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Effects of irrigation levels and nitrogen fertilizer rate on grain yield of wheat (*Triticum aestivum*) at Amibara, Middle Awash, Ethiopia

Jemal M. Hassen*, Fikadu R. Borena, Kebede N. Tufa, Wondimu T. Adugna, Nigusie A. Sori and Tesema M. Tedla

Ethiopian Institute of Agricultural Research/Werer Agricultural Research Center, P. O. Box 2003, Addis Ababa, Ethiopia.

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For three years, the response of wheat grain yield to varying amounts of nitrogen fertilizer and different levels of irrigation was investigated. Three levels of irrigation (100, 75, and 50%ETc) and five nitrogen rates (0, 23, 46, 69, and 92 kg/ha) were used in a split plot design. Irrigation and nitrogen levels both had a considerable impact on wheat grain yield, but there was no interaction between the two. The three-year combined analysis result revealed that the maximum grain yield of wheat was recorded at 92 kg/ha nitrogen rate and 100%ETc irrigation treatment. The minimum was obtained from no application of nitrogen and 50%ETc irrigation treatment. The study revealed that the above ground biomass and grain yield of wheat increased with the increasing rates of nitrogen fertilizer and the full application of irrigation. The partial budget analysis revealed that an application of 100%ETc and 46 kg/ha nitrogen fertilizer gave the maximum marginal rate of return and optimum net benefits. Therefore, application of 100%ETc irrigation and 46 kg/ha nitrogen is recommended for optimum returns of irrigation and nitrogen fertilization of wheat in the study area.

Key words: Nitrogen, Irrigation, Water use efficiency, partial budget, economic yield.

INTRODUCTION

Irrigated agriculture consumes the majority of the available water. Irrigation accounts for approximately 70% of total water abstraction and 60-80% of overall water usage (Huffaker and Hamilton, 2007). In order to feed 8 billion people by 2025, the irrigated area should be enlarged by more than 20% and the yield of irrigated crops improved by 40% (Lascano and Sojka, 2007). Improving agricultural water use efficiency is critical to achieving this goal. Many studies have been undertaken to gather experience in watering crops to enhance performance, efficiency, and profitability, and water-saving irrigation research will continue (Sleper et al., 2007). Agriculture's long-term water management has become a key challenge. Acceptance of methods for conserving irrigation water while keeping acceptable yields may help to preserve this increasingly scarce resource. In locations where water is a scarce resource, farmers may find that improving water productivity is more beneficial than boosting crop output. As a result, research should be established and carried out with the

*Corresponding author. E-mail: jemsmoha@gmail.com.

Table 1. During the farming season, the total monthly rainfall in the study region.

Month	Rainfall (mm) during the cropping season		
	2017/2018	2018/2019	2019/2020
November	1.4	59.8	122.4
December	0	0.6	50
January	0	0	0
February	6	16.4	0
Total	7.4	76.8	172.4
Effective rainfall	0	25.9	93.9

Source: Werer Agricultural Research Center Agrometeorological Observatory Station.

goal of increasing agricultural water productivity through various water-saving strategies in combination with the use of the correct fertilization scheme (Yakubu et al., 2019).

Wheat yields are increasing at an average rate of 0.9% globally, falling short of the required double crop production by 2050 (Ray et al., 2013). Nutrient efficiency advances, which have been observed in developed countries for the past three decades, will have an impact on future yield. Farmers, on the other hand, continue to use minimal fertilizer and deplete soil nutrient stocks across broad areas. This is especially true in Sub-Saharan Africa. Besides, when deciding whether or not to use fertilizer, smallholder farmers must also consider risk and uncertainty. Plant nutrients and water are complementary inputs; when water is not a constraint, the incremental return on fertilizer inputs is higher, and vice versa (Drechsel et al., 2014). The total productivity of the farming system, which includes crop output and soil nutrient levels, should be evaluated by combining the performance of agricultural inputs such as fertilizer and water use efficiency. Excessive and wasteful utilization of nitrogen fertilizer raises crop production costs and pollutes the environment (Galloway et al., 2008; Anas et al., 2020). The main contributing management factors to the crop yield gap are soil fertility and fertilization (Beza et al., 2017). Wheat producers would improve nitrogen fertilizer use under irrigated conditions, lowering the risk of environmental pollution. Nitrogen is a critical component for crop development and growth (Prieto et al., 2017). Water and nitrogen are the two most common limiting elements in the agricultural system, both of which are important for wheat growth and productivity. However, their optimal integration is not well identified, particularly in the study area. Therefore, this study was undertaken to determine the nitrogen rate and required irrigation level that optimize wheat yield in Amibara, a semi-arid part of Ethiopia.

MATERIALS AND METHODS

Description of study area

The research took place in Ethiopia's Werer Agricultural Research Center, which is located at 9°16'N latitude and 40°9'E longitude, with a mean altitude of 740 m above sea level. At the experimental site, the soil textural class was silty clay, with a bulk density of 1.3 g/cm^3. On a mass basis, the field capacity and permanent wilting point were 39.5 and 23%, respectively. The climate in the area is semi-arid, with an average annual rainfall of 590 mm and a bi-modal low and erratic rainfall pattern. The average temperature ranges from 26.7 to 40.8°C. The amount of rainfall during the farming season is described in Table 1.

Prior to sowing, soil samples were collected at a depth of (0- 30 cm) across the experimental field, composited, and soil physicochemical properties were analyzed at the Werer Agricultural Research Center laboratory; the results are described in Table 2. Before sowing, the total nitrogen value was 0.06% at a depth of 0-30 cm. The experimental site has a low total nitrogen content, according to the soil nitrogen classification category (Tadesse et al., 1991).

Experimental design and procedure

The experiment was conducted for three consecutive years, 2017/2018, 2018/2019 and 2019/2020 at the Werer Agricultural Research Centre experimental field. The treatment combinations are presented in Table 3. The experiment was conducted in a split plot design. The treatments were replicated three times and randomized at both the main and sub-plot levels. The irrigation levels (100, 75 and 50% ETc) were in the main plot while nitrogen fertilizer rate treatments (0, 23, 46, 69 and 92 kg/ha) were assigned to the sub plots. 100%ETc with 0 level of N was used as a control treatment for this experiment. Each application of water was measured using a 3-inch Parshall flume. A representative soil sample was taken from the experimental site for soil physicochemical analysis. The plot size for planting was 3.6 m by 5 m (18 m^2), accommodating 6 rows spaced 60 cm apart. The wheat (Ga'ambo variety) seed was sown by drilling on both sides of the rows at a rate of 100 kg/ha. For data collection and measurement, four central rows with a net plot size of 12 m^2 were used. At the time of seeding, all plots were given 100 kg/ha of triple superphosphate (TSP). Nitrogen, on the other hand, was applied in splits in the form of urea. Half at 20 days after sowing and the remaining half at 48 days after sowing. Following the water balancing Equation 1, the sum of daily ETc was added between two irrigation events.

$$ETc = P + I - D - \Delta S \qquad (1)$$

Where, ETc is crop evapotranspiration (mm), P is precipitation (mm), I is irrigation (mm), D is deep percolation (mm), and ΔS is change in soil water storage (mm).

Table 2. Soil physicochemical properties of the experimental area at depth of 0-30 cm before sowing of bread wheat.

Parameter	Values	Rating	References
Sand (%)	7	-	
Silt (%)	52	-	
Clay (%)	41	-	
Textural class	Silty clay	-	
EC (dS/m)	1.71	-	
pH 1:2.5 (H_2O)	8.40	Strongly alkaline	Tadesse et al. (1991)
Organic carbon (%)	0.64	Low	Tadesse et al. (1991)
Organic matter (%)	1.11	Low	Tadesse et al. (1991)
Total N (%)	0.06	Low	Tadesse et al. (1991)
Available P (ppm)	11.14	High	Olsen (1954)

Table 3. Treatment combinations.

Treatment	Nitrogen rate (kg/ha)				
Irrigation levels (%ETc)	0	23	46	69	92
100	T1	T2	T3	T4	T5
75	T6	T7	T8	T9	T10
50	T11	T12	T13	T14	T15

Note: 100, 75 and 50%ETc means full application, 25% deficit and 50% deficit application of the crop water requirement respectively.

Yield sampling methods

The yield data used in this study were estimated using yield sampling methods. This was achieved by using the crop cut methods by demarcating a plot 3 m by 3 m in size. Then, followed by harvesting the produce from the plots, threshing, winnowing, and drying the produce, and later determining the dry weight.

Data analysis

The three year combined yield, yield components and water use efficiency data were subjected to statistical analysis using the procedure of the SAS package (Cary, 2011). The mean comparison was done by the Least Significant Difference (LSD) test at the 5% level of significance (Gomez and Gomez, 1984).

Partial budget analysis

For economic evaluation of various treatments, partial budget analysis techniques were used in accordance with the procedure of International Maize and Wheat Improvement Center-CIMMYT (1988). The three-year combined average grain yield was reduced by 10% to account for differences in yields caused by differences in agronomic management between researchers and farmers using the same treatments. Costs for land preparation, water applied, fertilizer, seeds, pesticide, sacks, and labor for production are all included in the economic data. The cost of the sack, water, and fertilizer differed between treatments. Following the CIMMYT (1988) procedure, gross income, total variable costs, net benefits, and marginal rate of return were calculated from adjusted grain yields. The following Equation 2 was used to determine marginal rate of return.

$$MRR = (NB_2 - NB_1)/(VC_2 - VC_1) * 100 \quad (2)$$

MRR = Marginal rate of return
NB = Net benefits
VC = Costs that vary

Water use efficiency

The following Equation 3 was used to compute water use efficiency as a ratio of grain yield to total crop evapotranspiration (ETc) during the course of the growing season (Zwart and Bastiaanssen, 2004).

$$WUE = \frac{Y}{ETc} \quad (3)$$

Where, WUE is water use efficiency (kg/m^3), Y is crop yield (kg/ha) and ETc is the seasonal crop water consumption by evapotranspiration (m^3/ha).

RESULTS AND DISCUSSION

The effect of nitrogen rate and irrigation level on wheat grain yield and yield contributing parameters is described in Table 4. Among the irrigation treatments, 100% ETc produced the highest plant height and 50% ETc produced

Table 4. Presents the treatment effects on grain yield and yield components.

Treatment		PH (cm)	TT	ET	SL (cm)	NS/S	NK/S	TSW (gram)	ABMY (kg/ha)	GY (kg/ha)	WUE (kg/m^3)
Irrigation levels	100%ETc	65.57^a	9.28^a	9.27^a	8.97	16.14^a	36.96	39.65^b	10866.2^a	3525.7^a	0.50^c
	75%ETc	63.20^b	8.08^b	8.03^b	8.57	15.38^b	37.33	39.68^b	8399.8^b	3182.3^b	0.59^b
	50%ETc	63.00^b	8.98^a	8.97^a	8.66	15.82^{ab}	37.11	40.15^a	7936.4^b	2981.8^b	0.79^a
LSD (0.05)		2.11	0.72	0.82	NS	0.58	NS	0.39	905.09	266.68	0.05
Nitrogen rate (kg/ha)	0	61.45	8.48	8.17	8.33	15.10	33.30^b	39.37^b	7388.1^d	2580.5^c	0.50^c
	23	64.96	9.09	8.95	8.75	15.82	37.99^a	39.80^{ab}	8230.2^{cd}	2894.8^c	0.57^c
	46	64.98	8.72	8.69	8.78	15.87	37.44^a	39.89^a	9069.3^{cb}	3354.7^b	0.66^b
	69	64.41	8.73	9.05	8.86	15.99	38.30^a	40.27^a	9831.7^{ab}	3581.4^{ab}	0.69^{ab}
	92	63.79	9.20	8.91	8.94	15.89	37.50^a	39.82^{ab}	10818.0^a	3738.2^a	0.72^a
LSD (0.05)		NS	NS	NS	NS	NS	2.57	0.51	1168.5	344.28	0.07
CV (%)		7.92	19.55	22.43	10.07	8.82	12.91	2.36	23.89	19.76	20.16

Code abbreviations. PH: plant height, TT: total tiller, ET: effective tiller, SL: spike length, NS/S: number of spikelets per spike, NK/S: number of kernels per spike, TSW: thousand seed weight, ABMY: above ground biomass yield, GY: grain yield, and WUE: water use efficiency. Means followed by different letters in a column differ significantly and those followed by same letter are not significantly different at $p<0.05$ level of significance.

the shortest. The maximum number of total tillers per plant was obtained with a 100% ETc irrigation treatment, which was statistically similar to a 50% ETc irrigation treatment. A similar pattern was observed in the case of the number of effective tillers per plant. Plant height, total number of tillers per plant, effective tiller per plant, spike length, and number of spikelets per spike did not differ significantly between nitrogen treatments at the 5% level of significance. The number of kernels per spike did not significantly differ among the irrigation treatments. The maximum number of kernels per spike was obtained from 69 kg/ha nitrogen treatment, which was statistically identical to other nitrogen treatments except the control. The highest thousand seed weight was recorded from the 50%ETc irrigation treatment. Among the nitrogen treatments, the highest thousand seed weight was obtained at 69 kg/ha, which was statistically similar to other nitrogen treatments except the control.

Above ground biomass yield

The above ground biomass yield of wheat varied significantly among the irrigation level and nitrogen rate treatments (Table 4). From the three-year combined analysis, among the irrigation level treatments, the highest biomass yield (10866.2 kg/ha) was recorded from 100%ETc. whereas the lowest (7936.4 kg/ha) was obtained from 50%ETc. However, there was no significant variation between 50 and 75%ETc irrigation treatments. The availability of well distributed soil moisture due to the full irrigation application enhanced the growth of wheat and contributed to the highest biomass yield. The above ground biomass yield increased with the increasing rate of nitrogen doses (Table 4) with the maximum above ground biomass yield (10818 kg/ha) recorded from 92 kg/ha nitrogen treatment, which was statistically similar to the one found with 69 kg/ha nitrogen rate treatment. The minimum (7388.1 kg/ha) was obtained from the control treatment (no application of nitrogen). The results revealed that the application of 23 and 46 kg/ha nitrogen treatments were statistically similar in respect of above ground biomass yield. It can be seen that the above ground biomass yield increased with the increasing rates of nitrogen fertilizer and the full application of irrigation.

Grain yield

In terms of grain yield, the analysis of variance revealed a significant difference between irrigation levels and nitrogen rates (Table 4). There was no significant effect of interactions between irrigation levels and nitrogen rates on grain yield. Among the irrigation level treatments, the highest grain yield (3525.7 kg/ha) was attained at 100%ETc. The lowest yield (2981.8 kg/ha) was obtained from plots treated at 50%ETc, which was not statistically different to the one obtained with 75%ETc. The deficit level of irrigation significantly decreased the grain yield of wheat tested as compared to the control (full application of irrigation). Similar findings were also reported by Wang et al. (2012).

Among the nitrogen rate treatments, the nitrogen rate of 92 kg/ha produced the highest grain yield (3738.2 kg/ha), which did not statistically differ from the one achieved at the nitrogen rate of 69 kg/ha. The lowest grain yield (2580.5 kg/ha) was recorded on plots that did not receive any nitrogen fertilizer, which was statistically similar to the grain yield obtained with a nitrogen rate treatment of 23 kg/ha. The grain yield obtained from an application of nitrogen rate of 46 and 69 kg/ha were not

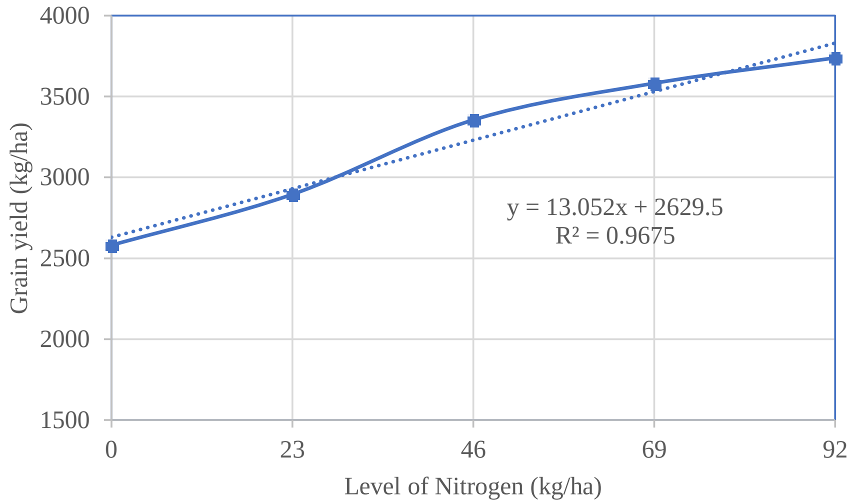

Figure 1. Response curve of wheat grain yield to five levels of nitrogen fertilizer.

statistically different (Table 4). The application of nitrogen increased considerably the grain yield of wheat tested as compared to the control (no nitrogen) treatment. This result is in agreement with a study conducted by Shirazi et al. (2014). The response curve of grain yield of wheat at five levels of nitrogen fertilizer is illustrated in Figure 1. The solid line in Figure 1 shows the grain yield of wheat for an application of different rates of nitrogen. And the dashed line shows the trend of grain yield with response to different rates of nitrogen.

Water use efficiency

The highest water use efficiency (0.79 kg/m^3) was obtained from the application of 50%ETc irrigation treatment and the lowest (0.5 kg/m^3) was obtained from 100%ETc. Among the nitrogen treatments, the highest water use efficiency (0.72 kg/m^3) was recorded at 92 kg/ha, which was statistically similar to 69 kg/ha. The lowest (0.5 kg/m^3) was obtained from plots which did not receive the application of nitrogen and was statistically similar to a 23 kg/ha nitrogen application (Table 4).

Partial budget analysis

Some main effects are significant but there are no significant interactions, since, economic analysis was conducted by means of separate budgets for each significant factor. The irrigation level treatments analyzed in Table 5a and nitrogen rate treatments analyzed in Table 5b. Among the irrigation treatments, the highest net benefit, 25839 Ethiopian birr (ETB) with a maximum marginal rate of return (MRR), was obtained from 100%ETc. Whereas, among the nitrogen treatments, the highest net benefit of 23900.08 ETB with the minimum MRR was recorded at 92 kg/ha. From this economic analysis, the results revealed that the maximum marginal rates of return were recorded from the application of 100%ETc irrigation and 46 kg/ha nitrogen fertilizer treatments. The lowest acceptable marginal rate of return (MRR) for farmers, according to CIMMYT (1988) experience, would be between 50 and 100%. In this study, 100% was considered as a minimum marginal rate of return for farmers to be recommended. With the exception of 92 kg/ha, all treatments yielded above the minimum acceptable marginal rate of return.

Conclusion

At the experimental field level, the impacts of a combination of nitrogen fertilizer rate and irrigation levels on wheat yield and yield contributing characteristics were investigated. Irrigation and nitrogen level had a substantial impact on wheat grain yield, while the interaction of nitrogen and irrigation level had no effect. From the study, it can be concluded that above ground biomass and grain yields of wheat were maximized by increasing the application rate of nitrogen fertilizer. The highest grain yield was obtained from the full application of irrigation 100%ETc and from an application of 92 kg/ha of nitrogen fertilizer. To obtain an optimum grain yield, net benefits and maximum marginal rate of return, a combination of nitrogen doses of 46 kg/ha and 100%ETc irrigation were the best treatments.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Table 5. factor by factor economic analysis of irrigation level and nitrogen rate treatments.

Irrigation levels	Grain yield (kg/ha)	Adjusted grain yield (kg/ha)	Gross income (ETB/ha)	Total variable cost (ETB/ha)	Net benefit (ETB/ha)	MRR (%)
			(a) Irrigation level			
50%ETc	2981.8	2683.62	42937.92	24871.29	18066.63	
75%ETc	3182.3	2864.07	45825.12	24896.19	20928.93	11497.04
100%ETc	3525.7	3173.13	50770.08	24931.08	25839.00	14070.56
			(b) Nitrogen rate			
0	2580.5	2322.45	37159.2	24820	12339.20	
23	2894.8	2605.32	41685.12	26400	15285.12	186.45
46	3354.7	3019.23	48307.68	27590	20717.68	456.52
69	3581.4	3223.26	51572.16	28760	22812.16	179.02
92	3738.2	3364.38	53830.08	29930	23900.08	92.98

Note: ETB (Ethiopian birr), MRR (Marginal rate of return), (at the time of this experiment 1 ETB is equivalent to 0.025 US dollar).

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