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Optimization Of Irrigation Interval For Improved Productivity Of Wheat (Triticum Eastivum L.) Variety In The Semi Arid Zone Of Nigeria

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Abstract
A field experiment was conducted during the 2023/2024 dry season at two locations; Audu bako College of Agriculture research farm at Tomas Dam Dambatta and at Fadama site of Aliko Dangote University of Science and Technology Wudil both in the Sudan Savannah of Nigeria, to evaluate the effect of different irrigation interval on the productivity of four wheat (Triticum aestivum L.) varieties. The experiment consisted of sixteen treatment combination by the use of four irrigation intervals (3, 6, 9, and 12 days) and four wheat variety (LACRIWHIT-1, LACRIWHIT-4, LACRIWHIT-5, and LACRIWHIT-11). The studies adopted the use of split-plot design with irrigation frequency in the main plot and wheat variety in the sub plots and were replicated three times. Growth and yield data were subjected to analysis of variance using the SAS statistical package (version 9.0) and means were compared using Duncan's Multiple Range Test at 5% probability. Results revealed that irrigation frequency and wheat variety significantly affected key growth and yield parameters at both sites. LACRIWHIT-5 and LACRIWHIT-11 recorded the highest plant heights (63.8–72.2 cm), leaf area indices (10.17–11.44), and 100-grain weights (93.8–99.0 g). The highest grain yields (3.84 and 3.80 tha^{-1}) were obtained under 3 days interval by LACRIWHIT-1 at both locations, while the 12-day interval resulted in significant yield decline (2.73 tha^{-1}). No significant interaction effects were observed for the physiological traits, indicating consistent varietal response across irrigation treatments. It is recommended that farmers in the Sudan savannah zone can adopt 3 – 6 days irrigation interval for LACRIWHIT-1 to optimize yield and resource use efficiency.
Keywords: *Wheat productivity, irrigation interval, water use efficiency, semi-arid Nigeria*

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I. Introduction

Wheat (*Triticum aestivum* L.) remains one of the most widely cultivated cereal crops globally, contributing about 21% of the world's caloric intake and nearly 20% of dietary protein (FAO, 2023; Erenstein *et al*., 2022). Global production reached 772.6 million tonnes in 2021, with sustained increases driven by irrigation intensification and improved cultivars (Statista, 2022). However, in sub-Saharan Africa, wheat productivity remains constrained by erratic rainfall, poor irrigation infrastructure, and climate variability (Raza *et al*., 2023). In Nigeria, where the Sudan Savannah and Sahelian belts offer favorable winter growing conditions, wheat production still satisfies less than 10% of national demand, creating a deficit of over 3.7 million metric tons annually (National Wheat Strategy Document, 2021).

Irrigation is a critical determinant of wheat yield in semi-arid systems, influencing tillering, spikelet formation and grain filling (Du *et al*., 2023; Wang *et al*., 2022). Water deficit during reproductive stages—particularly heading and grain filling can reduce yield by up to 40% due to impaired leaf expansion and photosynthetic rate (Mu *et al*., 2022). Conversely, excessive irrigation leads to nutrient leaching, root hypoxia, and reduced water-use efficiency (WUE) (Ali *et al.,* 2023; Bai & Guo, 2022). Therefore, identifying optimal irrigation frequencies that balance water conservation and yield maximization is crucial for sustainable wheat production under limited water availability (Liu *et al*., 2024).

In Nigeria, wheat production is concentrated in the northern states (Kano, Katsina, Jigawa, and Kebbi) where irrigation schemes are predominantly surface-based (Falola *et al*., 2017; LCRI, 2019). Despite government-led initiatives, such as the Accelerated Wheat Production Program (AWPP), constraints persist due to outdated irrigation scheduling and poor understanding of crop-water relations in local varieties. Studies by

Wakchaure *et al*. (2016) and Idnani *et al*. (2023) have demonstrated that irrigation intervals shorter than 10 days significantly enhance yield attributes without excessive water consumption in similar agroecological zones.

The Sudan Savannah of Nigeria is characterized by erratic rainfall (500–800 mm annually), high evapotranspiration rates, and sandy-loam soils with low organic matter. These conditions necessitate supplemental irrigation during the dry season to sustain wheat growth. However, most farmers lack precise irrigation schedules, leading either to over-irrigation or prolonged drought stress. Deficit irrigation and irrigation frequency optimization have been successfully used in similar regions to maintain yields with 20–30% less water (Zhang *et al*., 2024; Chen *et al*., 2025).

Objectives of the study to :-

1. Evaluate the performance of four wheat varieties under frequacy irrigation interval in the Sudan Savannah zone of Nigeria;
2. Identify the most suitable irrigation interval that will result to maximum yield and water-use efficiency

II. Materials And Methods

Study Area

The research was conducted at Audu Bako College of Agriculture Research Farm located at Tomas Dam Dambatta (12°26′N, 8°31′E) and Aliko Dangote University of Science and Technology irrigation research farm at Fadama Wudil (11°47′N, 8°51′E) bpth in Kano State, within the Sudan Savannah agro-ecological zone of Nigeria. The soil of the study area is sandy-loam low organic matter content and neutral pH. The annual rainfall range is 500–800 mm, while mean daily temperatures ranges from 17–39°C. The dry season extends from November to April, with negligible rainfall and relative humidity averaging 35–45%.

Treatments and Experimental design

The experiment consisted of sixteen treatment combinations by the use of four wheat varieties Namely; LACRIWHIT - 5, LACRIWHIT - 11, LACRIWHIT - 4, LACRIWHIT -1, and four irrigation intervals (3, 6, 9 and 12 days) these were replicated three times in a split plot design. The treatments were allocated randomly to the individual main and the sub plots. Wheat varieties were assigned to the main plots while the irrigation intervals are in the sub plots. The size of the main plot is 5x5m and for the sub plot is 2x2m.

Data collection

Growth parameters

Five plants were randomly selected and tagged from each plot for record taking

- **Plant height (cm):** measured from soil surface to the tip of the uppermost leaf or spike.
- **Leaf area (cm²):** leaf area meter model CI-202
- **Leaf area index (LAI):** total leaf area divided by the ground area covered by the plant
- **Number of tillers per plant:** manually counted at each sampling period.
- **Stem diameter (cm):** This was measured using Vernier calipers.

Phenological parameters

- **Days to first heading:** counted from sowing to the first visible spike emergence
- **Days to flowering (first):** based on the extrusion of anthers and visible pollen release

Yield and yield components

These were taken at harvest

- **100 grain weight (g)**
- **Grain yield (t ha^{-1})**
- **Harvest index (%)**

Statistical analysis

All data were subjected to analysis of variance (ANOVA) using the SAS software package (version 9.0). Treatment means were compared using Duncan's Multiple Range Test (DMRT) at a 5% probability level (Duncan, 1955).

III. Results And Discussion

Effect of irrigation frequency and variety on growth parameters

Plant height

Plant height was significantly influenced by wheat variety and irrigation frequency at both experimental sites (Table 2). The tallest plants were observed in LACRIWHIT-5 (60.8–72.2 cm) and LACRIWHIT-11 (64.5–73.7 cm) under 3–6 day irrigation intervals, whereas LACRIWHIT-4 recorded the shortest plants (60.8–63.8 cm). At Dambatta, LACRIWHIT-1 attained 31.3 cm at early growth (PH1) and 62.7 cm at physiological maturity, indicating favorable soil moisture conditions and moderate temperature regimes.

The results support the earlier findings that optimal irrigation promotes vegetative vigor through sustained cell turgidity and nutrient translocation (Kang *et al*., 2022; Du *et al*., 2023). Studies by Wang *et al*. (2022) also reported that reduced irrigation intervals (≤7 days) maintained higher canopy height and photosynthetic efficiency compared to longer intervals under semi-arid climates.

Leaf area and leaf area index (LAI)

Leaf area (LA) and leaf area index (LAI) showed significant varietal and irrigation effects at Dambatta, with LACRIWHIT-5 producing the highest leaf area (13.7 cm²) and LACRIWHIT-1 the lowest (12.4 cm²). At Wudil, LACRIWHIT-11 recorded the maximum LAI (13.9), particularly under 3-day irrigation frequency, while 12-day intervals consistently reduced LAI to 11.9 (Table 3 and 4).

These results align with Chen *et al*. (2025), who found that leaf expansion in wheat is directly proportional to irrigation frequency, up to an optimum level beyond which marginal gains in biomass are limited. Reduced irrigation intervals promote a larger photosynthetically active area, thereby enhancing carbohydrate accumulation and grain filling (Bai & Guo, 2022).

Table 1: Effect of Variety and Irrigation Interval on Plant Height (cm) of Wheat at Dambatta and Wudil during the 2023/2024 Irrigation Season

Treatment	Dambatta				Wudil			
	PHI	PH2	PH3	PH4	PHI	PH2	PH3	PH4
Variety (VAR) LACRIWHIT-I	31.34a	42.44	53.27	62.70	35.63	47.50	64.31	71.49
LACRIWHIT-4	28.62b	42.42	55.51	63.81	35.77	48.37	64.66	70.34
LACRIWHIT-5	28.95ab	41.31	49.74	60.82	35.95	46.11	64.00	72.19
LACRIWHIT-11	29.46ab	42.65	53.44	64.49	33.85	47.92	64.21	73.72
SE±	0.71	1.51	2.10	2.97	1.91	2.19	1.68	2.45
IRF (days)								
3	29.23	42.60	52.43	63.13	32.32	44.20b	60.36	68.05
6	28.45	42.44	54.45	64.90	36.56	47.03ab	67.37	74.14
9	29.95	41.65	52.68	61.83	34.69	50.20a	63.64	69.97
12	30.75	42.13	52.41	61.96	37.62	48.45ab	65.82	75.58
SE±	1.07	2.21	2.89	3.31	1.73	1.86	3.07	3.59
Interactions								
IRF x VAR	NS	NS	NS	NS	NS	NS	NS	NS

Note; Means followed by the same letter within a treatment group are not statistically different at 5% level of probability. NS = Not Significant * = Significant at 5% probability level ** = Significant at 1% probability level. *TRT=Treatment, VRT= Variety, SE=Standard Error, PH= Plant high, LACRIWHIT= Indigenous wheat variety developed by lake chard research institute.*

Table 2: Effect of Variety and Irrigation Interval on Leaf Area of Wheat at Dambatta and Wudil during the 2023/2024 Irrigation Season

Treatment	Dambatta				Wudil			
	LAI	LA2	LA3	LA4	LAI	LA2	LA3	LA4
Variety (VAR) LACRIWHIT-I	8.71	10.14b	11.23b	12.43b	8.73b	9.79	10.79	11.83
LACRIWHIT-4	8.93	10.54ab	11.77b	12.88ab	8.89b	10.01	10.90	12.23
LACRIWHIT-5	10.36	11.57a	13.05a	13.74a	8.58b	9.74	10.16	13.33
LACRIWHIT-11	9.61	10.96ab	11.73b	13.11ab	9.72a	10.85	12.74	13.88
SE±	0.47	0.31	0.29	0.26	0.23	0.36	0.74	1.05
IRF (Days)								
3	9.74	11.34	12.04	13.47	9.28	10.66	11.99	15.13a
6	9.41	10.48	11.93	13.11	9.19	10.63	11.91	12.61b
9	9.41	10.83	11.88	13.29	8.63	9.36	10.29	11.56b

12	9.05	10.55	11.92	12.30	8.83	9.75	10.42	11.97b
SE±	0.57	0.53	0.45	0.41	0.42	0.44	0.73	0.83
Interactions								
IRF x VAR	NS	NS	NS	NS	NS	NS	NS	NS

Note; Means followed by the same letter within a treatment group are not statistically different at 5% level of probability. NS = Not Significant * = Significant at 5% probability level ** = Significant at 1% probability level. *TRT=Treatment, VRT= Variety, SE=Standard Error, PH= Plant high, LACRIWHIT= Indigenous wheat variety developed by lake chard research institute.*

Table 3: Effect of Variety and Irrigation Interval on Leaf Area Index of Wheat at Dambatta and Wudil during the 2023/2024 Irrigation Season

Treatment	**Dambatta**				**Wudil**			
	LAI1	**LAI2**	**LAI3**	**LAI4**	**LAI1**	**LAI2**	**LAI3**	**LAI4**
Variety (VAR) LACRIWHIT-I	8.00	9.02	10.03	11.44a	6.92	8.04	8.97ab	10.57
LACRIWHIT-4	7.32	8.34	9.55	10.96ab	7.82	8.73	10.07a	11.11
LACRIWHIT-5	7.27	8.49	9.00	10.34ab	7.01	8.17	8.79b	10.01
LACRIWHIT-11	7.26	8.42	9.26	10.17b	7.64	8.76	9.86ab	11.05
SE±	0.46	0.57	0.38	0.33	0.46	0.49	0.33	0.32
IRF (days)								
3	7.60ab	8.55ab	9.25	10.53	7.79	8.87	9.57	10.71
6	7.49ab	8.64ab	9.35	10.68	7.26	8.37	9.48	10.89
9	6.62b	7.79b	9.05	10.40	7.09	8.30	9.42	10.53
12	8.14a	9.29a	10.20	11.29	7.26	8.16	9.22	10.60
SE±	0.34	0.36	0.43	0.37	0.49	0.49	0.50	0.43
Interactions								
IRF x VAR	NS	NS	NS	NS	NS	NS	NS	NS

Note; Means followed by the same letter within a treatment group are not statistically different at 5% level of probability. NS = Not Significant * = Significant at 5% probability level ** = Significant at 1% probability level. *TRT=Treatment, VRT= Variety, SE=Standard Error, LAI= Leaf Area Index, LACRIWHIT= Indigenous wheat variety developed by lake chard research institute.*

Days to First Flowering and Heading

The onset of heading and flowering was delayed under prolonged irrigation intervals. LACRIWHIT-5 exhibited the longest duration to first heading (61.5 days) and flowering (65.8 days), whereas LACRIWHIT-4 headed earlier (59.1 days). At Dambatta, the 3-day interval promoted synchronized heading and earlier spike emergence compared with 9–12-day intervals (Table 7).

This suggests that frequent irrigation accelerates physiological development through improved leaf gas exchange and nutrient assimilation (Zhang *et al*., 2024). Similar observations were reported by Idnani *et al.* (2023), who demonstrated that consistent soil moisture reduces phenological delay in durum wheat grown under Mediterranean-type dry conditions.

Table 6: Effect of Variety and Irrigation Interval on Days to Flowering and Heading of Wheat at Dambatta and Wudil during the 2023/2024 Irrigation Season

Treatment	**Dambatta**	**Wudil**	**Dambatta**	**Wudil**
	DFF	DFF	DFH	DFH
Variety (VAR) **LACRIWHIT - 5 (Norman)**	65.83a	63.08	61.50a	58.58
LACRIWHIT - 11 (Barlong)	61.33b	61.33	57.00c	57.00
LACRIWHIT - 4 (Attila)	63.08ab	63.08	59.08b	59.08
LACRIWHIT -1 (Seri 82)	63.08ab	63.08	57.50bc	57.50
SE ±	0.79	0.88	0.50	0.75
IRF (Days)				
3	63.08	63.08	58.58	58.50
6	63.50	61.92	59.08	58.00
9	63.67	62.50	58.17	57.00
12	63.08	63.08	59.25	58.67
SE ±	0.93	0.97	0.89	0.98
V x IRF	**NS**	**NS**	NS	NS

Note; Means followed by the same letter within a treatment group are not statistically different at 5% level of probability. NS = Not Significant * = Significant at 5% probability level ** = Significant at 1% probability level. *TRT=Treatment, VRT= Variety, SE=Standard Error, DFF= Days First Flowering, DFH= Days First Heading, LACRIWHIT= Indigenous wheat variety developed by lake chard research institute.*

Yield and yield components

100-grain weight

Varietal and irrigation effects were significant for 100-grain weight at both sites (Table 12). LACRIWHIT-5 and LACRIWHIT-11 recorded the highest mean grain weights (93.8–99.0 g), followed by LACRIWHIT-1 (96.5 g) and LACRIWHIT-4 (91.7 g). The 3- and 6-day irrigation intervals produced heavier grains than 9- and 12-day intervals, indicating improved assimilate translocation.

Grain yield per Hectare (t ha^{-1}) and harvest index (%)

Mean grain yield per hectare was significantly affected by irrigation frequency and location (Table 7). Dambatta recorded a higher mean yield (3.65 t ha^{-1}) than Wudil (3.10 t ha^{-1}), this is likely due to higher soil fertility and lower evapotranspiration rates. The 3-day irrigation interval resulted in the highest yield (3.6–3.7 t ha^{-1}), followed by the 6-day interval (3.3–3.5 t ha^{-1}), while 12-day intervals reduced yield by 25–30%.

The harvest index (HI) ranged from 36.5% to 47.8%, with LACRIWHIT-5 showing the highest efficiency under 6-day irrigation. This agrees with the principle that moderately frequent irrigation optimizes both water-use efficiency (WUE) and economic yield (Du *et al*., 2023; Liu et al., 2024). Excessive irrigation, conversely, lowers HI due to increased vegetative biomass at the expense of grain yield (Cavero *et al*., 2023).

Table 7: Effect of Variety and Irrigation Interval on 100 Grain Weight, Grain Yield per Hectare and Harvest Index of Wheat at Dambatta and Wudil during the 2023/2024 Irrigation Season

Treatment	Wudil	Dambatta	Wudil	Dambatta	Wudil	Dambatta
	100 Gw	100 Gw	Gyh	Gyh	Hi	Hi
Variety (Var) **Lacriwhit - 5 (Norman)**	93.75a	2.96b	3.08b	12.09	11.72	
Lacriwhit - 11 (Barlong)	93.58a	3.43a	3.60a	13.23	13.82	
Lacriwhit - 4 (Attila)	91.67b	3.19ab	3.32ab	12.53	11.94	
Lacriwhit -1 (Seri 82)	92.50ab	3.46a	3.41a	13.16	13.00	
Se±	0.39	0.09	0.09	0.36	0.73	
Irf (Days)						
3	92.92	3.84a	3.80a	14.05a	14.22a	
6	92.83	3.44b	3.54a	13.28a	13.07ab	
9	92.92	2.99c	3.08b	12.91a	11.94bc	
12	92.83	2.78c	2.98b	10.77b	11.25c	
Se±	0.76	0.13	0.09	0.40	0.57	
Interaction						
V X Irf	Ns	Ns	Ns	*	**Ns**	

Note; Means followed by the same letter within a treatment group are not statistically different at 5% level of probability. NS = Not Significant * = Significant at 5% probability level ** = Significant at 1% probability level. *TRT=Treatment, VRT= Variety, SE=Standard Error, SNM^2= Spike Number per m^2, LACRIWHIT= Indigenous wheat variety developed by lake chard research institute.*

IV. Conclusion And Recommendations

This study demonstrated that wheat (*Triticum aestivum* L.) productivity in the Sudan Savannah zone of Nigeria is highly dependent on irrigation frequency and varietal selection. Among the four varieties tested (LACRIWHIT-1, -4, -5, and -11), LACRIWHIT-5 and LACRIWHIT-11 consistently produced superior results in plant height (63–72 cm), leaf area index (10.17–11.44), and 100-grain weight (93.8–99.0 g). The highest grain yield was recorded under 3-day (3.65 t ha^{-1}) and 6-day (3.10 t ha^{-1}) irrigation intervals by LACRIWHIT-1 variety , while yield declined significantly (2.73 t ha^{-1}) under 12-day intervals, highlighting the importance of maintaining adequate soil moisture during critical growth stages.

The Dambatta site, characterized by higher soil fertility and slightly lower evapotranspiration, produced superior yields and biomass accumulation compared to Wudil, confirming location-specific effects. The absence of strong variety × irrigation interactions suggests stable varietal performance across moisture regimes, which is beneficial for scaling and breeding efforts in similar semi arid agroecological zones of Nigeria.

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