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

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## ABSTRACT

*Rice is a staple food cultivated and consumed in Nigeria. Several research efforts on the crop had centered on the agronomic, soil and disease behavioural pattern with little work on its water use pattern. The study was aimed at estimating irrigation water requirements and establishing crop water use with its attendant effect on the rice crop. A two-year dry season experiment was conducted at the research farm of International Institute of Tropical Agriculture, IITA Ibadan, Nigeria. Two upland rice varieties (NERICA 2 and NERICA 4) were planted on a 5m X 5m plot in a randomized complete block design (RCBD). Four treatments based on different water distribution levels were adopted. Daily meteorological data were used to determine reference evapotranspiration (ET) and other supporting information relating to crop water use were also obtained. The results were subjected to statistical analysis. Total irrigation water applied were 3047mm, 2656mm, 2223mm and 1789mm while reference ET were 236.5mm, 260.6mm, 283.9mm 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 for NERICA 4. The total average weekly crop ET used were 31.6mm, 36.8mm, 39.9mm and 42.9mm in all the four treatments while the highest weekly crop water use was observed during ripening stage at 8 WAP in all the treatments; 3.18mm/day (A), 3.66mm/day (B), 3.94mm/day (C) and 4.24mm/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 behaviour 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. Increasing irrigation water application does not imply increased but decreased crop water use.*

**Keywords**: Upland rice, Water use, Sprinkler irrigation, Evapotranspiration.

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## 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 (Bandyopadhay and Roy, 1992). In Nigeria, rice is the sixth major crop in cultivated land area after sorghum, millet, cowpea, cassava and yam {Dauda and Dzivama, 2004; Olaleye *et al* 2004}. 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 {Kehinde, 1997}. The irrigated ecology has very high potential for rice production but contributes only 10-15% of the national production {Misari *et al* 2001}. 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 population 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 {Akintola, 2000}. Rice importation rose from 7,000 tons in the 1960s to 657,000 tons in the 1990s {WARDA, 1996}. 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, {WARDA, 2003}. 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 yield shows that water is the main factor for yield gaps and yield variability from experiment stations to farm {Papademetriou, 2001}. Irrigated agriculture is the dominant use of water, accounting for about 80 % of global and 86% of developing countries water consumption as at 1995 {Rosegrant *et al* 2002c}. 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 {IWMI 2000}. 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. Irrigated rice was responsible for about 75% of the world's total rice production {Rosegrant *et al* 2002a}. 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 {Rosegrant *et al* 2002b}. 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 {Guerra *et al*, 1998}. 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 {Akinbile, 2009}. 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

The study was carried out at the farmyard of the International Institute of Topical Agriculture (IITA) Ibadan, the Oyo State capital, Nigeria. It is located between latitude $3^0$ 54'E and $7^0$ 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 $27.2^0$C during dry season and $25.6^0$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 {IITA, 2002}.

Field experiment were conducted for two dry seasons to ascertain the crop's water use under irrigated conditions, between November 2005 and 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 6 x 6m triangular configuration. There was pre-planting irrigation for about two days before planting to allow soil attain field capacity, promote germination and easy crop establishment. The specifications of sprinklers heads are 48mm range by 40mm sprinkler nozzles. The plot area was leveled as sprinklers placed on 100cm high and 2.5cm diameter risers attached to a 3.0cm 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 5m x 5m with 1m 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 ($ET_o$) 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.

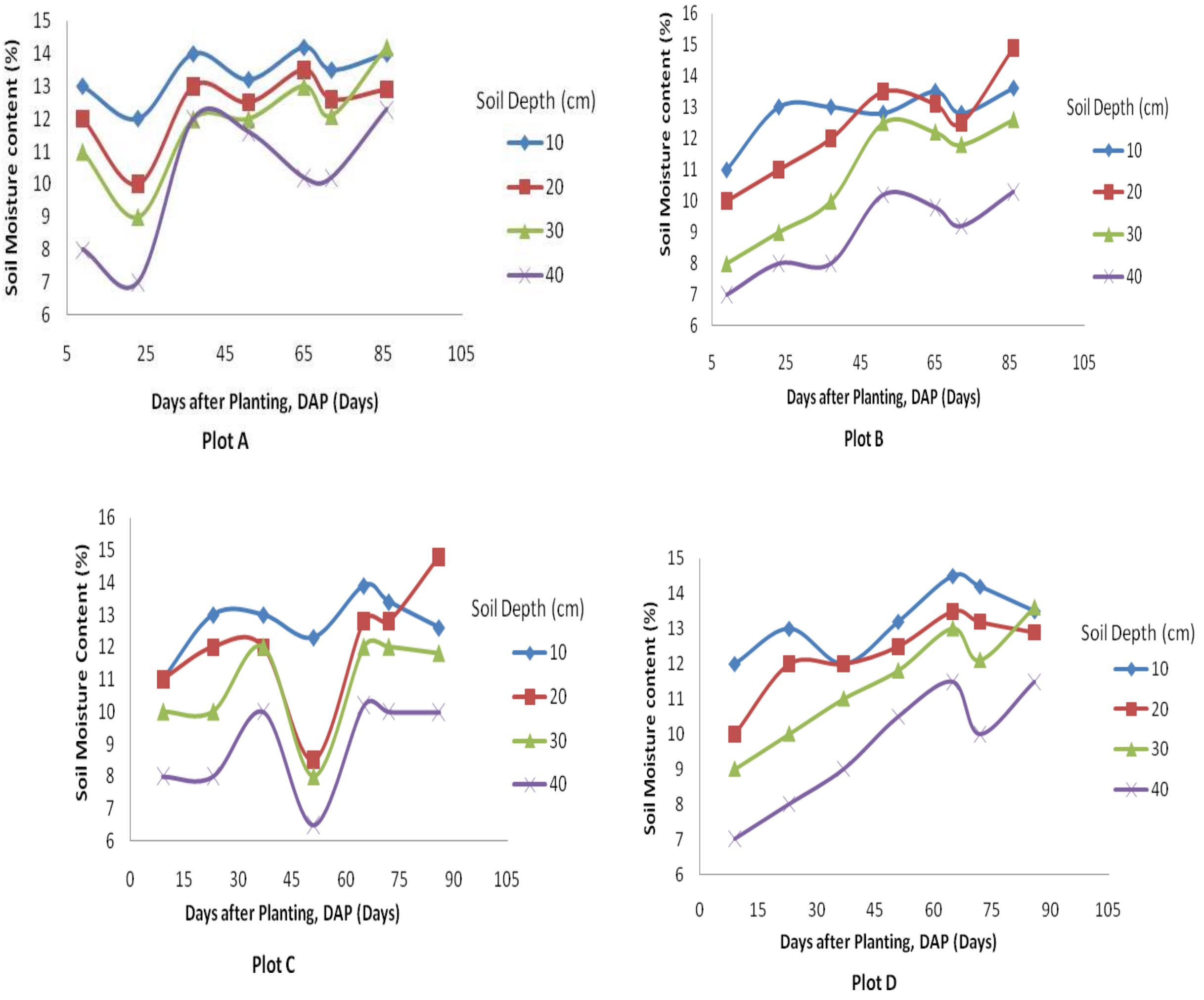
## RESULTS AND DISCUSSION

### 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 Fig. 1. The effect of the four irrigation levels began after the crop had reached the vegetative stage, which is between 35 to 50 days after planting (DAP). At 20 DAP, the soil moisture content storages at 10, 20, 30 and 40cm 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 is 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 is mostly affected by temperature. It takes 30 days in the tropics and 65 days in the temperate regions (Allen *et al*, 1998)

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 Fig. 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 0.25in 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 20cm (Fig.2), the soil moisture potential was between 0.18 and 0.23, the moisture content being between 10 and 13 %. The exactable 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 23cm (Fig.2), the soil water potential ranged between 0.18 and 0.25 kPa while the moisture content was between 7 and 13% (Fig 1). There was more concentration of available soil water within this crop root depth but was not sufficient to meet the crop water requirement.



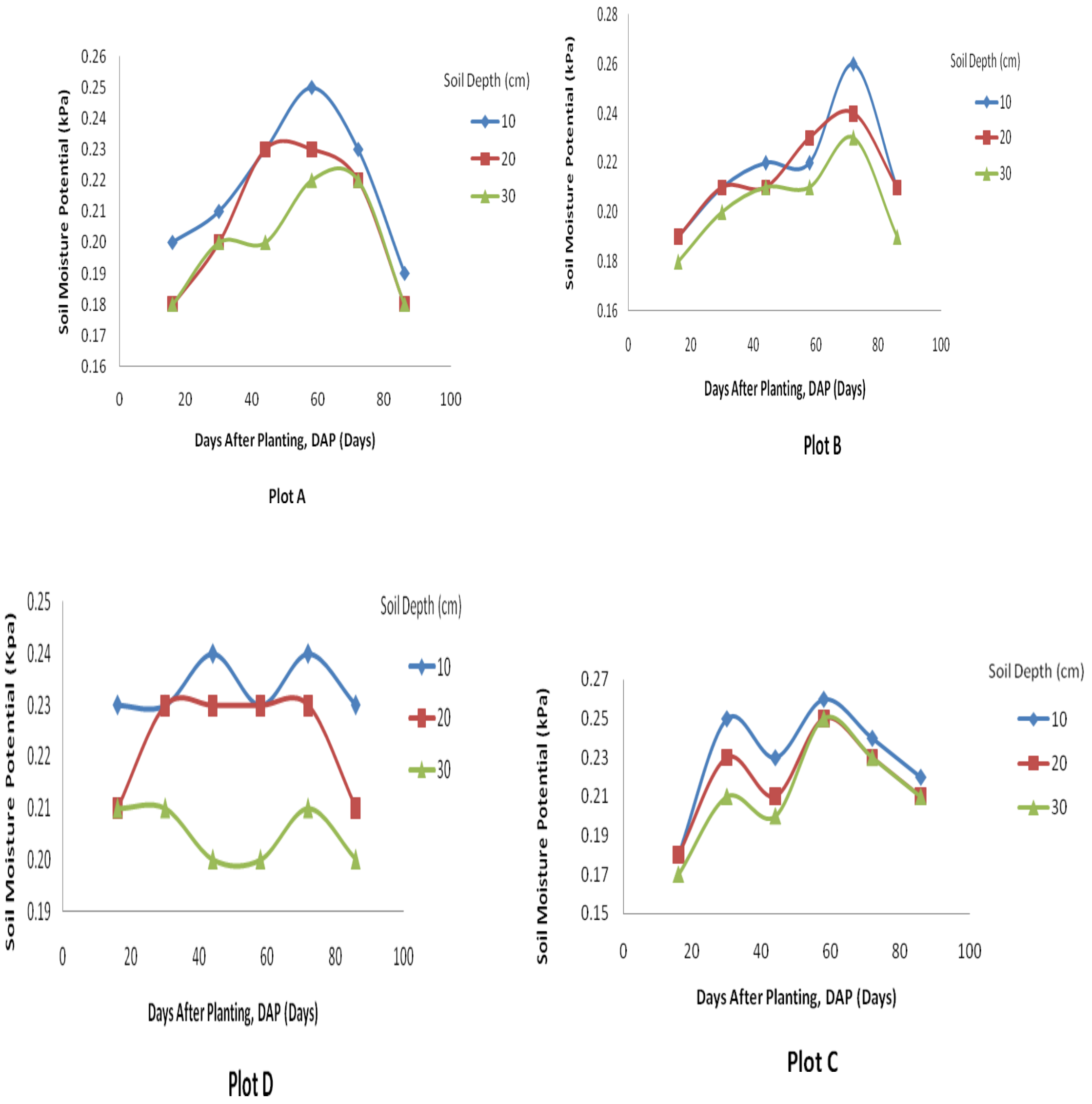
Plot A

Plot B

Plot C

Plot D

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



Plot A

Plot B

Plot D

Plot C

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

## Relationships between Crop Yield and Evapotranspiration

A relationship was established between the crop yield and reference Evapotranspiration during the experiment. Singh *et al* {1997} 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 are 86 - 105 mm and 1.36 to 0.16 t/ha respectively. 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. Raes *et al*, {1997} reported that ET values ranging from 200 to 480mm was 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. From Table 2, total irrigation water applied varied from 3047mm in treatment A, 2656mm in treatment B, 2223mm in C and 1789mm 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 literature, the maximum yield of rice that could be attained under standard environmental conditions was between 0.9 – 2.0 t/ha {Misari *et al*, 2001}. Producing 1.94 t/ha of upland rice using 3047 mm of applied irrigation water was significantly reasonable. This statement was supported by Doorenbos and Kassam {1979} and Lafitte *et al*, 2004 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 |

The flowering stage i.e booting, dough and milky are considered the most critical (Raemaekers, 2001). 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 Nwadukwe and Chude {1998}.

**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 |

## Crop Water Use Pattern and Irrigation Scheduling

Figs 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 Fig 4, average weekly water use varies from 1.16 mm/day (13 WAP in A) to 4.24 mm/day (8 WAP in D). 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 behaviour was observed during the first experimental trial (Fig. 3). Raes *et al*, 1997 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 (Fig. 3) and 6 -10 WAP in the second trial (Fig. 4). The responses of water supply to plant height, leaf area index (LAI) and canopy shading all showed a definite pattern of crop behaviour to specific water application peculiar to each of the three stages of crop growth. 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.

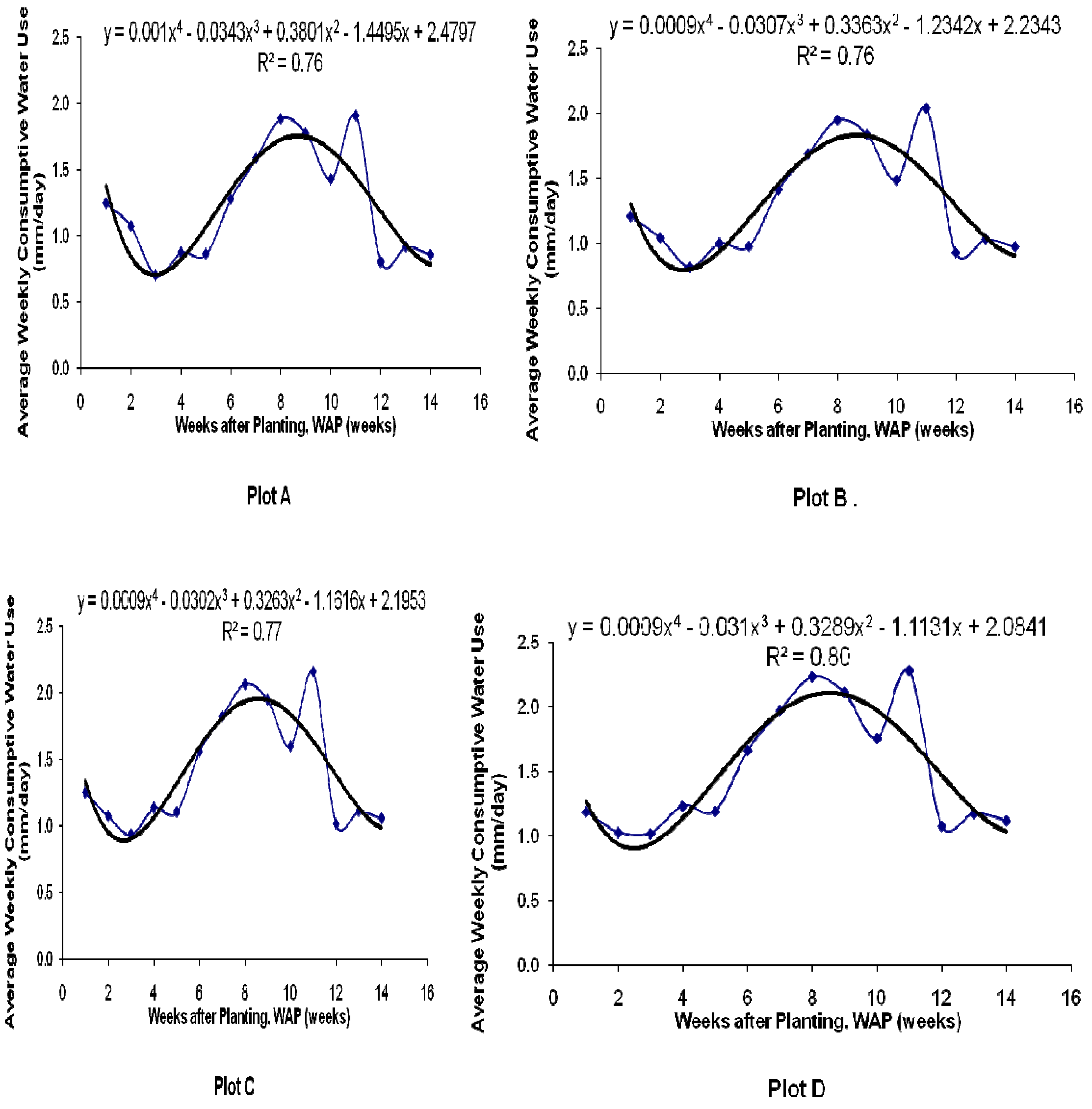


**Fig. 3: Average weekly Consumptive Water Use versus Weeks after Planting (WAP) for all the treatments of 2005/06 Field Experiment**

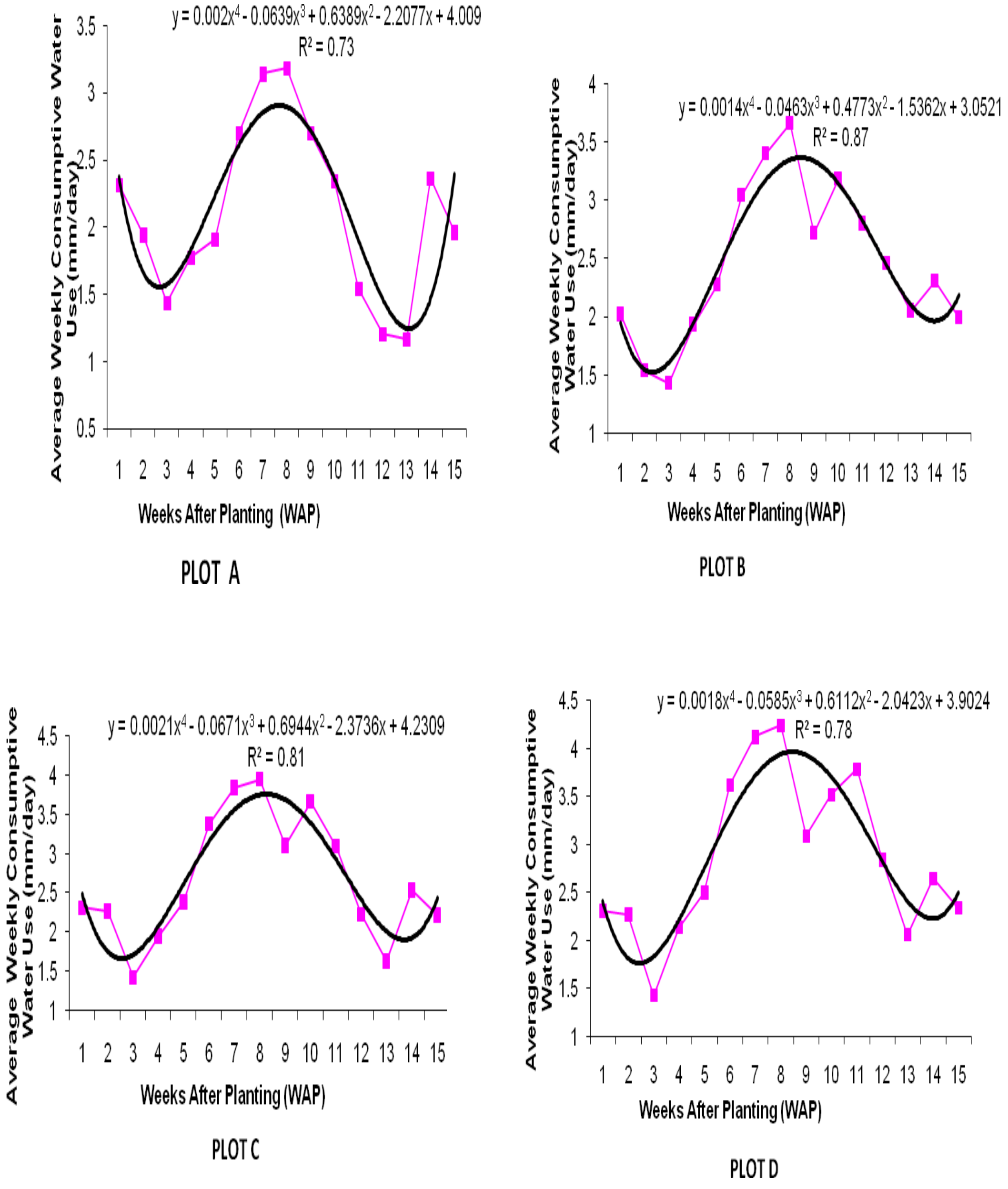


**Fig.4: Average weekly Consumptive Water Use versus Weeks after Planting (WAP) all the treatments of 2006/07 Field Experiment**

## 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 emergence of whiteheads was an indication of shortfalls in water requirements at this stage. The behaviour of rice crop in extracting water varied with the phenological stages.

It was observed that the highest amount of soil water extraction took place at the mid season/reproductive stage. This was due to increase in metabolic activities at that stage and hence greater consumptive water use. This showed that increased irrigation water application does not imply increased crop water use. 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 behaviour 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.

### *Recommendations for further Research*

- Estimating irrigation requirements for more upland rice cultivars (NERICA 1, 3, 5-19) is recommended 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. This is imperative since there may be the need to use saline water (coastal dwellers) to irrigate rice fields in their domains.
- 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 round the field to prevent rodents and grass cutters invasion. This is useful where human efforts (bird scarer) may not be enough to prevent birds from attacking rice fields.

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