Original Research Article

Increasing Water Use Efficiency of Irrigated Rice through Water Saving Techniques in Yobe Basin, North East, Nigeria

ABSTRACT

Increasing world population and dwindling water resources is exerting pressure to develop strategies for producing more food using less water.

Aims: to investigate the effect of different irrigation schedules on grain yield and water use efficiency (WUE) of FARO 44 rice variety.

Study design: The research was laid out in a split plot arrangement. Twelve treatments replicated three time comprising of 3 irrigation intervals as main plot and 4 irrigation depth as sub plot.

Place and Duration of Study: Gashua, Yobe State on the floodplains of river Yobe, Nigeria between March 2023 and July 2023.

Methodology: comprised of 3, 5 and 7 days irrigation intervals as main plot, with irrigation depth (amount) at 100% of crop water requirement (ETc), 85% of ETc, 70% of ETc and the farmers flooding practice as the sub plot treatments. Some growth, yield and components of the rice were determined. Reference evapotranspiration (ETo) and Crop evapotranspiration (ETc) were computed using Cropwat model. Crop and irrigation water use efficiencies were also calculated.

Results: The 3 days irrigation interval produced the maximum growth parameters of rice along with both application of 100% of crop water requirement and the traditional flooding type of irrigation. The interaction of 3 days irrigation interval and 100%ETc and 85% of ETc significantly produced the highest grain yield (6484.85 kg ha^{-1}.) 3 and 5 days irrigation interval with 100% and 85% of ETc irrigation depths significantly produced the highest water use efficiencies. A well fitted linear relationship ($R^2 = 0.834$) existed between the irrigation scenarios and the rice grain yield.

Conclusion: It can be concluded that irrigation frequency and amount can be reduced to arrive at highly acceptable yield in the study area. High rice yield can be maintained with 3 days irrigation interval and 85% of the crop water requirement and also improve its water use efficiency.

Keywords: Irrigation, productivity, rice, water, Yobe

1. INTRODUCTION

The population on earth by 2050 is projected to be about 9.8 billion, which means that food production must expand significantly to feed these people [1]. The majority of the rise in food demand will take place in developing nations, where agriculture is the most crucial factor for food security, employment and income generation. A significant problem to augmenting the food supply is the scarcity of water resources and since agriculture is the main cause of freshwater exploitation, this must change to become a more resource-efficient occupation to achieve that [2].

Crop water productivity (CWP), also known as water productivity per crop, is the amount of agricultural output per volume of water and one of the main strategies for addressing water scarcity and enhanced crop-water relations is improving crop water use efficiency [3]. To increase production efficiency while preserving water resources, it makes sense to increase the potential output per unit of water utilized. Water productivity is a viable approach to address issues related to food security and water availability and therefore, maintaining the social and economic circumstances of lives ultimately depends on boosting agricultural water productivity in a sustainable way. Deficit irrigation and small-scale water saving management techniques are useful in increasing the water consumption efficiency of many crops when switching from rain-fed to irrigated farming systems [4].

Crop water productivity (CWP), or water productivity per crop, is the amount of product over the amount of water applied. Farmers are typically motivated by increasing farming's profitability or enhancing food security for the family while focusing less on water output [5]. Rice is third in terms of production and consumption after wheat and maize and is one of the staple foods consume across nations of the world. In sub-Saharan Africa after sorghum, maize, and millet, rice is the fourth most produced crop. Nigeria produces more than 46% of the rice harvested in West Africa, making it the top producer on the continent and is a major consumer as well [6]. Nigeria is one of the biggest markets for parboiled rice worldwide, consuming $4 billion worth of the grain annually on average. Nigeria had to import a difference to argument about 5.4 million metric tons production in 2022 from it's nearly 7 million metric tons of consumption [7].

The primary irrigation technique in use particularly in Nigeria's semi-arid and dry zones is the continuous flooding of water for irrigated rice, where water levels after transplanting are typically 3 cm at first, rising to 5–10 cm with growing plant height, and staying there the entire season until the field is drained 7–10 days prior to harvest [8]. Due to their flooded nature, rice paddies are posing a significant water consumption issues, because it uses more water than any other irrigated crop, requiring up to three times as much water as other crops particularly in the country's semi-arid and arid regions where water is scarce [9]. According to majority of researches on obstacles to high rice yields, water was observed to be the primary cause of production gaps and yield variations as recorded from many experimental stations [10]. It was observed that many dry season rice farmers in the Yobe Basin have no clearly defined irrigation schedule for rice, which often leads to waste of energy and resources.

Given rice's significance in both food and non-food utilizations, as well as its place in Nigerian agriculture, it is essential to investigate ways to improve the crop's water use efficiency in order to boost yield and provide poor resource farmers with food security and improved livelihood. In particular, FARO 44 was chosen because it has a reputation for being more resilient to diseases and pests than other rice varieties, and it also has a higher threshold for floods. FARO-44 also grows faster than other types and has a higher potential yield [11]. It was also observed that majority of farmers in Bade LGA have adopted the variety for both irrigated and rain-fed farming [12]. Therefore, the research was designed with following objectives: to compare the grain yield of the FARO 44 rice variety under various irrigation management strategies and to determine how different irrigation management strategies affect the FARO 44 rice variety's water use efficiency in the basin.

2. MATERIALS AND METHODS

2.1 Research location

The research was conducted in Gashua, Bade Local Government Area, Yobe State, Nigeria at a farm on the floodplains of river Yobe in Gashua located at latitude 12.85936° N, longitude of 11.00256° E, and an altitude of 229 m above mean sea level. The area has a semi-arid climate typical of the area, with average annual rainfall of about 500 mm and annual evapotranspiration of 1723.01 mm. The highest temperature is usually recorded between April and May (average 40^{O}C).

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Geographical location map

The area is an agrarian community where people produce many varieties of crops like millet, sorghum, cowpea, wheat, soybeans and rice and engage in trading and fishing. Irrigated land is used to produce vegetables and rice. Rice has become a popular economic crop in Bade Local Government Area. It is cultivated twice in a year on irrigated land between February and June, and as rain-fed crop between June and September [13].

2.2 Rice variety and cultural practices

FARO 44 rice variety were obtained from IAR ABU Zaria and sown in a nursery bed on 4th March, 2023. The seedlings were then transplanted at 24 days after emergence (28th March, 2023) and two seedlings were transplanted per stand at a spacing of 25 x 20 cm.
The recommended dose of inorganic fertilizers (120: 60: 60, N P K kg/ha) were applied in two spilt doses. Full dose of phosphorus and potassium was applied and 1/3 of nitrogen was applied at basal during transplanting and urea (N-46%) fertilizer was used to top dress at 3rd and 7th weeks after transplanting. The plots were sprayed with selective post emergence herbicide (Butachlor 50% EC at 2.5 litres/ ha) 2 days after transplanting for weed control.

2.3 Soil sampling and analysis

A composite sample of the soils of the research farm was taken 20cm depths, processed and analyzed in the laboratory using the standard routine soil as presented in Table 1.

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Map of the different sampling points

2.3.1 Physico-chemical properties of the soils of the study site

The results indicated that the soils of the study area (Table 1) is sandy clay loam in texture with bulk density ($1.68gcm^{-3}$) and low available water holding capacity (7.70%). The chemical properties showed that the soil is neutral (pH.6.73) non-saline, very low in soil organic carbon and total nitrogen content. The soil is low in available phosphorus, sodium and CEC; moderate in calcium and magnesium and high in potassium according [14] critical limits for interpreting levels of soil fertility.

Table 1. Physico-chemical properties of the soils of the research farm

Physical properties	Value	Chemical properties	Value
Sand (%)	66.14	pH (water)	6.73
Silt (%)	10.56	EC (dS/m)	0.14
Clay (%)	23.31	Organic Carbon (%)	0.75
Textural Class	SCL	N (%)	0.06
Bulk Density (g/cm^3)	1.68	Av.P (mg/kg)	5.13
Porosity (%)	36.60	Ca (cmol(+)/kg)	2.09
Field Capacity (%)	21.90	Mg (cmol(+)/kg)	0.44
Wilting Point (%)	14.20	K (cmol(+)/kg)	0.39
Available Water (%)	7.70	Na (cmol(+)/kg)	0.07

	CEC (cmol(+)/kg)	2.99

SCL = sandy clay loam

2.4 Experimental design

The experiment was laid out as a split plot design and replicated three (3) times, giving a total of 36 plots and the area of each plot is 2.4 x 3m. The two factors involved were: irrigation frequency and volume. The level of the irrigation frequency included: irrigation after every 3 days (I_1), irrigation after every 5 days (I_2), irrigation after every 7 days (I_3) arranged in the main plot while, the irrigation volume were; 100% of the crop water requirement (ETc) as (V1), 85% of ETc (V2), 70% of ET (V3) and the farmers irrigation practice of flooding the plots as (V4) placed in the subplots. The levels of the factors were combined to form twelve (12) treatments.

2.5 Water management

Polyvinyl chloride (PVC) pipes with a diameter of 5 cm were used to irrigate the rice plants. The discharge from the pipes were monitored using a stop watch to determine the depth of water applied to each basin using [15] velocity – bucket method as in eq. (1):

Flow rate = volume/time (1)

2.6 Data collection and analysis

Data were taken before harvesting, plants within a 1 m^2 area per plot were sampled randomly and the plant height, number of tillers per hill, number of panicles, number of spikelets per panicle, 1000-grain weight, grain yield and above ground biomass were determined. Plant height was recorded by measuring the height of plants from the soil surface to the tip of the highest leaf. Number of tillers per hill was determined by counting all the tillers formed by the plant in each plot. Harvest index (HI) was calculated as described in [16].

HI was calculated according to following formula:

Harvest index (%) = Grain yield /Biological yield × 100. (2)

2.7 Computation of reference evapotranspiration (ETo) and Crop evapotranspiration (ETc)

The reference evapotranspiration ETo of the agro-ecological area was calculated by FAO Penman-Monteith method, using decision support software –CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 [5]. The FAO CROPWAT program [17] incorporates procedures for reference crop evapotranspiration and crop water requirements and allow the simulation of crop water use under various climate, soil and crops conditions.

In this study a recorded meteorological data of 25 years of 1998 to 2018 and 2019 to 2022 were collected from North East Arid Zone Development Programme (NEAZDP) and Federal University Gashua stations respectively. These meteorological stations are located around the study area. Soil characteristics considered for estimation of crop water requirement were sourced from [18].

Crop coefficient values (Kc) are taken from available published data. Kc values for initial, mid and late growth stages of rice are used for the dry season months [5].

ETo is then multiplied by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration (ETc), as described in equation 3 [5].

ETc = Kc x ETo (3)

2.8 Computation of water use efficiency

Water use efficiencies were expressed according to [19].

The Crop Water Use Efficiency (CWUE) was computed using the equation:

$CWUE = Y/ETc$ (4)

Where Y was the Crop yield (kg ha^{-1}) and ETc was the Total amount of water used in evapotranspiration (mm).

The Irrigation Water Use Efficiency (IWUE) was computed using the equation:

$IWUE = Y/Q$ (5)

Where Q was the Total amount of water used in the field (mm) and Y was the Yield (kg ha^{-1}).

2.9 Data analysis

Data collected were subjected to the analysis of variance (ANOVA) and the mean values among treatments were grouped and compared using least significant difference (LSD) at 5% probability level. R version 4.3.2 statistical computing platform with doebioresearch package was used in the analysis. Multiple regression analysis was conducted to examine the relationship between rice grain yield and irrigation treatments as potential predictors. [20, 21].

3. RESULTS AND DISCUSSION

3.1 Effect of irrigation schedules on some growth parameters and yield components of rice

The effect of irrigation schedules on some growth and yield components of rice results as presented in Table 2 showed that irrigation interval has no significant effect on plant height and number of spike per hill, while 3 days irrigation interval gave significantly high influence on number of tillers per hill (16.33) and number of panicles per hill (27.47). The irrigation volume on the other side did not affect plant height and number of panicles per hill. Number of tillers and spike per hill were found to be higher with the application of 100% of crop water requirement and the traditional flooding type of irrigation treatments and minimum with application of irrigation at 70% of ETc. There were no significant interaction effect of irrigation interval and irrigation volume on the growth parameters and yield components measured (Table 2). This finding was in agreement with [22] who reported that rice was found to be affected by different irrigation intervals with the minimum number of irrigation cycles giving higher number of tillers and number of panicles. Equally it was reported that prolonging irrigation intervals markedly reduced growth characteristics of rice [23].

Table 2. Effect of irrigation schedules on some growth parameters and yield components

Treatment	Plant height (cm)	Number of tillers /hill	Number of panicle /hill	Number of spike /hill
Irrigation Interval (I)				
3 days	71.91	16.33a	27.47a	20.39
5 days	67.36	13.00b	24.72b	19.36
7 days	63.08	11.83b	23.95b	19.19
LSD (0.05)	ns	1.3623	2.3205	ns
Irrigation volume (V)				

100% of ETc	68.11	14.67a	27.35	20.16a
85% of ETc	67.20	12.67b	24.56	19.32ab
70% of ETc	65.45	12.78b	23.72	18.94b
Flooding	69.02	14.78a	25.90	20.15a
LSD (0.05)	ns	1.2535	ns	0.9574
I x V	ns	ns	ns	ns

Means with the same letter are not significantly different, ns = non-significant.

3.2 Effect of irrigation schedules on rice yield and harvest index

The 1000 grain weight, grain and biological yield (kg ha-1)and harvest index (%) indicated significant difference with a decreasing trend with increase in irrigation interval (Table 3). 3 days irrigation interval consistently produced the highest values, while 7 days interval remained the lowest. This suggest that 3 days irrigation interval could be the most suitable irrigation frequency for dry season rice production in the study area. The irrigation amount also showed significant difference in 1000 grain weight, grain and biological yield (kg ha^{-1}) except for harvest index (%) which did not differ significantly. Irrigation amount at 100%ETc significantly gave maximum 1000 grain weight and biological yield, while the minimum was with 70%ETc (Table 3). The total grain yield was higher with 100%ETc irrigation depth, but significantly at par with 85%ETc and flooding type of irrigation, while minimum grain yield was recorded with 70%ETc. This shows that little difference in irrigation amount may not affect grain yield significantly.

Table 3. Effect of irrigation schedules on rice yield and harvest index

Treatment	1000 grain weight (g)	Grain yield (kg ha^{-3})	Biological yield (kg ha^{-3})	Harvest index (%)
Irrigation Interval (I)				
3 days	23.60a	5386.84a	9113.88a	58.59a
5 days	22.11b	3068.33b	7571.48b	40.67b
7 days	21.03b	1855.63c	6977.62c	26.82c
LSD (0.05)	1.27	365.98	511.61	5.885
Irrigation volume (V)				
100% of ETc	23.51a	4152.26a	9149.47a	43.93
85% of ETc	22.49b	3496.15a	8144.69b	41.47
70% of ETc	20.44c	2418.16b	5996.42c	39.84

Flooding	22.56b	3681.17a	8260.06b	42.86
LSD (0.05)	0.6338	446.40	589.66	ns
I x V	ns	*	ns	ns

*Means with the same letter are not significantly different, ns = non-significant, * significant.*

3.3 Interaction effect of irrigation schedules on rice yield (kg ha^{-1})

The interaction of 3 days irrigation interval (I1) and 100%ETc (V1) significantly produced the highest grain yield (6484.85 kg ha^{-1}) which was at par with I1V2 and I1V4 with 5862.08 kg ha-1 and 6129.57 kg ha^{-1} grain yields respectively (Table 4). This showed that farmers can reduce the amount of irrigation water by 15% and obtained yields with non-significant difference.

Table 4. Interaction effect of irrigation schedules on rice yield (kg ha^{-1})

	V1	V2	V3	V4
I1	6484.85a	5862.08ab	3470.86c	6129.57ab
I2	3714.04c	3183.56c	2330.16de	3045.58cd
I3	2257.88e	1842.82ef	1453.47f	1868.36ef
LSD (0.05)		773.18		

Means with the same letter are not significantly different.

3.4 Effect of irrigation schedules on crop and irrigation water use efficiency

Table 5 presents the effect of irrigation schedules on crop and irrigation water use efficiencies of the rice crop. The crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE) were significantly affected by the irrigation intervals and irrigation depths. 3 days irrigation interval produced the maximum CWUE (3.35kg/ha-mm) and IWUE (3.75 kg/ha-mm) at par with 5 days irrigation interval. The implication is that considering only crop and irrigation water used, the rice crop perform equally well with 5 days irrigation interval in Bade LGA, thus saving about 39.1% of the water used when irrigating after every 3 days. The irrigation depth (mm) also showed that 100% ETc (5.65 and 3.95kg/ha-mm) and 85% of ETc (5.60 and 3.92kg/ha-mm) were significantly at par and recorded the highest water use efficiencies for CWUE and IWUE respectively over other treatments (Table 5).

Table 5. **Effect of irrigation schedules on crop and irrigation water use efficiencies**

Treatment	CWUE	ETc (mm)	IWUE	Water used (mm)
Irrigation Interval (I)				
3 days	5.35a	1020.20a	3.75a	1457.42a
5 days	5.12a	621.37b	3.58a	887.67b

7 days	4.36b	441.34c	3.05b	630.48c
LSD (0.05)	0.6900	30.3413	0.4836	43.3451
Irrigation volume (V)				
100% of ETc	5.65a	714.69b	3.95a	1020.99b
85% of ETc	5.60a	606.38c	3.92a	866.25c
70% of ETc	4.85b	499.62d	3.39b	713.74d
Flooding	3.66c	956.51a	2.56c	1366.44a
LSD (0.05)	0.7152	26.8126	0.5013	38.3047
I x V	*	ns	*	ns

Means with the same letter are not significantly different, ns = non-significant.

3.5 Interaction effect of irrigation schedules on CWUE (kg ha^{-1}-mm)

The interaction of irrigation intervals and amount of irrigation water has significantly influenced crop and irrigation water use efficiencies of the rice crop. 3 days irrigation interval with 100% and 85% of ETc significantly produced the highest water use efficiencies (Table 6) but are at par with 5 days interval with 100% and 85% of ETc irrigation depths. This indicated that irrigation frequency and amount can be reduced with proper management to get a yield that is in significantly lower than the expected yield in the study area. It shows from the results that irrigation frequency exert more effect than irrigation depth on water use efficiency.

Table 6. Interaction effect of irrigation schedules on CWUE and IWUE (kg ha^{-1}-mm)

Treatments interaction	CWUE	IWUE
I1:V1	6.18a	4.33a
I1:V2	6.14a	4.30a
I1:V3	5.86ab	4.10ab
I2:V1	5.81abc	4.07abc
I2:V2	5.25abcd	3.67abcd
I3:V1	4.96abcd	3.47abcd
I3:V2	4.81bcd	3.36bcd
I2:V3	4.71bcde	3.30bcde
I3:V3	4.58cde	3.20cde

I1:V4	4.37de	3.06de
I2:V4	3.54ef	2.48ef
I3:V4	3.08f	2.15f
LSD (*0.05*)	1.24	0.87

Means with the same letter are not significantly different.

3.6 Regression analysis of irrigation frequency and irrigation water amount and grain yield

The effects of irrigation frequency and irrigation water amount were regressed to grain yield of FARO 44 rice variety using linear regression. The multiple regression model with the two predictors (irrigation interval and irrigation volume), produced $R^2 = 0.834$, F (2, 33) = 82.87, $p < .001$. The irrigation water amount had significant positive regression weight (1.98), indicating higher irrigation volume were expected to have higher grain yield, after controlling for the other variables in the model. The irrigation interval on the other side depicted negative regression weight (-473.08) showing the lower the irrigation interval the higher the grain yield will be (Table 7). The value of R2 of 0.8340 is indicating that the fitting of the function is excellent accounting for about 83% of the variation in grain yield of rice in the study area.

The fitted model is $y = 3836.74 + 1.98V - 473.08I$

Where y = rice grain yield (kg ha-1); V = irrigation volume (mm); I = irrigation interval (days).

Table 7. **Regression analysis parameter estimates**

Variable	Estimate	Std. Error	t value	Pr(>|t|)	R^2
Intercept	3836.74	982.86	3.9	0.0004	0.8340
Volume	1.98	0.45	4.44	0.0001	
Interval	-473.09	117.73	-4.02	0.0003	

4. CONCLUSION

The traditional continuously flooded rice production system has no yield advantage over the irrigation amount at reduced level of crop water requirements (ETc) in Yobe basin. Consistently, highest yields were obtained with 3 days irrigation interval with reduced volume. This indicates that it is possible to increase yields while reducing the total irrigation volume. At the basin application of the 85% of crop water requirement irrigation depth with 3 days irrigation interval will help farmers to sustain and improve the yields of irrigated rice under present and future water scarcity and labour cost.

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