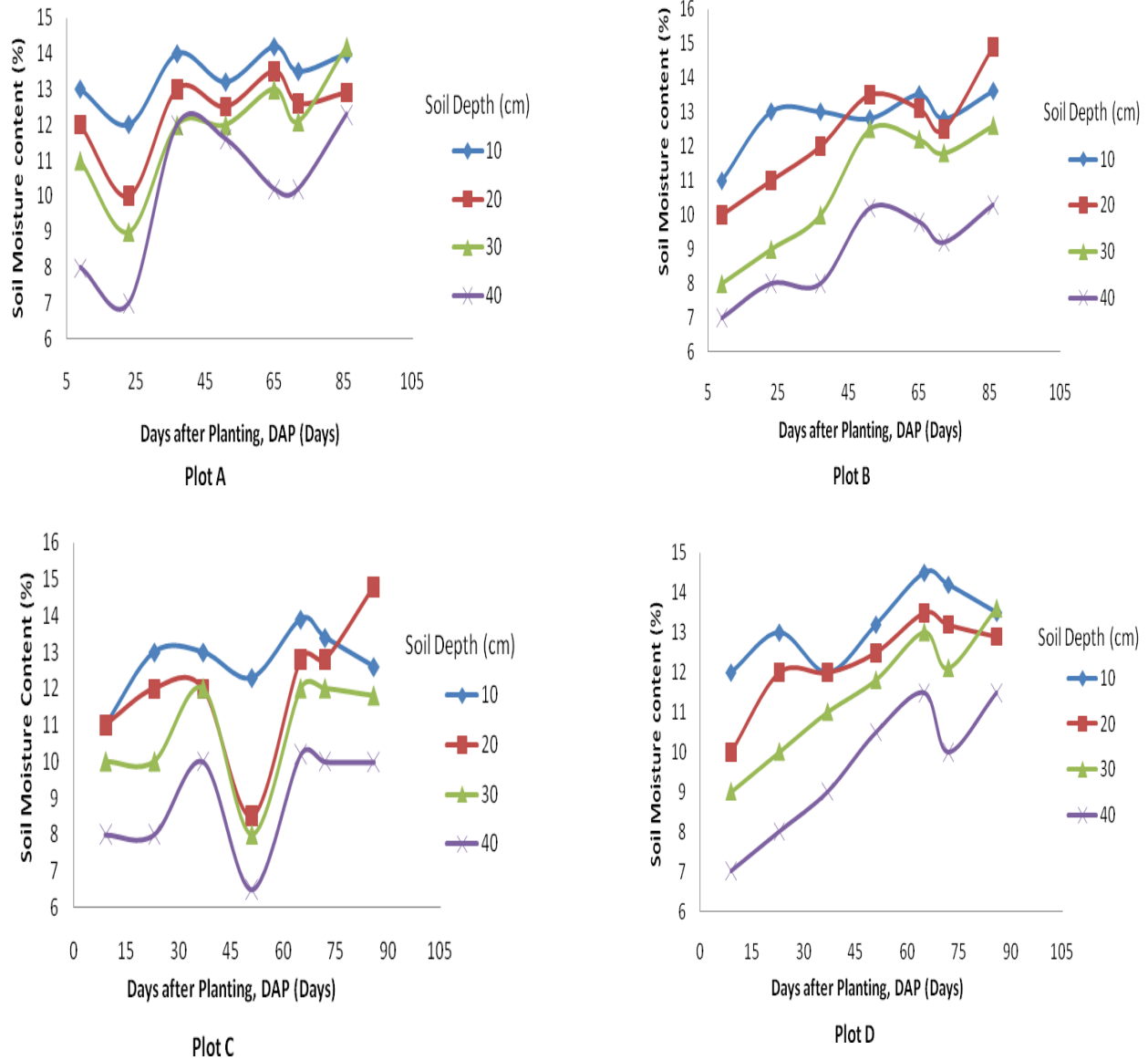
The water demand was high due to the agronomic changes peculiar to the mid season stage, which include booting, heading and flowering for reproductive and milky, dough and maturity for ripening stages. The length of ripening was mostly affected by temperature. It takes 30 days in the tropics and 65 days in the temperate regions {17}. The variation of soil moisture potential with soil depth during the entire growing season in plots A/B and C/D, respectively, are as shown in Figure 2.

At the vegetative stages when the crop root depth was about 10cm, the moisture content was also between 12 and 14 % while the soil water potential was between 0.19 and 0.25 in all the plots. It was observed that extractable soil water for the crop was decreasing with increase in soil depth. At the flowering stages, when the root depth was about 20 cm (Figure 2), the soil moisture potential was between 0.18 and 0.23, the moisture content being between 10 and 13 %.

The extractable soil water was diminishing and the crop was becoming more dependent upon the applied irrigation water for its survival. At maturity stage when the crop root depth was about 23 cm (Figure 2), the soil water potential ranged between 0.18 and 0.25 kPa while the moisture content was between 7 and 13% (Figure 1). There was more concentration of available soil water within this crop root depth but was not sufficient to meet the crop water requirement.

### Relationships between Crop Yield and Evapotranspiration

A relationship was established between the crop yield and reference evapotranspiration during the experiment. Researchers {18} remarked that the relations for crop production functions without considering the time of water deficit may be modified by replacing the amount of irrigation water with seasonal ET. Table 1 gives the summary of the total grain yield, and the seasonal ET in each of the treatment plots. Under irrigation, ET depends on the quantity of water applied and time of irrigation. From the Table, the range of ET and yield were 86 - 105 mm and 1.36 to 0.16 t/ha, respectively.

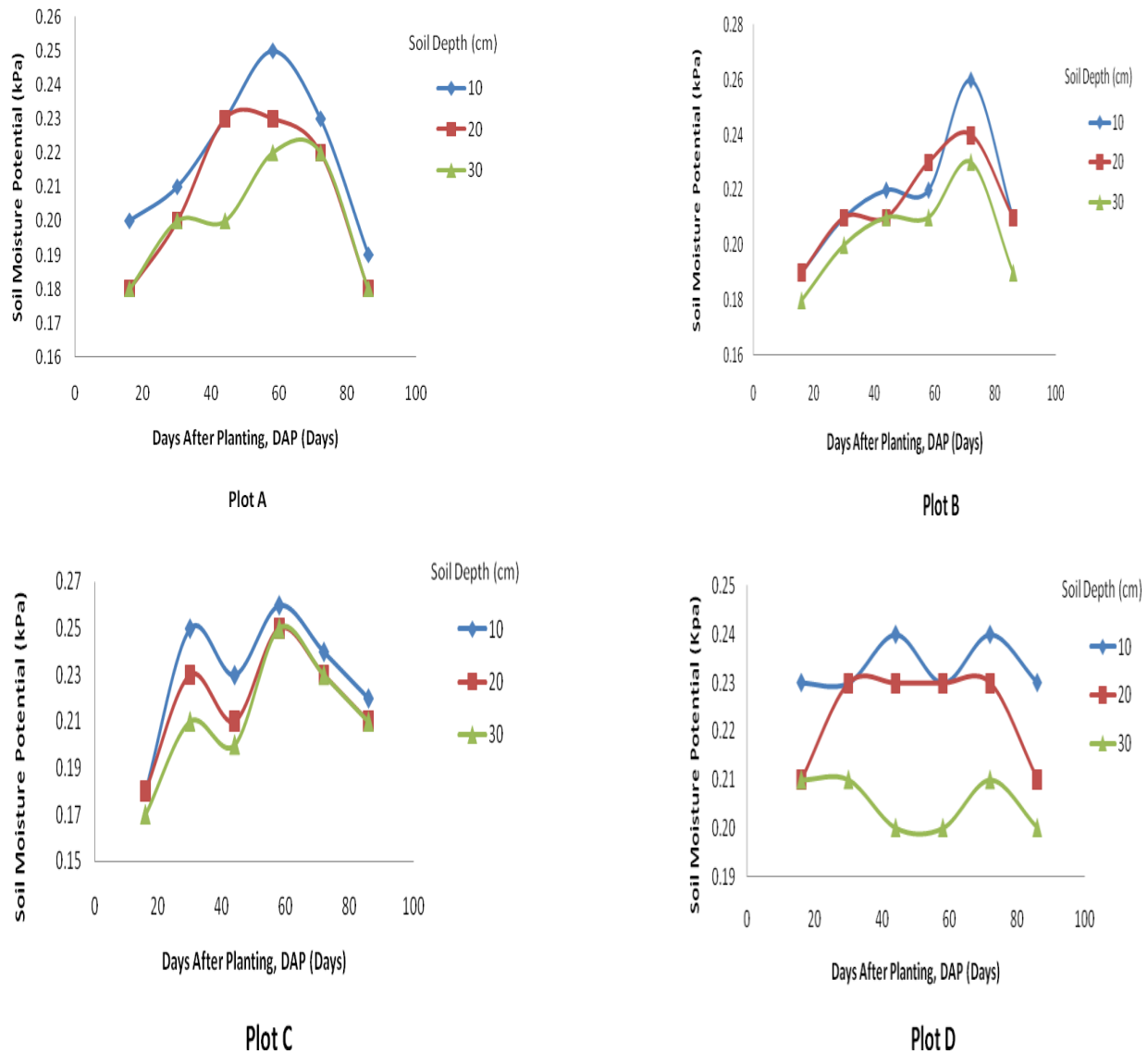


**Figure 1:** Variation of Soil Moisture Content against Days after Planting (DAP) in all the Treatments.

This was for the first trial, (2005/2006 experiment). For the 2006/2007 experiment, the ranged of ET and total grain yield was between 237 - 311mm and 1.94 - 0.29 t/ha, respectively, in all the treatments (Table 2). This was an indication that there is a direct relationship between ET and yield. In this study, reference ET of between 87 and 107mm was required to produce minimum grain yield while a range of between 237 and 311mm was required to produce the maximum grain yield under a limited water supply. Researchers {19} reported that ET values ranging from 200 to 480mm were sufficient for rice production in northern part of Senegal.

This is an indication that the findings of this research in a tropical rain forest zone of Nigeria are adequate in producing optimum rice yield without wasting water. The crop uses less stored soil water when the amount of irrigation is 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 will be at the maximum. Therefore, the rainfall during the crop-growing season and the stored soil water at pre-planting need to be considered when irrigation scheduling is made.



**Figure 2:** Variation of Soil Water Potential versus Days after Planting (DAP) in all the Treatments.

From Table 2, total irrigation water applied varied from 3047mm in treatment A, 2656 mm in treatment B, 2223 mm in C, and 1789 mm in treatment D with a slightly higher yield. This was an indication that increasing irrigation water for the first experimental trial will result in increase in yield. Above the water value in A, increase in yield will not be significant when compared with the quantity of water applied. Increasing irrigation water above the quantity applied in A will only increase water loss and not translate to yield increase. From the literature, the maximum yield of rice that could be attained under standard environmental conditions was between 0.9 – 2.0

t/ha {5}. Producing 1.94 t/ha of upland rice using 3047 mm of applied irrigation water was significantly reasonable. This statement was supported by {20} and {21} in their respective studies to determine yield responses to excess and deficit water application, respectively.

As for the efficient use of water by the crop, Table 3 showed the estimated values of water use efficiencies of rice in the treatment plots for the 2005/2006 experimental trials. The values for 2006/2007 trials were not different from that of the previous year. The water use efficiency decreased from treatment A,(0.0165 t/ha/mm) to

treatment B, (0.0152 t/ha/mm) and further decreased to treatment C (0.0099 t/ha/mm) and treatment D, (0.0044 t/ha/mm). The same pattern was observed from A-N4 through D-N4. It could therefore be concluded that water use efficiencies decreased in the order of the amount of water

received per treatment. Any water deficit at the different growth stages of rice would greatly reduce yield. This was evident as the emergence of whiteheads (Table 4) was observed at 78 DAP after deficit irrigation was introduced during ripening stage.

**Table1:** Summary of the Grain Yield and ET in Treatment Plots for 2005/2006 Experimental Trial.

Treatment Plots	Irrigation Water Applied (mm)	Total ET mm	Total Grain Yield t/ha
A-N2	1190.50	86.01	1.36
B-N2	1040.75	91.98	0.81
C-N2	850.00	99.04	0.30
D-N2	694.17	105.83	0.16

**Table 2:** Summary of the Grain yield and ET in Treatment Plots for 2006/2007 Experimental Trial.

Treatment Plots	Irrigation Water Applied (mm)	Total ET (mm)	Total Grain Yield (t/ha)
A-N2	3047	236.47	3.89
B-N2	2656	260.64	3.95
C-N2	2223	283.95	2.81
D-N2	1789	310.98	1.38
A-N4	3054	238.56	4.17
B-N4	2649	258.76	3.98
C-N4	2220	285.85	3.13
D-N4	1792	308.77	2.67

**Table 3:** Estimated Values of Water use Efficiency (WUE) in Treatment Plots for 2006/2007 Experiment.

Treatment Plots	Irrigation Water Applied (mm)	Total ET (mm)	WUE t/ha/mm	Kg/ha/mm
A-N2	3047	236.47	0.0165	16.45
B-N2	2656	260.64	0.0152	15.155
C-N2	2223	283.95	0.0099	9.896
D-N2	1789	310.98	0.0044	4.437
A-N4	3054	238.56	0.0175	17.48
B-N4	2649	258.76	0.0154	15.38
C-N4	2220	285.85	0.01095	10.95
D-N4	1792	308.77	0.00865	8.647

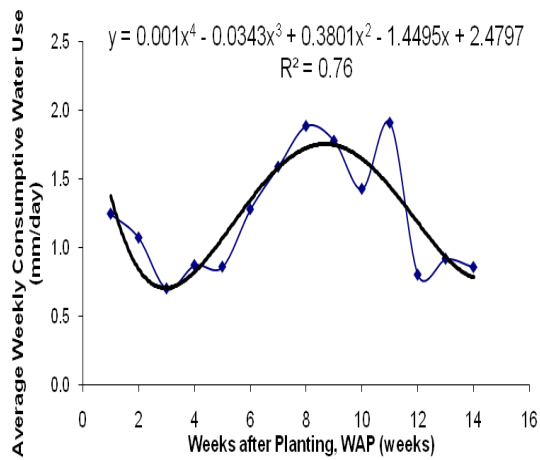
**Table 4:** Number of Whiteheads in the Plots at 78 DAP in the 2005/2006 Trial.

Plot	Whiteheads	% Composition per plot
A	47	7.4
B	81	15.7
C	94	16.1
D	98	16.6

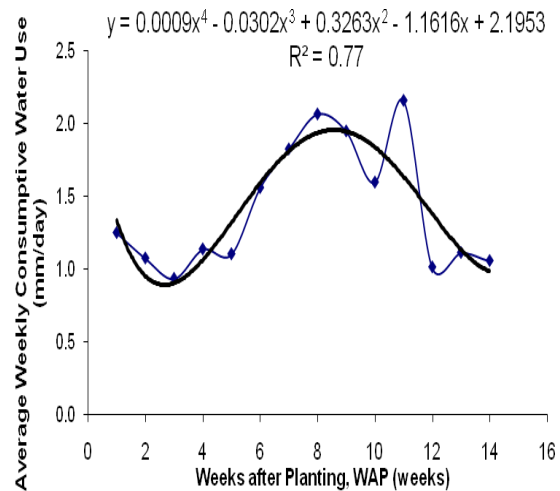
The flowering stages (i.e. booting, dough, and milky) are considered the most critical [22]. The decline in yield in the treatment plots suggest the various water supply conditions that prevailed during the experiment. As water use efficiency entails maximum production per unit water applied, the findings further confirmed that water is a major yield-limiting factor for rice production and also in line with the works of [23].

### Crop Water Use Pattern and Irrigation Scheduling

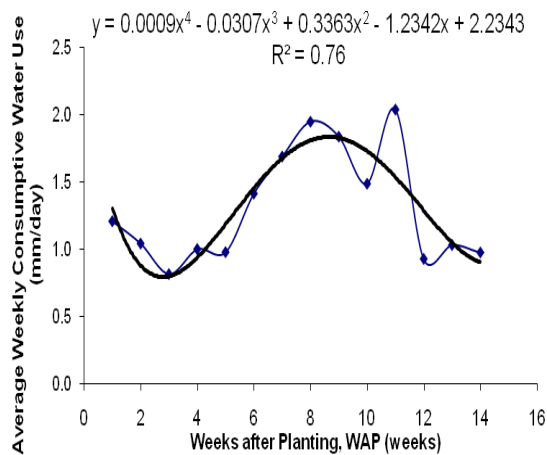
Figures 3 and 4 showed the graphs of the average weekly consumptive water use plotted against weeks after planting (WAP) in 2005/2006 and 2006/2007 experimental trials. From Figure 4, average weekly water use varies from 1.16 mm/day (13 WAP in A) to 4.24 mm/day (8 WAP in D).



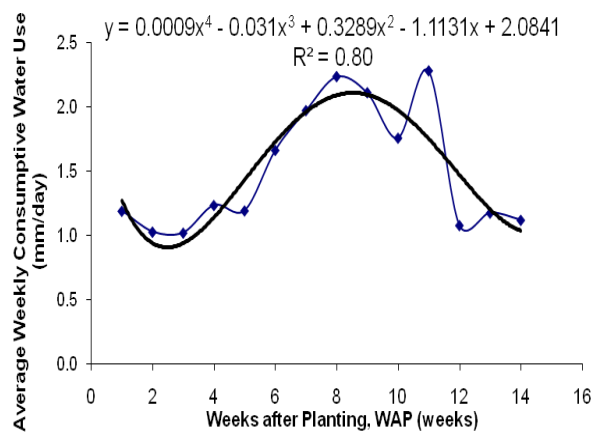
Plot A



Plot C

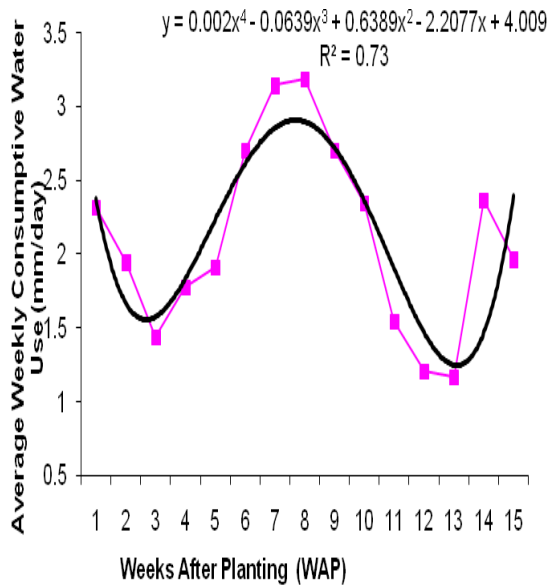


Plot B .

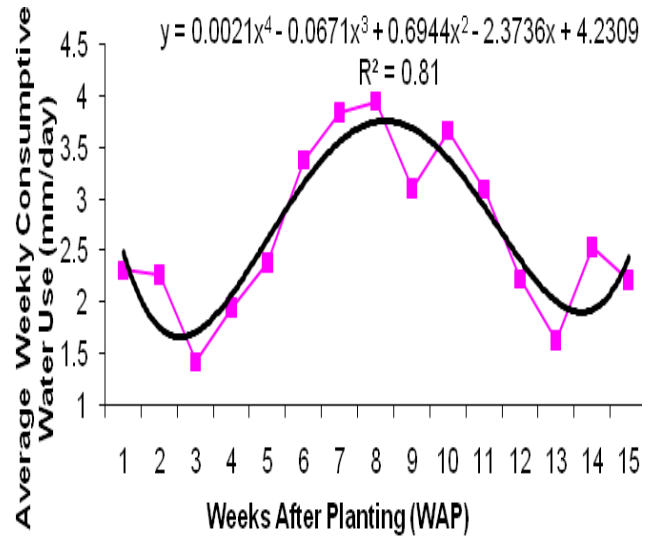


Plot D

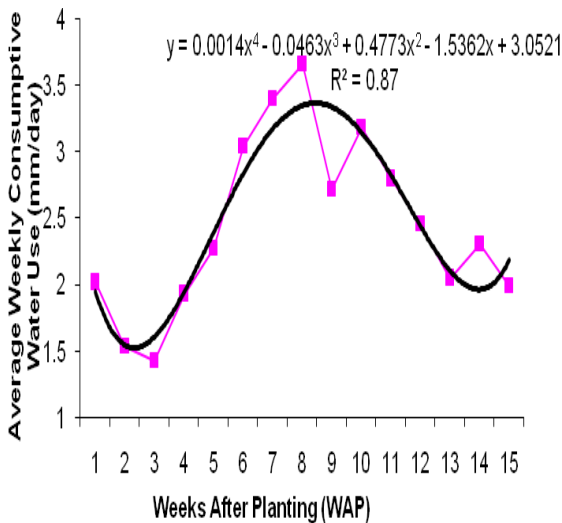
**Figure 3:** Average Weekly Consumptive Water Use versus Weeks after Planting (WAP) for all the Treatments of 2005/06 Field Experiment.



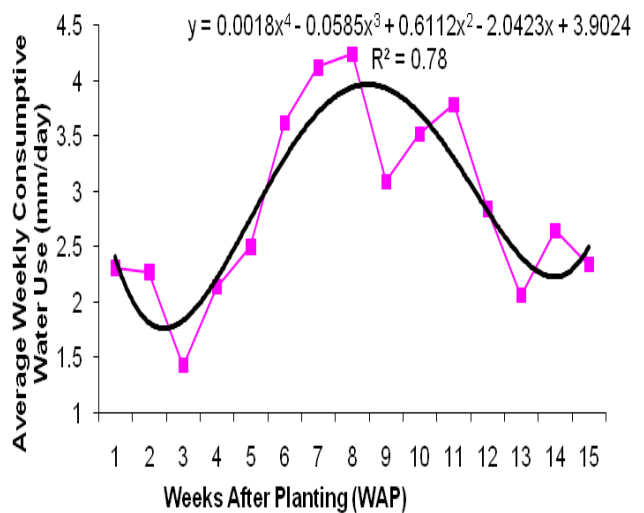
PLOT A



PLOT C



PLOT B



PLOT D

**Figure 4:** Average Weekly Consumptive Water Use versus Weeks after Planting (WAP) all the Treatments of 2006/07 Field Experiment.

The data showed that water stress leads to corresponding increase in water use at certain stages of crop growth and development, hence the higher consumptive water use during the later stages of ripening. The same behavior was observed during the first experimental trial (Figure

3). Other researchers {19} remarked that between 6.5 to 9 mm/day were the results of his findings when similar study was carried out in northern Senegal which is a semi-arid zone. The highest water use was recorded between 7-11 WAP in the first trial (Figure 3) and 6-10 WAP in



the second trial (Figure 4). These observations led to a patterned crop water use which could be used to plan irrigation scheduling. From the study, three distinct stages of water application were observed. The first stage, vegetative (1-7 WAP) has less water use due to low agronomic and metabolic activities. At this stage, irrigation should be normal due to less crop water requirements.

During the second or mid-season stage corresponding to 7-12 WAP; water applied was highest. This was due to the severe negative effect of the shortage of water application on growth, yield and development of rice grain formation. This was evident in the formation of whiteheads at this stage during the experiment (Table 4). At the third or maturity stage (12-15 WAP), irrigation was reduced because sustained increase in water application will not translate to further increase in yield as grain formation must have been completed at the mid season stage.

## CONCLUSION

A two year field experiment to evaluate differential water application of upland NERICA rice as it relates to increased productivity was carried out at the farmyard of the International Institute of Tropical Agriculture, (IITA) Ibadan, Nigeria. The choice of upland rice was informed by the fact that the irrigated upland ecology has very high potential for rice production but contributes between 10 and 15 percent to national production.

Findings showed that known quantities of irrigation water could be used in producing optimum yield for upland cultivars. Adopting strict water conservation measures will lead crop failure at a certain stage, indicating that the effect of water stress leads to corresponding increase in water use at certain stages of crop growth and development. The behavior of rice crop in extracting water varied with the phenological stages.

From the study, three distinct stages of water application for proper irrigation scheduling were observed. At the first stage, irrigation should be normal due to low crop water requirements. During the second stage, irrigation should be increased by 100% due to high water demand and at the third stage; irrigation should revert back to normal because sustained increase in water application will not lead to further increase in yield as grain formation must have been completed.

The water use efficiencies decreased in accordance with the amount of water received per treatment and in line with water distribution pattern indicating excellent water management. The crop water use behavior at periods of very low water availability suggests its capacity to adjust physiologically to stress and is therefore a major yield-limiting factor for rice production.

The application of water, being a dominant factor affecting growth and grain yield of rice needs to be properly scheduled for improved rice production and to avoid waste. A significant increase in yield of about 15 % can be guaranteed and rice production could be increased from 2 to 3 cycles per year if irrigation scheduling is properly done. Some areas of further research includes estimating irrigation requirements for more upland rice cultivars (NERICA 1, 3, 5-19) to have a wider range of water use. This will give definite information about the water use of each variety for proper water management planning and irrigation scheduling

Rice response to various degrees of salt contents in water and soils should be investigated to determine the optimum salt level that will produce appreciable yield when compared with the one produced from non-saline soils and water.

Research should be conducted into using modern technologies for bird scaring to reduce considerable yields of rice being lost annually. This is to ensure reliable yield data. The age long, primitive method of human bird scaring is effective only on small fields. However, the use of nets as temporary measures to prevent rice invasion by birds (small or medium fields) is suggested. Similarly, chicken wire mesh should be placed around the field to prevent rodents and grass cutters invasion. This is useful where human efforts (bird scaring) may not be enough to prevent birds from attacking rice fields.

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## REFERENCES

1. Bandyopadhyay, S. and Roy, C.N. 1992. *Rice Processing Technology*. IBTT Publishing Co. PVT.: Japath, New Delhi, India. 66.
2. Dauda, S.M. and Dzivama, A.U. 2004. "Comparative Performance of a Locally Developed Rice Thresher with an Imported Votex Rice Fan". *Proceedings of the 5th International Conference of the Nigerian Institution of Agricultural Engineers*, Ilorin, Nigeria. 26; 29-32.
3. Olaleye, A.O., Osiname, O.A. and Cofie, O. 2004. "Soil and Water Management for Rice Production in Nigeria". *Proceedings of the West Africa International Conference on Hunger without Frontiers*. West African Society for Agricultural Engineering (WASAE), 20-24 September, 2004. Kumasi, Ghana. 259-265
4. Kehinde, J.K. 1997. "Advances in Rice Production". In: *Rice Production and Processing Workshop*. National Cereals Research Institute. Badeggi, Niger State. 1-14
5. Misari, S.M., Ukwungwu, M.N., and Imolehin, E.D. 2001. "Accelerated Development and Production of Quality Rice in Nigeria". *2nd meeting of the National Executive Committee of Rice Farmers' Association of Nigeria*. Gwagwalada, Nigeria. 28th February, 2001
6. Akintola, A.A. 2000. "Increased Rice Production and Processing in Nigeria: The Way Forward". *The Nigerian Agricultural Engineer; A Journal of the South East Regional Chapter of the Nigerian Institution of Agricultural Engineers*, 1 (1):10-17. September, 2000. SNAAD Press Limited: Enugu, Nigeria.
7. WARDA. 1996. *Rice Trends in Sub-Saharan Africa, Second edition*. WARDA: Bouake
8. Doorenbos, J. and Pruitt, W.O. 1992. "Crop Water Requirements". FAO Irrigation and Drainage Paper 24. FAO: Rome, Italy.
9. Papadimitriou, M.K. 2001. "Issues and Perspectives of Rice Production in Asia and the Pacific Region". *Yield Gap and Productivity Decline in Rice Production Consultation*. Rome, Italy. 5-7:39-67
10. Droogers, P. and Allen, R.G. 2002. "Estimating Reference Evapotranspiration under inaccurate Data Conditions". *Irrigation and Drainage Systems*, 16: 33-45. Kluwer Academic Publishers
11. International Water Management Institute (IWMI). 2000. *Research Contributions to the World Water vision*. IWMI: Colombo, Sri Lanka.
12. Rosegrant, W.K, Cai, X. and Cline, S.A. 2002a. *Global Water Outlook to 2005: A Food Policy Report*. International Food Policy Research Institute: Washington, D.C.
13. Rosegrant, W.M., Cai, X. and Cline, S.A. 2002b. *Water and Food to 2025; Policy Responses to the Threat of Scarcity*. International Food Policy Research Institute: Washington, D.C.
14. Guerra, L.C., Bhuiyan, S.I., Tuong, T.R., and Barker, R. 1998. "Producing more Rice with less Water". IWIM, Paper 5. International Water Management Institute (IWMI): Colombo, Sri Lanka. 21.
15. Akinbile, C.O. 2009. "Crop Yield Responses of Upland Rice to Differential Water Application under Sprinkler Irrigation System". Unpublished Ph.D. Thesis, Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria.
16. International Institute of Tropical Agriculture (IITA). 2002. *Annual Report*. [http://www.iita.org/annual\\_report2002.aspx](http://www.iita.org/annual_report2002.aspx)
17. Allen, G.A., Pereira, L.S., Raes, D., and Smith, M. 1998. "Crop Evapotranspiration –Guidelines for Computing Crop Water Requirement". FAO Irrigation and Drainage Paper 56. FAO: Rome, Italy. 78-86.
18. Singh, B.N., Fagade, S., Ukwungwu, M.N., William, C., Japtap, S.S., Oladimeji, O., Effiisue, A., and Okhidiebie, O. 1997. "Rice Growing Environments and Biophysical Constraints in Different Agro ecological Zones of Nigeria". *Meteorology Journal*. 2(1):35-44.
19. Raes, D., Sy, B., and Deckers, J. 2006. "Simulation of Irrigation Water Requirements of Rice Schemes in the Senegal River Delta and Valley". Miezán, K.N., Wopereis, N.C.S., Dingkuhn, M., Deckers, J., and Randolph, T.F. (Eds.). *Irrigated Rice in the Sahel: Prospects for Sustainable Development*. West Africa Rice Development Association: Bouake, Cote d'Ivoire.
20. Doorenbos, J. and Kassam. A.H. 1979. "Yield Responses to Water". FAO Irrigation and Drainage Paper 33. FAO: Rome, Italy.
21. Lafitte, H.R., Price. A.H., and Courtois. B. 2004. "Yield Response to Water Deficit in an Upland Rice Mapping Population: Associations among Traits and Genetic Markers". *Theoretical and Applied Genetics*. 109:1237–1246.

22. Raemakers, R.H. 2001. "Crop Production in Tropical Africa". Directorate General for International Cooperation (DGIC) Belgium. 59-76.
23. Nwadukwe, P.O. and. Chude, V.O. 1998. "Manipulation of the Irrigation Schedule of Rice (*Oryza sativa* L.) as a means of Maximizing Water Use Efficiency and Irrigation Efficiency in the Semi-arid Tropics". *Journal of Arid Environments*. 40(3):331-339
24. WARDA. 2006. *Africa Rice Center (WARDA) Annual Report 2005-2006: Providing What's Needed*. WARDA: Cotonou, Benin. 52pp

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