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Effects of Supplemental Irrigation and Nitrogen Applied on Yield and Yield Components of Bread Wheat at the Saïs Region of Morocco

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Authors' contributions

This work was carried out in collaboration between all authors. Author BA designed the study, performed the experiment and statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors MI and RD managed the analyses of the study. Authors RD, MI, AK and KD supervised the study and managed the literature searches. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

The objective of this study is to determinate the optimal growth stage for applying supplemental irrigation and nitrogen to enhance bread wheat (*Triticum aestivum* L.) productivity and water use efficiency under rainfed condition in Morocco. Field trial was conducted during two years (2007-2008 and 2008-2009). Three genotypes (G) of Moroccan bread wheat; Achtar, Arrehane and an Advanced Line II were combined with five nitrogen doses (N); 0, 40, 80, 120 and 160 kg N ha^{-1} and three water treatments (I); rainfed (I_0), irrigated (60 mm) at 21 according to the Zadoks scale (I_1) and irrigated (60 mm) at 59 according to the Zadoks scale (I_2). Results in the drought year (2007-2008) show that I_2 improves water use efficiency, grain yield and its components by 91 and 60% respectively, compared to I_0 and I_1 treatments. I_2 has limited the effects of the Chergui –hot and dry wind coming from the Sahara- which has a negative impact on growth mainly at the end of the cycle of the crop. Grain yield and other yield components increased simultaneously with the increase in nitrogen inputs during the second 2008-2009 crop year which was rainy. The 120 kg N ha^{-1} dose allowed the highest results, with no significant difference with the yield obtained after a 160 kg N ha^{-1} input. Genotype appeared to have no significant effect neither on grain yield nor on water use efficiency in both the years.

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1. INTRODUCTION

Cereals are the most important crops in Morocco; it covers 5 million hectares which represent 80% of arable land in the country. Unfortunately, yields are low and variable due to rainfall scarcity and variability [1]. Climatic change pattern in Mediterranean region would increase drought frequency with high fluctuation in precipitation [2]. In fact, at the Saïs region of Morocco, the average rainfall is passed from 600 mm per year during the period 1960-1980 to 440 mm for the period 1981-2000 [3]. By 2020, the climate change scenarios in Morocco in relation with agricultural production include a reduction in grain yield of cereals estimated at 50% in dry years and 10% in normal years [4]. In Morocco, agriculture is facing challenges to produce for a population increasingly growing and to be more efficient in the use of water given the competition from other non-agricultural sectors [4].

Under these conditions, to increase and stabilize production there has been a tendency to adopt application of high rates of nitrogen under irrigated conditions [5]. Indeed, compared to non-irrigated treatment, an increase in grain yield for bread wheat of 419, 389 and 281% respectively for the full supplemental irrigation (FSI), 2/3rd of the FSI and 1/3rd of the FSI has obtained in northern Syria [6]. The effect of supplemental irrigation is more remarkable as it is made in the early stages of crop development (early tillering) for varieties with low tillering and heading stage for varieties with high coefficient of tillering. In both cases, the yield increases up to 100% [7].

Also, nitrogen use of cereals is the second factor after water, which determines the level of intensification of the production. It is one of the most difficult practices in the dry areas. Indeed, the addition of high amounts of nitrogen in dry years and this element deficiency in wet years often cause considerable falls in cereal yields [8]. Water and nitrogen use should be carefully managed to avoid losses [9]. In the North of France, on the new variety of wheat Recital, with 170 kg N ha^{-1} gave an increase of 87% of yield comparatively to control (0 kg N ha^{-1}). While the old variety Cappelle is indifferent to the dose of nitrogen applied, but its efficiency is low [10].

A field trial was set up in experimental stations with the objectives to stabilize and increase the production of bread wheat in Moroccan rainfed area of the Saïs through better management of supplemental irrigation (application stage), the nitrogen dose and the genotypes with the aim of increasing the efficiency of their use.

2. MATERIALS AND METHODS

2.1 Experimental Site

A field trail was conducted in Saïs region at the Experimental Station Douyet (National Agricultural Research Institute, Morocco) in the province of Fez (34°2'N, 4°50'W, altitude: 416 m), for two years 2007-08 and 2008-09.

2.2 Treatments

Sowing was done by a seeder on 26 December for the two years of the trial at a dose equal to 160 kg ha^{-1}. The three factors tested were: Water regime (I_0; rainfed, I_1; irrigated (60 mm) at 21 according to the Zadoks scale [11] and I_2; irrigated (60 mm) at 59 according to the Zadoks scale), Nitrogen dose (N_0: 0 kg N ha^{-1}, N_1: 40 kg N ha^{-1} (sowing), N_2: 80 kg N ha^{-1} (40 kg N ha^{-1} at sowing and 40 kg N ha^{-1} at 21 according to the Zadoks scale), N_3: 120 kg N ha^{-1} (40 kg N ha^{-1} at sowing, 40 kg N ha^{-1} at 21 according to the Zadoks scale) and 40 kg N ha^{-1} at 30 according to the Zadoks scale and N_4 :160 kg N ha^{-1} ha (40 kg N ha^{-1} at sowing, 40 kg N ha^{-1} at 21 according to the Zadoks scale and 80 kg N ha^{-1} at 30 according to the Zadoks scale)) and Genotypes (Achtar, Arrehane and an Advanced line II) (Table 1).

Table 1. Characteristics of genotypes

Variety	Achtar	Arrehane
- Origin	INRA-Morocco	INRA-Morocco
- Year of Registration	1988	1996
- Maturity to heading	Medium-early	Early
- Size	Average	High
- Zone adaptation	Rainfed-irrigated	Rainfed-irrigated
- Resistance		
Septoria	Tolerant	-
Brown rust	Tolerant	Resistant
Yellow rust	-	Resistant
Cecidomyie	-	Resistant

The third genotype is an Advanced Lineage II (LA II) from the Moroccan Observation Nursery (INRA), its origin is a cross between of Moroccan variety Nesma and Australian Lineage (Nesma x 2/14-2/7/ Ias 20 x 5/H567.71/6/Bow"S"), they are resistant to the Cecidomyie, Rusts and Septoria.

The experiment design was a split-plot with 3 replications, the water regime in main plots while genotype and nitrogen were allotted to sub-plots. The experimental area was divided into 135 plots of 5 m x 3.5 m each, with an alley of 2 m between adjacent plots and 8 m between main plots. Spray irrigation was used and was controlled by the location of several graduated cylinders at the irrigated plots. The final results showed that irrigation water doses were made between 55 and 65 mm.

Analysis of nitrogen soil before installation of the test showed that the soil was rich in this element (40 ppm NO_3^-).

2.3 Sampling and Analysis

Measurements at physiological maturity included grain and straw yield, biomass, 1000 kernel weight, kernel number per unit area, harvest index and soil moisture at sowing and physiological maturity. The gravimetric method [12] was used to determine volumetric water content for soil sample taken by hand auger from 0-20, 20-40 and 40-60 cm profile depths (the virtisols and hand auger used does not allow penetration into the deeper horizons more than 60 cm). Water use efficiency (WUE) for grain or dry matter is calculated: WUE = Grain or dry matter / ET, (kg ha^{-1} mm^{-1}).

To quantify water consumption throughout the crop cycle, we used the water balance equation [13] that actual evapotranspiration (ET) is calculated as: $ET = P + I – R – D \pm \Delta S$
P: Rainfall, I: Irrigation, ΔS: Change in stocks of water in the soil. R: Runoff, D: Drainage, were neglected.

2.4 Statistical Analysis

SPSS 17.0 and SNK (Student-Newman-Keuls) was used for analysis of variance and mean comparison.

3. RESULTS AND DISCUSSION

3.1 Weather Conditions

In 2007-2008 crop year total rainfall throughout the season was 334 mm; 115 mm before sowing and 219 mm during the test period (Figure 1). While the 2008-2009 crop year recorded 750 mm of rainfall; 388 mm before sowing and 362 mm between sowing and physiological maturity. Rainfall during the last year was well distributed throughout the crop cycle (Figure 1).

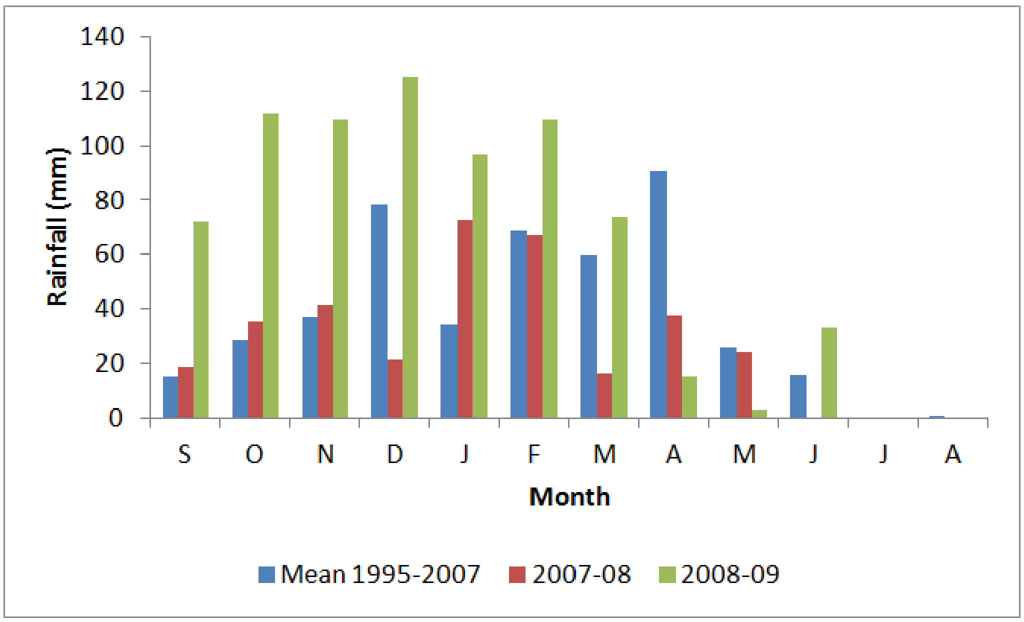

Figure 1. Rainfall distribution in the experimental station of Douyet for 2007-2008 and 2008-2009 crop year and the mean of 1995-2007

3.2 Grain Yield

The 2007-2008 crop year was a relatively dry year, the water supply had a highly significant effect on grain yield. Indeed, supplemental irrigation at 21 according to the Zadoks scale and 59 according to the Zadoks scale have resulted in improvements in grain yield respectively from 59.43 and 90.96% compared to no-irrigated (Table 2). Increased yield noticeably support the findings in Asia [14,15] and in the semi-arid region of Settat (Morocco) [7,16] in favor of the potential for conjunctive use of supplemental irrigation. Nitrogen dose did not affect the grain yield. The low yields in 2007-2008 compared to the potential of the region and the effect of two successive drought years (2006-2008) have limited samples the nitrogen supply and we would suggest that the balance of nitrogen from previous years was sufficient to produce yields recorded. Genotype and the interactions did not show significant effects.

Since the genotype had no significant effect on most of the parameters measured only the results of the water regime and nitrogen dose will be presented in the Tables (2, 3, 4, 5, and 6).

Table 2. Effect of water regime and nitrogen dose on grain yield (qx ha^{-1}) in 2007-2008 and 2008-2009 crops years

	N_0	N_1	N_2	N_3	N_4	Mean I
2007-2008						
I_0	18,24	17,81	16,39	17,07	16,51	17,20 a
I_1	20,30	20,80	21,83	22,57	20,86	21,27 b
I_2	31,74	32,66	32,86	32,70	32,25	32,44 c
Mean N	23,43	23,76	23,69	24,11	23,21	23,64
2008-2009						
I_0	39,53	44,86	47,92	50,18	50,37	46,57
I_1	44,26	47,03	49,37	53,74	54,58	49,79
I_2	43,06	47,33	49,35	52,15	53,68	49,11
Mean N	42,279 a	46,41 b	48,88 b	52,03 c	52,88 c	42,28

In each growing season, Means followed by different letters are significantly different at 5% level of probability

The second season (2008-2009) was very rainy, as expected; nitrogen dose had a significant effect on grain yield. N_4 and N_3 gave the highest grain yield with an average of 52.46 qx ha^{-1}, respectively, followed by N_2 and N_1 which recorded an average of 47.65 qx ha^{-1}. While the lowest grain yield of 42.3 qx ha^{-1} was recorded by N_0 (Table 2). Similar results were found in France [10] and in Morocco [17]. The addition of 168 kg N ha^{-1} had no significant effect on grain yield of durum wheat (variety Karim) compared to an intake of 126 kg N ha^{-1} [17]. While, the dose 170 kg N ha^{-1} gave a yield higher than 87% compared to the doses 0 N ha^{-1} for wheat Recital [10]. Statistically supplemental irrigation and genotype had no significant effect on grain yield. However, the two water regimes (irrigated at 59 according to the Zadoks scale and irrigated at 21 according to the Zadoks scale) gave an average of 49.38 qx ha^{-1}, higher than 3 qx ha^{-1} compared to no-irrigated. The interactions did not show significant effects.

3.3 Water Use Efficiency

Supplemental irrigation had a significant effect on the water use efficiency (WUE) for grain in 2007-08. Irrigated at 59 according to the Zadoks scale showed an efficiency of 11.89 kg ha^{-1} mm^{-1}, higher respectively from 40.3 and 49.8% compared with irrigated at 21 according to the Zadoks scale and no-irrigated regime (Table 3). Similar results were observed for WUE for total biomass. In dry year, a relatively small amount of irrigation water applied at strategic growth stages of cereals could realize an important increase in WUE of rainfed wheat [18,19].

WUE for grain and total dry matter in the rainy season 2008-2009 was influenced by the nitrogen dose. Statistical analyses showed that N_4 and N_3 allow the highest WUE for grain (6.43 kg ha^{-1} mm^{-1}), higher respectively from 41.9% for N_0 and 19.5% for N_2 and N_1 (Table 3). These results corroborate those found in northern Syria in the case of supplemental irrigation [20]. Indeed, the dose 100 kg N ha^{-1} allowed the highest WUE for the grain (2.2 kg ha^{-1} mm^{-1}), followed by the doses 150 and 50 kg N ha^{-1} (1.4 kg ha^{-1} mm^{-1}) and finally the dose 0 kg N ha^{-1} (0.7 kg ha^{-1} mm^{-1}). The difference in water use efficiency between these 2 years was due mostly to the difference in grain yield.

Table 3. Effect of water regime and nitrogen dose on WUE (kg ha^{-1} mm^{-1}) in 2007-2008 and 2008-2009 crops years

	N_0	N_1	N_2	N_3	N_4	Mean I
2007-2008						
I_0	5,21	6,80	6,50	5,90	5,39	5,96 a
I_1	6,95	7,49	7,49	6,60	6,91	7,09 b
I_2	11,07	11,91	11,69	12,61	12,18	11,89 c
Mean N	7,74	8,73	8,56	8,37	8,16	8,31
2008-2009						
I_0	4,21	5,60	6,00	6,01	6,54	5,67
I_1	3,26	4,47	5,27	6,06	6,57	5,13
I_2	3,73	5,08	4,60	6,69	6,68	5,36
Mean N	3,73 a	5,05 b	5,29 b	6,25 c	6,60 c	5,38

In each growing season, Means followed by different letters are significantly different at 5% level of probability

3.4 Harvest Index

Statistical analyses revealed in 2007-2008 season a significant effect of water regime on harvest index (HI). The results are similar to those obtained for grain yield. In fact, the rainfall regime gave the lowest HI with an average of 30.71%, followed respectively by the regime irrigated at 21 according to the Zadoks scale with an increase average of 9.34% and the regime irrigated at 59 according to the Zadoks scale with an increase average of 26.12% (Table 4). Climatic conditions during the development of kernel have a direct effect on HI. Irrigation especially at 59 according to Zadoks scale, realized upon the cessation of rains has allowed remobilization of the photoassimilates from source to sink.

In 2008-2009 crop year, the water regime has no influence on this component unlike to nitrogen dose. Statistical analyses revealed that the higher HI was obtained by N_4 with an average of 38.98. While, N_0 have registered the lower HI with an average of 30.25 (Table 4). The difference in performance for different doses of nitrogen was more influenced by the amount of dry matter produced rather than the translocation of photoassimilates to the grain as the case for the dry year.

Table 4. Effect of water regime and nitrogen dose on HI in 2007-2008 and 2008-2009 crops years

	N_0	N_1	N_2	N_3	N_4	Mean I
2007-2008						
I_0	32,61	29,09	29,64	29,86	32,21	30,71 a
I_1	33,63	33,73	30,79	35,91	33,86	33,58 b
I_2	40,14	37,27	39,62	40,01	36,48	38,73 c
Mean N	35,46	33,38	33,35	35,26	34,20	34,34
2008-2009						
I_0	31,75	38,74	35,30	38,28	35,08	35,83
I_1	32,18	30,34	34,45	35,34	36,25	33,71
I_2	26,82	33,09	31,19	39,42	45,62	35,23
Mean N	30,25 a	34,06 a,b	33,65 a,b	37,68 a,b	38,98 b	34,92

In each growing season, Means followed by different letters are significantly different at 5% level of probability

3.5 Kernel Weight

The 1000 kernels weight (KW) in 2007-2008 season have been influenced by the water regime. The highest KW (36.15) was obtained with regime irrigation at 59 according to the Zadoks scale, while the other two water regimes showed values statistically equal (26.26 g) (Table 5). Even under irrigation in the 59 according to the Zadoks scale did not express the highest potential weight of 1000 kernels. However, irrigation at this stage helped cushion the negative effect of hot winds (Chergui) that prevalent in the region at the end of the crop cycle. For genotype and nitrogen dose, the effect was not significant on this component.

In 2008-2009 crop year, nitrogen had a significant effect on this component. The N_0 gave the lowest KW with an average of 32.41g, followed by the other nitrogen doses which have statistically similar effect with an average of 36.95 g (Table 5). In contrast, in France for fifteen wheat genotypes tested the average for KW was equal to 43.1 g for nitrogen dose 0 kg ha^{-1} and an average of 40.9 g for dose 170 kg N ha^{-1}. Unlike the KW of five genotypes VM014, Audace, Etoile de Choisy, Sidéral and Camp Rémy are indifferent to the nitrogen dose applied [10]. Rainfed regime gave a KW equal to 35.34 g followed by irrigated regime at 59 according to the Zadoks scale with kW 36.39 g. The regime irrigated at 21 according to the Zadoks scale is statistically similar to the two regimes. This difference was not very important to influence the final grain yield. Genotype and the different interactions had no effect on this component.

Table 5. Effect of water regime and nitrogen dose on kernel Weight (g) in 2007-2008 and 2008-2009 crops years

	N_0	N_1	N_2	N_3	N_4	Mean I
2007-2008						
I_0	25,15	25,98	25,43	26,37	26,75	25,94 a
I_1	27,21	27,59	25,17	26,28	26,87	26,62 a
I_2	36,05	35,46	35,91	37,12	36,13	36,13 b
Mean N	29,47	29,68	28,83	29,92	29,92	29,56
2008-2009						
I_0	31,97	35,54	35,91	37,71	35,56	35.34
I_1	34,76	37,33	36,53	36,70	38,27	36,72
I_2	30,50	36,32	38,27	38,18	37,07	36,07
Mean N	32,41 a	36,40 b	36,90 b	37,53 b	36,97 b	36,04

In each growing season, Means followed by different letters are significantly different at 5% level of probability

3.6 Number of Kernels per Unit Area

Water regime had a highly significant effect in 2007-2008 crop year on the number of grains per unit area. The ranking shows that averages the highest number was recorded for water supply at 59 according to the Zadoks scale (8980 kernels m^{-2}), followed by water supply at 21 according to the Zadoks scale (8006 kernels m^{-2}) and late rainfall regime (6640 kernels m^{-2}) (Table 6). In general, the number of grains per unit area was determined by the population spike only, rather than the other components that have not recorded any significant differences. This result confirms those found in the semi-arid region of Settat (Morocco) [16].

Number of grains per unit area has been influenced in 2008-09 by the nitrogen dose. N_1 gave the lowest number (12408 kernels m^{-2}), while N_4 gave the highest number (14303 kernels m^{-2}). Although N_1 gave a number of grains per unit area small than N_0, it was offset by the kernel weight for a high yield of grain.

Table 6. Effect of water regime and nitrogen dose on Number of kernel per unit area in 2007-2008 and 2008-2009 crops years

	N_0	N_1	N_2	N_3	N_4	Mean I
2007-2008						
I_0	7254	6855	6445	6474	6171	6640 a
I_1	7460	7540	8675	8589	7764	8006 b
I_2	8804	9209	9152	8810	8926	8980 c
Mean N	7839	7868	8091	7958	7620	7875
2008-2009						
I_0	12364	12622	13345	13306	14165	13161
I_1	12734	12600	13514	14643	14263	13551
I_2	14117	13031	12896	13658	14480	13636
Mean N	13072 a,b	12751a	13252 a,b	13869 a,b	14303 b	13449

In each growing season, Means followed by different letters are significantly different at 5% level of probability

4. CONCLUSION

With climatic change and rainfall scarcity, supplemental irrigation could be an opportunity to enhance wheat grain yields and respond to population food demand. In fact, during the dry year 2007-2008, water regime greatly influences the production of bread wheat in the Saïs region of Morocco. Minimal Irrigation (60 mm) at 59 according to the Zadoks scale increase grain yield by 91% comparatively to rainfed regime. While, during years of heavy rainfall as 2008-2009, supplemental irrigation at 21 or 59 according to the Zadoks scale gives an increase of 3 qx ha^{-1} even if this increase was not statistically significant. This gain compensates amply the irrigation's cost. For nitrogen, during 2007-2008, no significant effect was recorded, while during 2008-2009, 120 kg N ha^{-1} gave the highest grain yield because of more rainfall availability. Genotypes and also the different interactions have no significant effects on grain yield during both years. This experiment should be reconducted in different soils and climatic conditions for extension of findings. The introduction of efficient genotypes for water and nitrogen uses should be of great interest. Responses to supplemental irrigation, nitrogen and genotypes can be modeled in order to use this model in other areas of Morocco and in the Mediterranean region.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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