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Grain Yield, Yield Components And Water Use Efficiency Of Wheat (Triticum Aestivum L.) Varieties Under Three Irrigation Regimes On A Clay-Loamy Soil In Semi-Arid Zone Of Southern Niger Republic

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Abstract—Wheat is among the most important crops in the world and its consumption in Niger republic is increasing rapidly. Adequate irrigation management practices as well as choice of improved varieties can significantly increase yield of wheat. In southern Niger republic farmers grow wheat in dry and cold season under irrigation. They apply irrigation at diverse regimes without having technical recommendations on irrigation patterns suitable for their area. To alleviate this constraint, a field experiment was conducted during 2016/2017 and 2017/2018 dry seasons at Djirataoua (13°25'59''N, 7°8'12''E) in southern Niger Republic. The aim of the study was to determine the appropriate regime of irrigation for highest yield and water use efficiency of wheat varieties. The treatments consisted of three irrigation regimes (7, 10 and 14 days interval at 30 mm) and four wheat varieties (El-Kodaraoua as local check, Sokoll/3/, Norman and Reyna-28). The experiment was laid out in a split plot design with three replications. Data collected on grain yield, yield components and water use efficiency were subjected to the analysis of variance and mean comparison was done using Fisher's LSD. The water use efficiency was calculated to determine the optimum irrigation regime for economic production. The results showed that irrigation at 7 and 10 days interval and 30 mm resulted in higher grain and straw yields. Significant interactions between the studied factors on growth and yield characters were observed. The highest grain yield was achieved by interaction of Reyna-28 and Sokoll/3/ with 7 days irrigation interval. In contrary the water use efficiency was highest at 10 and 14 days of irrigation intervals. Based on these findings, irrigation at 7 days interval of 30mm and using Reyna-28 or Sokoll/3/ is recommended for maximum grain yield. But in conditions of water scarcity, irrigation can be applied each 10 days for economic yield.

Keywords—wheat; irrigation regime; yield; yield components; water use efficiency.

I. INTRODUCTION

Niger is a dry country that is predicted to get drier with climate change. The irrigation potential of this country is estimated at 270,000 hectares in terms of surface water and groundwater [1]. Wheat is cultivated in Niger during the cold off-season under irrigation with an average grain yield of less than 1 ton/ha [2]. The main zones of production are Agadez in the northern part,

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Tahoua, Diffa and Maradi on irrigated perimeters in the southern part of the country. Wheat production in this country is failing to keep pace with growing demand [3]. Efficient use of water is one of the most important factors determining the yield of wheat. Results obtained by [4] indicated that yield potential of wheat varieties in warm areas can be further exploited by improved management practices such as irrigation regime and fertilization. A study made by [5] in Niger republic, showed that wheat yield can be increased up to 3-4 tons ha-1 through good agronomic practices. Given the soil water holding capacity, it is important to decide the number of irrigations, the amount of water and interval between successive irrigations so that crop may not suffer from water stress. Proper timing and frequency of supplementary irrigation in relation to crop yield are crucial in irrigation scheduling for the most effective use of available water in optimizing wheat production [6]. Grain yield increased with increase in the frequency of irrigation as reported by [7], [8] and [9]. A study carried out by [10] at Kadawa in Northern Nigeria, area very similar to southern Niger republic, showed that ten days of irrigation interval significantly produced taller plants, longer days to 50% flowering and heading and higher panicle and grain yield. [11] reported that highest grain yield was obtained from watering every 14 days until the boot stage and 10 days thereafter. According to the findings of [12] the highest water use efficiency was obtained when crop was irrigated at one week interval while [13] found that irrigation every 7 and 10 days gave the highest protein content, grain and straw yield and field water use efficiency, but for economic reason irrigation every 10 days is recommended in semi-arid environment.

A survey recently conducted in the district of Djirataoua showed that wheat growers use mostly local cultivars with traditional methods of irrigation. Irrigation is typically practiced in opened shallow furrows. This method is inefficient because water is used excessively and flow-rates are not uniform resulting in drainage, water logging, and consequently increasing the salinity of the soil. Therefore, knowledge of when to apply the available water is necessary for maximum grain yield and efficient water use in this area.

The objectives of this study were to determine the appropriate irrigation regime for the best response of wheat varieties on grain yield and water use efficiency suitable for southern Sahel ecological zone of Niger republic.

II. Materials and Methods

2.1 Experimental site

The experiment was carried out during 2016/2017 and 2017/2018 dry/cold seasons at Djirataoua in the south of Niger republic. The experimental field was located in an irrigated orchard lying along the Goulbin Maradi River: 13° 25' 59" North and 7° 8' 12" East. Rainfall: 350-600 mm (Sahelian climate). Soil texture: Clay-loamy.

Before the implementation of the trial soil samples were collected randomly across the experimental field at a depth from 0–20 cm for physicochemical characterization of the soil. Samples were analyzed at the Soil Department Laboratory of Bayero University Kano. Weather data on temperature and relative humidity were recorded on the experimental field using a data logger (TINYTAG PLUS-2).

2.2 Treatments and experimental design

The treatments consisted of the combination of four wheat varieties (El-Kodaraoua, Norman, Reyna-28 and Sokoll/3/) and three irrigation regimes: 7 days interval of irrigation at 30 mm (7 DII), 10 days interval of irrigation at 30 mm (10 DII) and 14 days interval of irrigation at 30 mm (14 DII) laid out in split-plot design with three replications. The main plots were allocated for irrigation regime while the wheat varieties were randomly arranged on the sub-plots. The unit plot (sub-plot) size for planting was 1.2 m × 2.0 m (2.4 m2) accommodating 4 rows spaced 30 cm apart. Two central rows with a net plot size of 1.2 m2 were used for data collection and others measurements. The sowing was done by means of single row hand drill on 25 November 2016 during 2016/2017 dry season and 13 November 2017 during 2017/2018 dry season. Fertilizers were applied in the form of NPK (15-15-15), SSP (0-18-0) and Urea (46-0-0). The Phosphorus and Potassium fertilizers were applied as basal application at the constant rate of 60 kg ha-1 and 40 kg ha-1 respectively, while the Urea was applied at the stage of first node emergence (jointing stage) at 120 kg ha-1 as recommended.

2.3 Data collected

Data were collected on number of spike per m2 (NS), number of grain per spike (NGS), thousand kernel weight (TKW), grain

yield (GY) and straw yield (SY). The harvest index (HI) and water use efficiency (WUE) were calculated using the formula (1) and (2) respectively:

(1) According to [14]

$$HI(\%) = \frac{Grain\ yield\ (kg/ha)}{Grain\ yield + straw\ yield\ (kg/ha)} * 100$$

(2) According to [15]

$$WUE(\mathrm{kg/m3}) = \frac{Grain\ yield\ (kg/ha)}{Applied\ water\ rate\ (m3/ha)}$$

2.4 Statistical data analysis

Data were subjected to the analysis of variance (ANOVA) to sort significant difference among treatments using the software GENSTAT 18th Edition and comparison of means was done using Fisher protected LSD at 5% level of significance.

III. Results of the Study

3.1 Yield and yield components

Grain yield (GY) and straw yield (SY) were significantly affected by irrigation regime during 2016/2017 dry season (Table 1). The highest GY (2740 kg/ha) was achieved by plants irrigated at 7 DII, followed by treatment of 10 DII (2551 kg/ha) while the lowest GY was recorded at 14 DII (1976 kg/ha). Plants irrigated at 7 and 10 DII were statistically similar and produced highest SY (5533 and 5346 kg/ha respectively) compared to irrigation at 14 DII that produced the lowest SY (4089 kg/ha). In 2017/2018 the thousand kernels weight (TKW) and the GY responded significantly to irrigation regimes. The highest TKW was recorded at 7 DII (31.15 g) followed by irrigation treatment at 10 DII (29.41 g) while plants irrigated at 14 DII produced grains with lowest TKW (28.31 g). However the number of spike per m2 (NS), the number of grain per spike (NGS) and the harvest index (HI) did not respond to irrigation regime treatments all over the study.

On other hand, the wheat varieties expressed significant differences in grain yield and yield components. Reyna-28 recorded highest GY (2842 and 2914 kg/ha in 2016/2017 and 2017/2018 respectively) and highest HI (35.68 and 30.57% in 2016/2017 and 2017/2018 respectively); Sokoll/3/ produced highest TKW and SY. The lowest GY, TKW and HI were observed on the local variety El-Kodaraoua.

The interactions between irrigation regime and wheat variety on GY, TKW and HI were significant during both dry seasons. The figures 1 and 2 displayed the interaction of wheat varieties with irrigation regimes on GY. Reyna-28 achieved the highest GY at 7 DII and then decreased to the lowest GY at 14 DII. Sokoll/3/ recorded the highest GY at 10 DII during both dry seasons (Fig. 1). Globally, the highest GY was achieved at interaction 7 DII x Reyna-28 (3187 kg/ha) and 10 DII x Sokoll/3/ (3124 kg/ha) (Fig. 2).

Table 1: Mean value for the effects of irrigation Regimes (IR), variety (V) and interactions (IR x V) on Number of spikes m^{-2} (NS), Number of grains $spike^{-1}$ (NGS), Thousand kernels weight (TKW), grain yield (GY), straw yield (SY) and harvest index (HI) during 2016/2017 and 2017/2018 at Djirataoua, Southern Niger republic.

Treatments	2016/2017						2017/2018					
	NS	NGS	TKW	GY	SY	HI	NS	NGS	TKW	GY	SY	HI
Irrigation Regimes (IR)												
7 DII	365	36.6	31.44	2740a	5533a	31	281	34.9	31.15a	2524a	7252	26
10 DII	303	37.9	29.08	2551b	5346a	30	281	37.2	29.41ab	2284ab	6874	24
14 DII	256	32.1	29.34	1976c	4089b	31	280	30.6	28.31b	1968b	6663	22
LSD (5%)	135.9	3.115	4.502	134.3	410.4	1.6	25.8	2.422	1.753	322.8	1966.4	3.4
Variety (V)												
El-Kod. (Check)	252	33.34b	23.56c	1825c	5058ab	25.00c	268b	30.48c	23.37d	1846c	7184	20.34c
Sokoll/3/	292	33.16b	34.06a	2701a	5442a	31.29b	290b	34.00b	34.84a	2584b	6766	27.23b
Norman	362	40.03a	31.49b	2322b	4745b	30.70b	241c	39.00a	29.01c	1690c	7040	19.05c
Reyna 28	325	35.64ab	30.71b	2842a	4711b	35.68a	323a	36.22b	31.27b	2914a	6728	30.57a
LSD (5%)	116.4	2.835	1.525	231.1	446.2	2.1	24.3	2.015	1.405	237.6	650.3	1.6
Interactions												
IR x V	0.468	0.223	0.001*	0.031*	0.142	0.017*	0.198	0.099	0.009*	0.012*	0.543	< .001**

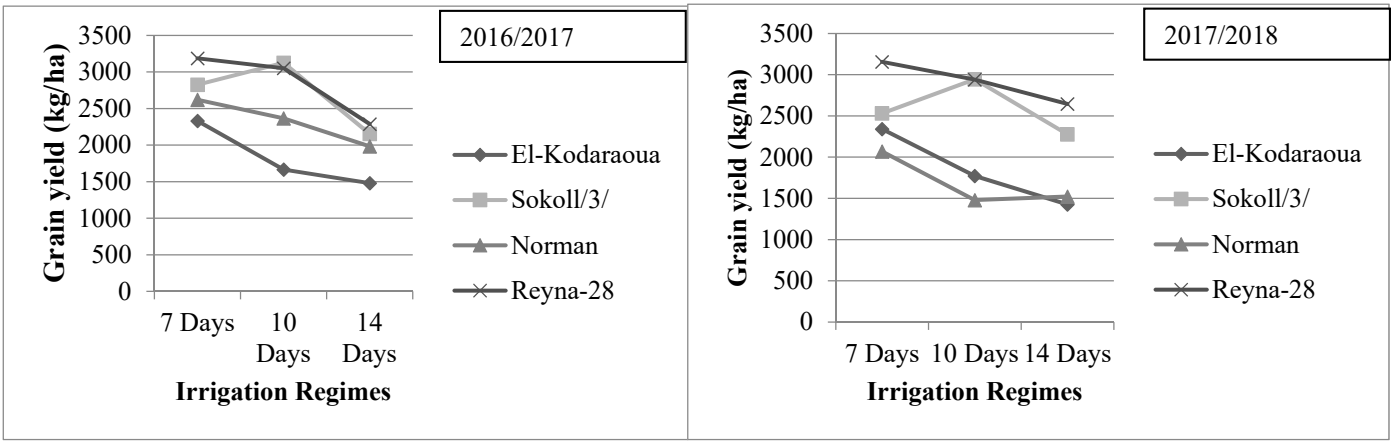

Fig. 1and 2: Response of wheat varieties to irrigation regimes during 2016/2017 and 2017/2018 seasons

3.2 Water use efficiency

The water use efficiency (WUE) was highest at regime of 14 DII and 10 DII with 0.96 and 0.92 kg/m3 respectively during 2016/2017 dry season while irrigation at 7 DII resulted in the lowest WUE (0.71 kg/m3) (Table 2). The variety Reyna-28 recorded the highest WUE (1.27 kg/m3) at 14 DII followed by Sokoll/3/ with 1.16 kg/m3 at 10 DII. The lowest WUE (0.60 kg/m3) was recorded by the local variety El-Kodaraoua at 7 DII. It was observed the similar tendency in 2017/2018 showing the highest WUE at 10 and 14 DII with 0.91 and 0.79 kg/m3 respectively. The varieties Reyna-28 and Sokoll/3/ recorded the highest WUE with 1.26 and 1.08 kg/m3 at 14 DII but the lowest WUE was recorded at 7 DII (0.46 kg/m3) and 10 DII (0.45 kg/m3) with variety Norman.

Table 2: Water use efficiency (kg/m^3) of irrigation regimes and wheat varieties during 2016/2017 and 2017/2018 dry seasons at Djirataoua, Niger republic.

2016/2017						**2017/2018**					
Irrigation Regimes		**Wheat variety**				**Irrigation Regimes**		**Wheat variety**			
		El-Kod.	Sokoll/3/	Norman	Reyna-28			El-Kod.	Sokoll/3/	Norman	Reyna-28
7 DII	0.71b	0.6e	0.72de	0.62e	0.89c	7 DII	0.63b	0.6efgh	0.65efg	0.46fh	0.81cd
10 DII	0.92a	0.62e	1.16ab	0.79cd	1.13b	10 DII	0.79ab	0.66def	0.98bc	0.45gh	1.09ab
14 DII	0.96a	0.7de	1.03b	0.83cd	1.27a	14 DII	0.91a	0.68de	1.08b	0.63d-h	1.26a
LSD	0.045	0.136				LSD	0.199	0.207			

Table 3: Results of the physicochemical analysis of the soil of the experimental site of Djirataoua, Southern Niger republic.

Physical properties	
Particle size distribution (g kg^{-1})	
Sand	510.6
Silt	327.7
Clay	161.6
Texture	Loamy
Water Holding Capacity (%)	57.2
Chemical properties	
pH (H_2O)	6.62
pH ($CaCl_2$)	6.06
Organic Matter (g kg^{-1})	9.94
Nitrogen $NH4^-$ (g kg^{-1})	0.05
Nitrogen $NO3^-$ (g kg^{-1})	0.02
Total Nitrogen (g kg^{-1})	1.05
Available Phosphorus (mg kg^{-1})	5.94
Exchangeable Cations (Cmol kg^{-1})	
K	0.26
Na	0.38
Ca	1.15
Mg	1.18
CEC	3.3

Table 4: Meteorological data showing minimum and maximum temperature, relative humidity (RH) during 2016/2017 and 2017/2018 dry seasons at Djirataoua.

Month	Decade	Temperature (°C)			RH (%)	
		Min	Max	Mean	Min	Max
			2016/2017			
Nov. 2016	01-10	19.51	29.59	27.6	13.4	34.4
	11-20	19.43	29.94	27.71	16.6	39.6
	21-30	19.89	31.37	28.67	15.3	45.5
Dec. 2016	01-10	17.36	28.52	26.52	16.6	36.2
	11-20	15.08	23.02	24.56	28.14	41.7
	21-31	14.39	22.15	22.36	25.57	31.84
Jan. 2017	01-10	13.48	21.63	21.17	22.66	29.7
	11-20	15.58	22.73	23.35	28.07	41.04
	21-31	18.1	25.61	25.31	23.98	33.09
Feb. 2017	01-10	16.97	24.69	24.19	16.25	22.91
	11-20	16.3	24.38	23.67	15.11	20.2
	21-28	18.3	26.43	26.3	17.75	27.13
Mar. 2017	01-10	20.86	30.31	29.86	20.83	30.8
	11-20	19.41	29.87	28.69	15.01	23.32
	21-31	23.41	32.44	31.8	21.46	31.56
Mean		17.87	26.85	26.12	19.78	32.6
			2017/2018			
Nov. 2017	01-10	17.96	30.06	25.33	11.7	36.4
	11-20	18.55	31.78	27.3	11.1	42.3
	21-30	17.09	28.94	25.27	9.8	33.4
Dec. 2017	01-10	15.63	26.15	23.3	14.4	37.5
	11-20	16.44	27.52	24.18	16.8	44.3
	21-31	14.33	24.81	19.99	14.73	40.45
Jan. 2018	01-10	12.05	24.04	20.79	13.5	39.8
	11-20	11.95	24.56	20.91	14.2	34.8
	21-31	13.36	23.83	21.15	7.82	27.64
Feb. 2018	01-10	14.74	30.07	25.24	6.8	29.6
	11-20	16.95	29.02	25.97	6.6	22.4
	21-28	24.19	33.73	31.59	17.75	43.25

Mar. 2018	01-10	19.05	35.07	30.55	6	29.3
	11-20	20.55	3.89	31.35	3.6	20.3
	21-31	22.68	3.46	30.45	5.27	17.64
Mean		17.03	25.13	25.56	10.67	33.27

IV. Discussion of the Results

The yield and yield components of wheat had significantly increased with shorter irrigation regimes in this study. This result might be explained by the improvement of nutrients extraction by the roots from the soil and the translocation of carbohydrates for better grains filling due to water availability in the root zone corroborating the findings of [16] who reported that adequate irrigation enhanced grain yield and yield components by improving the growth of the crop and thus enabling it to intercept more photosynthetic radiation over less irrigated wheat plants.

The significance of interaction between irrigation regime and wheat variety on grain yield and other yield components showed a differential response of the studied wheat varieties to irrigation regime. This might indicate that, variety choice is important for a good response of these characters to different irrigation regimes, as earlier explained by [17].

The range of WUE was 0.46 to 1.27 kg/m3 is close to that of [18] and [19] who reported that in general, the wheat WUE ranges from 0.40 to 1.83 kg/m3 globally on a yield basis. In the same range, [13] found the highest water use efficiency at 10 days of irrigation intervals in a semi-arid environment, which is consistent to the results of this study.

V. Conclusion

The results of this study showed that grain yield, yield components and water use efficiency of wheat varieties were significantly influenced by irrigation regimes. Highest grain yield and yield components were observed at 7 and 10 days interval of irrigation at 30 mm, while irrigation at 14 days interval resulted in a decrease of these characters. The studied wheat varieties expressed differential response in grain yield, yield components and water use efficiency depending on their genetic potential. Reyna-28 and Sokoll/3/ produced highest grain yield, harvest index and water use efficiency. This result could be useful for wheat growers in irrigated schemes of this area to allocate the cultivars more tolerant to moisture stress in location where irrigation water is scarce or more difficult to manage while the highly responsive varieties to shorter irrigation intervals could be proposed for intensive production in well watered areas, which can contribute to food security of the country.

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