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Original Research Article

Effect of N Rates and Seeding Rates on Agronomic Efficiency, Partial Factor Productivity, Grain Yield, and Grain Quality of Wheat under Irrigation in West Shewa, Ethiopia

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Abstract: Recently, wheat research has been established in Ethiopia for irrigated areas with the goal of developing high-yielding, higher-quality wheat cultivars. Nonetheless, two of the most crucial production variables are the N rate and the seeding rate, both of which need for the determination of ideal rates. Hence, a field experiment was conducted to determine the optimum N rate and seeding rate for bread wheat production under irrigated conditions in West Shewa highland areas during 2020–21 on different soil types. A factorial combination of seeding rates (125, 150, and 175 kg/ha) and N rates (0, 23, 46, 89, and 111 kg/ha N) with consideration of 19 kg of N content in 100 kg NPS fertilizer that was applied uniformly for all experimental plots except for those without fertilizer (zero rate plot) at sowing. The experiment was laid out in an RCB design with three replications. Most of the interactions were non-significant for grain yield and other parameters, while the main effects of seeding rates and N rates showed a significant effect on grain yield and other parameters measured. The highest test weight, agronomic efficiency, and partial factor productivity were recorded for the black soil type. Agronomic efficiency showed an unpredictable trend, while partial factor productivity showed a decreasing trend with an increasing seeding rate and N rate. Depending on the agronomic and economic analysis results, it can be concluded that a seeding rate of 175 kg/ha and an N rate of 111 kg/ha were found to be optimal for the production of the wheat variety '*Kakaba*' under irrigation in the highlands of west Shewa.

Keywords: Black Soil, Efficiency, Irrigation, Nitrogen Fertilizer, Productivity, Red Soil, Seeding Rate.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the important grain crops produced worldwide and is a staple food for about one-third of the world's population. Its flour has many uses, but the main use is to make bread, providing more protein than any other cereal crop (Nuru and Taminaw, 2021). Bread wheat accounts for more than 90% of global wheat production and is grown on a substantial scale (over 100,000 ha) in more than 70 countries on five continents (Lantican *et al.*, 2005). Ethiopia is the second-largest producer of wheat in Sub-Saharan Africa, following South Africa (White, 2001).

According to EIAR (n.d), wheat is now one of the strategic crops in Ethiopia because of its role in food security as well as the import substitution and supply of raw materials for the agro-processing industry. It is produced by 4.6 million smallholder farmers on 1.8 million hectares of land, with an estimated annual production of 5.0 million tons at an average productivity of 2.8 t/ha, which has been consistently increasing for the last 25 years but is much lower than the world average of 3.3 t/ha. The gap between demand and supply is widening because of the rapidly increasing population, changing preferences towards wheat-based food items, and precarious wheat yield resulting from climate change and its consequent adverse effects such as drought, diseases, and insect pests. Nevertheless, while consumption is increasing at a rate of 9.0% per year, local production is increasing at only 7.8%, making the demand outstrip the supply.

To fill this gap, irrigated agriculture may provide a degree of self-sufficiency in food, or at least contribute to ensuring national food security, raising the

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rural population's living standard, creating employment opportunities, and reducing urbanization pressure. Many countries, including Ethiopia, apply irrigation as an important means of achieving food self-sufficiency. In dryland areas, irrigation intervention are believed to improve the productive potential from very low to better, reduce the risk of crop failure, and lead to multiple cropping (Eyasu, 2005). Yield increases of 100 to 400% have been recorded in developing countries through irrigation (FAO, 1997). On the other hand, it is suggested that irrigation development can meet its objectives if it is managed properly. Poor management may result in adverse effects. In many irrigation schemes in arid and semi-arid areas, crop yields are reduced and even land is abandoned due to environmental hazards such as waterlogging, salinity, erosion, and sedimentation of reservoirs (Eyasu, 2005). Moreover, to ensure wheat self-sufficiency, the major bottlenecks include the shortage of alternative varieties suitable for irrigated areas in Ethiopia and the associated agronomic practices for the suitable genotypes (EIAR, n.d).

One of the agronomic packages to be determined for the irrigated wheat production in Ethiopia is the seeding rate. Seeding rate plays a vital role in achieving optimum plant densities, which is a pre-requisite for increased seed yield. A higher seeding rate produces more plants per unit area, resulting in less intra-crop competition and thereby affecting yield and production costs. On the other hand, a lower seeding rate may reduce the yield drastically, while an optimum seeding rate is considered an important management factor for improving the yield of wheat. It is of particular importance in wheat production because it is under the farmers control in most cropping systems. In Ethiopia, seeding rates ranging from 125 to 175 kg/ha is recommended for different varieties of bread wheat under rain-fed conditions (Nuru and Taminaw, 2021).

The other package to be determined for the irrigated wheat production in Ethiopia is the nitrogen fertilizer rate. Low soil fertility, especially nitrogen deficiency, is one of the major constraints limiting wheat production in the Ethiopian highlands (Erkossa and Teklewold, 2009). The key role that fertilizer N has played in increasing crop yields and improving the quality of grain and straw in wheat is also widely recognized (Dressa *et al*., 2012). However, reports have shown that about 50% of applied N fertilizer remains unavailable to a crop due to temporary immobilization in soil organic matter or due to losses by leaching, erosion, nitrification, or volatilization (Zafar and Muhammad, 2007). The essential role of N in increasing crop production and its dynamic nature and property for N loss from the soil-plant system create a unique and challenging environment for its efficient management (Beyenesh *et al*., 2017). Hence, the efficient utilization of nitrogen by wheat and other cereals has become increasingly important because of the increased cost associated with the manufacturing and distribution of fertilizers. The increased use of nitrogen in agricultural production has raised concerns because of the risk of groundwater contamination. These concerns have advised the farmers to use nitrogen more efficiently. Nitrogen use efficiency may prove to be a mitigation alternative to reduce leaching (Li *et al*., 2007). Routes to the improvement of nitrogen use efficiency may be through the selection of an appropriate environment for the crop, an appropriate variety (Chaudhary and Mehmood, 1998), better management, and crop genetic improvement (Iqbal *et al*., 2012). Currently, the national recommended rate for rainfed wheat production is 100 kg/ha of NPS fertilizer and 200 kg/ha of urea for red soil and 100 kg/ha of NPS fertilizer and 250 kg/ha of urea for black soil (MoA, 2018). However, no recommendation has been made for irrigated wheat production.

In Ethiopia, irrigated agriculture is not well developed, and its impact on supporting food demand is very small. However, the Awash River basin supports most of the large-scale irrigated commercial farms and several smallholder-irrigated lands (Eyasu, 2005). Similarly, wheat research for irrigated areas has recently been established for the development of wheat varieties that can give high yields with better quality under irrigated conditions. In addition, the N fertilizer rate and seeding rate are among the most important production factors for irrigated wheat, which requires the identification of optimum rates. Hence, to ensure the availability of full agronomic packages for irrigated wheat production, the experiment was conducted to determine the economically optimum N fertilizer rate and seeding rate applied for higher yield and quality of bread wheat under irrigated areas.

MATERIALS AND METHODS

Treatments and Experimental Design

An experiment was conducted during the off-season of 2020/21 in two soil types (for red soil Duffa irrigation site in Wolmera district and for black/*vertisol* Ejersa lafo irrigation site in Ejere district) on farmers' fields that were selected as representatives in terms of agricultural production, specifically, on their irrigation potential. The experiment comprised 15 treatments in factorial combination of three seeding rates (125, 150, and 175 kg/ha) and five rates of N fertilizer (0, 23, 46, 89 and 111 kg/ha N), out of which 23, 46, 69 and 92 kg N/ha were obtained from urea at the rate of 0, 50, 100, 150, and 200 kg/ha Urea for the 2nd, 3rd, 4th, and 5th levels, respectively, while 19 kg/ha N was obtained from 100 kg NPS/ha (containing 19% N, 38% P_2O_5 and 7% S) that was uniformly applied for experimental plots except for without fertilizer (zero rate plot). Accordingly, 0, 23+19, 46+19, 69+19, and 92+19 N kg/ha were used for 5 N levels (Table 1). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The gross plot size of 15 m^2 (3 m × 5 m) with a ridge-to-ridge distance of 60 cm and five ridge rows was used. The spacing between ridge rows, plots, and blocks was 0.6, 1, and 2 m, respectively.

Table 1: The combination of seed rate and N fertilizer rates of experimental treatments

Treatment no.	**Treatment combination**		**Sources of N**		
	Seeding rate (kg/ha)	**Fertilizer treatments**	**N in 100 kg NPS**	**N in Urea**	**Total N**
1	125	0 kg Urea + 0 NPS kg N/ha	0	0	0
2	125	50 kg Urea + 100 NPS kg N/ha	19	23	42
3	125	100 kg Urea + 100 NPS kg N/ha	19	46	65
4	125	150 kg Urea + 100 NPS kg N/ha	19	69	88
5	125	200 kg Urea + 100 NPS kg N/ha	19	92	111
6	150	0 kg Urea + 0 NPS kg N/ha	0	0	0
7	150	50 kg Urea + 100 NPS kg N/ha	19	23	42
8	150	100 kg Urea + 100 NPS kg N/ha	19	46	65
9	150	150 kg Urea + 100 NPS kg N/ha	19	69	88
10	150	200 kg Urea + 100 NPS kg N/ha	19	92	111
11	175	0 kg Urea + 0 NPS kg N/ha	0	0	0
12	175	50 kg Urea + 100 NPS kg N/ha	19	23	42
13	175	100 kg Urea + 100 NPS kg N/ha	19	46	65
14	175	150 kg Urea + 100 NPS kg N/ha	19	69	88
15	175	200 kg Urea + 100 NPS kg N/ha	19	92	111

Experimental Procedure

The land was plowed using an oxen (traditional) plow system. Irrigation channels 1 m wide were used in between the replications for irrigation of individual plots independently and equally until the crop grew up to the maturity stage. All the recommended (100 kg/ha) NPS fertilizer was applied uniformly at sowing except the control (zero) plots. Nitrogen was applied to the plants in consideration of splits (i.e., 1/3 at sowing and 2/3 at tillering), respectively. The crop was irrigated at a 7–10-day interval, depending on the soil moisture content and type of soil. The bread wheat variety "*Kakaba*" was used to conduct the experiment that was selected based on its adaptation and better performance in yield. Other necessary agronomic practices were applied uniformly to all plots as needed. Data were collected from the central three ridge rows.

Soil Sampling and Analysis

One representative composite soil sample was taken at a depth of 0–30 cm from five randomly selected spots diagonally across the experimental field using an auger before planting from each soil type (red and black soil). The sample was analyzed for selected physio-chemical properties, namely soil pH which was measured in water with a solid-to-liquid ratio of 1:2.5 as described by Tekalign (1991), organic carbon, which was determined by using the Walkley and Black wet digestion methods as described by Tekalign (1991), total N, which was measured using the Kjeldhal method as described by Berhanu (1980) and available P which was measured using the Olsen method as described by Cottenie (1980).

Data Collected

Plant height was measured in cm from the ground level to the tip of the spike, excluding the awns at physiological maturity, from ten randomly selected mother plants (main shoots). The number of total tillers per plant was counted from the demarcated ten plants in the net plot area and expressed as the average number of total tillers per plant. The number of productive tillers per plant was counted from the demarcated ten plants in the net plot area by excluding non-productive tillers and expressed as the average number of productive tillers per plant. Spike length was measured in cm from the base to the tip of the spike, excluding awns from ten randomly selected mother plants (main shoots). The number of spikelet per spike was taken as the average number of spikelet per spike of 10 randomly selected spikes at harvest and expressed as the average number of spikelet per spike. The number of kernels per spike was taken as the average number of kernels per spike of 10 randomly chosen plants at harvest and expressed as the average number of kernels per plant. Thousand-kernel weight (g) was determined as the weight of 1000 seeds sampled from the harvested plot area using a sensitive balance. Grain yield (t/ha) was determined by weighing clean threshed seeds from the net plot area and was adjusted to 12.5% grain moisture, which was determined using a grain moisture tester. Hectoliter weight (HL) (kg/hl) or test weight was determined as described by Buerstmayr *et al*., (2007).

Data Analysis

Data were analyzed by analysis of variance (ANOVA) following the procedure of Gomez and Gomez (1984) using statistical procedures in SAS version 9.1.2. Treatments showing significant differences were subjected to Fisher's least significant difference (LSD) and Duncan's multiple range tests for mean separation at the 5% level of significance. While combining the two soil types, homogeneity of variance was also evaluated using Bartlett's test as described by Gomez and Gomez (1984). Both the combined and separate analyses of variance are presented in the result section for reference.

Nitrogen Use Efficiency

The different nitrogen utilization efficiencies (agronomic efficiency and partial factor productivity) were calculated from the established formulae of Dobermann (2007) as below:

Agronomic Efficiency (AE)

Is described as the economic production obtained per unit of nitrogen applied (Chapter 1, 2014) and was calculated as AE=(Y-Y0)/F, where Y is the grain yield in the fertilized plot (kg), Y_0 is the grain yield in the un-fertilized plot (kg), and F is the quantity of nutrient applied (kg).

Partial factor productivity (PFP)

Is a simple production efficiency expression calculated in units of crop yield per unit of nutrient applied (Chapter 1, 2014). It is easily calculated for any farm that keeps records of inputs and yields and is calculated as PFP = Y/F, where Y = yield of harvested portion of crop with nutrient applied and F = amount of nutrient applied.

Economic Analysis

The economic analysis was carried out using the methodology described in CIMMYT (1988), in which prevailing market prices for inputs at planting and for outputs at harvesting were used. Furthermore, all costs and benefits were based on the average of the two soil types. Accordingly, the variable costs included the cost of seed during sowing (June) and were estimated at 30.00 ETB per kg; the price of the grain yield of the bread wheat variety "*Kakaba*" was estimated at 29 Ethiopian Birr (ETB) per kg; and the price of nitrogen fertilizer was estimated at 35.49 ETB per kg. The mean grain yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers would expect to get from the same treatment. In order to use the marginal rate of return (MRR) as a basis for fertilizer and seeding rate recommendations, the minimum acceptable rate of return was set at 100% (CIMMYT 1988). A treatment having a higher total cost that varies and a lower net benefit than the immediately preceding treatment with a lower total cost that varies and a higher net benefit was considered to be dominated and was eliminated from further analysis.

RESULTS AND DISCUSSION

Soil Physicochemical Properties of the Experimental Site

As presented in Table 2, the pre-plant soil analysis results of the study sites (soil types) revealed that the soil pH was found to be neutral on red soil and strongly alkaline on black soil, as rated by Tekalign (1991). Further, the analysis of the soil organic carbon found it to be low on black soil to moderate on red soil, as rated by Tekalign (1991). The total N percent in the experimental field was found to be low on black soil to medium on red soil, as rated by Berhanu (1980). Finally, the available phosphorous in the experimental soils ranged from 12.797 ppm on red soil to 15.984 ppm on black soil and was found to be medium on both soil types, as rated by Cottenie (1980).

Table 2: Pre-planting soil analysis results of the soil types

Parameter	Red soil	Black soil	Mean value	Rating	Rated by
pH (1:2.5 H_2O)	6.610	8.220	7.415	Neutral on red soil type to strongly alkaline on black soil type	Tekalign (1991)
OC (%)	1.560	1.050	1.305	Low on black soil type to moderate on red soil type	Tekalign (1991)
TN (%)	0.150	0.072	0.111	Low on black soil type to medium on red soil type	Berhanu (1980)
Av. P (ppm)	12.797	15.984	14.391	Medium on both soil types	Cottenie (1980)

pH= is the measure of soil acidity or alkalinity, OC = organic carbon, TN = total nitrogen; Av. P=available phosphorus

Source: Holeta agricultural research center laboratory result

Growth Parameters

In this paper, the results of the combined analysis over soil types as well as separate analysis results for each soil type are presented for each measured parameter.

Plant Height

From the combined analysis, the soil type significantly affected plant height, and the tallest plants (79.9 cm high) were observed in the red soil type (Table 3). The main effect of seeding rate showed a non-significant effect for the combined mean and on black soil type, while it showed a significant effect on red soil type. Accordingly, the tallest plants (81.5 cm high) were observed at a seeding rate of 175 kg/ha on red soil, though not significantly different from the seeding rate of 125 kg/ha (Table 3). In a similar experiment, Iqbal *et al.*, (2012) reported taller plants at a seed rate of 150 kg/ha than at a seed rate of 175 kg/ha. The main effect of nitrogen showed a significant effect on the combined mean and on both soil types (Table 3). The tallest plants (76.8, 83.8, and 72.4 cm high) were observed at N levels of 88, 88, and 111 kg/ha for the combined red and black soil types, respectively, while the smallest plants were recorded at zero levels of nitrogen for the combined mean and both soil types (Table 3). Iqbal *et al.*, (2012) obtained taller plants at a nitrogen level of 125 kg/ha, followed by 100 and 150 kg/ha, while the shortest plants were at a nitrogen level of zero. In our experiment, only soil type by nitrogen level showed a significant effect on plant height, where the plants in the red soil type were significantly taller than the plants in the black soil type at all nitrogen levels (Table 4). In a similar results, Biri *et al*., (2023), reported a significant seeding rate by nitrogen level interaction across five low land locations for irrigated wheat in the Oromia region of Ethiopia, and the tallest plants (73.3 cm) were observed at a seeding rate of 175 kg/ha + 46 kg N/ha, though not significantly different from many of the combinations, while the smallest plants (68.9cm) were recorded at a seeding rate of 125 kg/ha + 0 kg N/ha, though not significantly different from many of the combinations.

Number of Total Tillers per Plant

From the combined analysis, the soil type significantly affected the number of total tillers, and the higher number (8.1) was recorded for the black soil type (Table 3). The main effect of seeding rate showed a non-significant effect on the number of total tillers for the combined mean and both soil types (Table 3). In line with this result, neither the main effects nor the combined mean effects of seeding rate showed a significant influence on total tiller per plant (Biri *et al*., 2023). The main effect of nitrogen showed a significant effect on the number of total tillers for the combined mean and on black soil type (Table 3). Accordingly, a higher number of total tillers (8.2 and 9.2) were observed at N levels of 65 kg/ha for both the combined mean and black soil types (Table 3). Though not significant, in similar fashion, the highest number of total tillers (7.2) was recorded at the nitrogen level of 65 kg/ha on the red soil type too (Table 3), while the lowest were recorded at the lowest nitrogen level for the combined mean and both soil types (Table 3). In this case, nitrogen fertilization also contributed to increasing tiller production up to an optimum level, above which the decrease in tillers might be due to the competition for space (Islam *et al*., 2002). In line with our result, Iqbal *et al*., (2012) reported a statistically significant difference among nitrogen levels for numbers of tillers per unit area, obtaining maximum numbers of tillers from the highest nitrogen level (125 kg/ha) and the lowest from the zero-nitrogen level. In our experiment, none of the interactions significantly affected total tillers.

Number of Productive Tillers per Plant

From the combined analysis, the soil type significantly affected the number of productive tillers, and the higher number (5.3) was recorded for the black soil type (Table 3). The main effect of seeding rate showed a non-significant effect on the number of productive tillers for the combined mean and both soil types (Table 3). In line with this result, neither the main effects nor the combined mean effects of seeding rate showed a significant influence on productive tillers per plant (Biri *et al*., 2023). On the other hand, the main effect of nitrogen showed a significant effect on the number of productive tillers for the combined mean and on both soil types (Table 3). Accordingly, a higher number of productive tillers (8.2 and 9.2) were observed at N levels of 65 kg/ha for both the combined mean and black soil types (Table 3). Though not significant, in similar fashion, the highest number of productive tillers (7.2) was recorded at the nitrogen level of 65 kg/ha on the red soil type (Table 3), while the lowest were recorded at the lowest nitrogen level for the combined mean and both soil types (Table 3). In this experiment, none of the interactions significantly affected productive tillers.

Spike Length

From the combined analysis, the soil type significantly affected spike length, and the higher number (8.6) was recorded for the red soil type (Table 3). The main effect of seeding rate showed a significant effect on the spike length for the combined mean and red soil type (Table 3). Accordingly, the highest spike length (8.1 and 9.1 cm) was recorded at a seeding rate of 125 kg/ha for the combined mean and red soil type, respectively (Table 3). Contrary to this result, Iqbal *et al*., (2012) reported a maximum spike length of 12.81 cm at a seeding rate of 150 kg/ha that was on par with 175 kg/ha (12.60 cm), while the shortest spike length was 12.07 cm at a seeding rate of 125 kg/ha. The main effect of nitrogen showed a significant effect on the spike length for the combined mean and on both soil types (Table 3). Accordingly, the tallest spikes (9.2 and 8.3 cm) were observed at N levels of 88 kg/ha for the combined mean and red soil type, respectively, while the taller spike (7.6 cm) was recorded at N levels of 111 kg/ha for the black soil type. The shortest spike length was recorded at zero level for the combined mean and both soil types (Table 3). Iqbal *et al*., (2012) obtained significantly longer spikes at a nitrogen level of 125 kg/ha, followed by 150 kg/ha and 100 kg/ha, while the shorter spikes were recorded at a nitrogen level of zero. Only soil type by nitrogen level interaction showed a significant effect on spike length, where the spikes in red soil were significantly taller than the spikes in black soil at all nitrogen levels (Table 4).

Table 3: Main effects of N rates and seeding rates on some growth parameters of bread wheat under irrigation in West Shewa black and red soil types and combined mean

Treatment	**Plant height (cm)**			**Number of total tillers**			**Number of productive tillers**			**Spike length (cm)**		
	Red soil	**Black soil**	**Comb ined**	**Red soil**	**Black soil**	**Comb ined**	**Red soil**	**Black soil**	**Comb ined**	**Red soil**	**Black soil**	**Comb ined**
Soil type (St)												
Red soil	-	-	79.9a	-	-	6.7b	-	-	4.9b	-	-	8.6a
Black soil	-	-	67.5b	-	-	8.1a	-	-	5.3a	-	-	6.9b
LSD (%)	-	-	1.314	-	-	0.465	-	-	0.318	-	-	0.290

Treatment	**Plant height (cm)**			**Number of total tillers**			**Number of productive tillers**			**Spike length (cm)**		
	Red soil	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**
Seeding rate (Sr) (kg/ha)												
125	80.2ab	67.1	73.6	7.0	8.1	7.6	5.1	5.5	5.3	9.1a	7.1	8.1a
150	78.1b	67.4	72.8	6.5	8.3	7.4	4.8	5.5	5.1	8.3b	6.9	7.6b
175	81.5a	67.9	74.7	6.6	8.0	7.3	4.9	5.0	4.9	8.5ab	6.7	7.6b
LSD (%)	2.5	ns	ns	ns	ns	ns	ns	ns	ns	0.6	ns	0.355
Nitrogen rate (N) (kg/ha)												
0	74.1c	59.9d	67.0c	6.3	7.3bc	6.8b	4.4	4.8bc	4.6b	8.0c	5.8d	6.9c
42	82.3ab	66.9c	74.6b	6.6	7.1c	6.8b	4.7	4.6c	4.6b	8.8ab	6.5c	7.6b
65	79.9b	68.4bc	74.2b	7.2	9.2a	8.2a	5.5	5.9a	5.7a	8.8ab	7.0b	7.9ab
88	83.8a	69.8ab	76.8a	6.9	8.4ab	7.7a	5.5	5.4ab	5.5a	9.2a	7.4ab	8.3a
111	79.6b	72.4a	76.0ab	6.6	8.6a	7.6a	4.6	5.8a	5.2a	8.4bc	7.6a	8.0ab
LSD (%)	3.28	2.70	2.08	ns	1.21	0.74	0.68	0.77	0.50	0.77	0.54	0.46
Mean	80	67.5	73.7	6.7	8.1	7.428	4.9	5.3	5.11	8.6	6.9	7.755
CV (%)	4.3	4.14	4.22	14	15.3	14.83	14	15.1	14.70	9.2	8.09	8.84
Sr*N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
St*Sr	-	-	ns	-	-	ns	-	-	ns	-	-	ns
St*N	-	-	3.08	-	-	ns	-	-	ns	-	-	0.64
St*Sr*N	-	-	ns	-	-	ns	-	-	ns	-	-	ns

Table 4: Two-way interaction effects of N rates and seeding rates on plant height and spike length of bread wheat under irrigation in West Shewa, combined over soil types

Soil type	**N rate (kg/ha)**				
	0	**42**	**65**	**88**	**111**
Plant height (cm)					
Red soil	74.1c	82.3ab	79.9b	83.8a	79.6b
Black soil	59.9f	66.9e	68.4e	69.8de	72.4cd
Difference	14.2	15.4	11.5	14.0	7.2
Spike length (cm)					
Red soil	8.0cd	8.8ab	8.8ab	9.2a	8.4bc
Black soil	5.8g	6.5f	7.0ef	7.4de	7.6de
Difference	2.2	2.3	1.8	1.8	0.8

Number of Spikelet/Spike

From the combined analysis, the number of spikelet/spike was significantly affected by the soil type, and the higher number (18.2) was recorded for the red soil type (Table 5). The main effect of seeding rate showed a non-significant effect on the number of spikelet per spike for the combined mean and both soil types (Table 5). Similarly, Iqbal *et al.*, (2012) reported a non-significant effect of seeding rate on the number of spikelet per spike. On the other hand, the main effect of nitrogen showed a significant effect on the number of spikelet per spike for the combined mean and on black soil type (Table 5). Accordingly, the higher number of spikelet (16.6 and 14.6) were observed at the N levels of 88 and 111 kg/ha for the combined mean and black soil type, respectively, while the lowest were recorded at the lowest nitrogen levels for the combined mean and both soil types (Table 5). Iqbal *et al.*, (2012) reported a maximum number of spikelet under a nitrogen level of 125 kg/ha, followed by 100 kg/ha, 150 kg/ha, and 175 kg/ha. Only soil type by nitrogen level showed a significant effect on the number of spikelet per spike, where the number of spikelet per spike in red soil was significantly higher than the number of spikelet per spike in black soil at all nitrogen levels (Table 6).

Number of Kernels per Spike

The number of grains per spike determines the potential of a wheat spike, which is an important yield component of grain yield (Shah *et al.*, 2016). From the combined analysis, the soil type significantly affected the number of kernels per spike, and the higher number (46.2) was recorded in the red soil (Table 5). The main effect of seeding rate showed a non-significant effect on the number of kernels per spike for the combined mean and both soil types (Table 5). In contrast to this result, Iqbal *et al.*, (2012) reported the significantly highest number of kernels per spike (45.27) at the seeding rate of 150 kg/ha, which was on par with the number of kernels per spike at the seeding rate of 175 kg/ha (44.53). Similarly, more kernels per spike (62) were produced when plots were seeded with a 120 kg/ha seeding rate, whereas a smaller number of kernels per spike (54) were noted with a 60 kg/ha seeding rate (Shah *et al.*, 2016). On the other hand, the main effect of nitrogen showed a significant effect on the number of kernels per spike for the combined mean and on black soil type (Table 5). Accordingly, the higher number of kernels per spike (44.9 and 44.1) were observed at the N levels of 88 and 111 kg/ha for the combined mean and black soil type, respectively, while the lowest were recorded at the lowest (zero) nitrogen levels for the combined mean and both soil types (Table 5). In agreement with this result, Iqbal *et al.*, (2012) reported the significantly highest number of grains per spike at a nitrogen level of 125 kg/ha, followed by 100 kg/ha and 150 kg/ha, while the least number of kernels per spike (38.44) was recorded at a zero level of nitrogen, justifying that the increased number of kernels per spike might be due to an optimum crop stand with better nutrition. Only soil type by nitrogen level interaction showed a significant effect on the number of kernels per spike, where the number of kernels per spike in red soil was significantly higher than the number of kernels per spike in black soil at all nitrogen levels (Table 6).

1000-Grain Weight

From the combined analysis, the soil type significantly affected 1000-grain weight, and the highest (35.13g) was recorded from the red soil (Table 5). The main effect of seeding rate showed a significant effect on the 1000-grain weight for the combined mean and red soil type (Table 5). The highest 1000-grain weight (34.91 and 36.05 cm) was recorded at a seeding rate of 175 kg/ha for the combined mean and red soil type, respectively (Table 5). Also, Iqbal *et al*., (2012) reported the heaviest 1000-grain weights (47.28 g) and (47.17 g) at a seeding rate of 150 kg/ha and 175 kg/ha. Similarly, the heavier grains (43.15 g) were produced at the second highest seeding rate (120 kg/ha), while lighter grains (39.30 g) were recorded at the lowest seeding rate (60 kg/ha) (Shah *et al*., 2016). On the other hand, the main effect of nitrogen showed a non-significant effect on 1000-grain weight for the combined mean and on both soil types (Table 5). In contrast, Iqbal *et al.*, (2012) obtained the significantly heaviest 1000-grain weights at a nitrogen level of 125 kg/ha, followed by 100 kg/ha and 150 kg/ha, while the lowest 1000-grain weight (41.17 g) was obtained at a nitrogen level of zero. None of the interactions significantly affected 1000-grain weight (Table 5).

Grain Yield

From the combined analysis, the soil type (Table 5) did not significantly affect grain yield, whereas the main effect of seeding rate showed a significant effect on the grain yield for the combined mean and red soil type (Table 5). Significantly, the highest grain yield (2.13 t/ha) was recorded at a seeding rate of 175 kg/ha for the combined mean and red soil type, respectively (Table 5). Though not significant, a similar grain yield (2.13 t/ha) was recorded at a seeding rate of 175 kg/ha on the black soil type too (Table 5). In line with this result, Iqbal *et al*., (2012) obtained significantly the highest grain yield of wheat (4242.07 kg/ha) at a seeding rate of 150 kg/ha, while a lower grain yield (3949.13 kg/ha) was recorded at a seeding rate of 125 kg/ha. Similarly, maximum grain yield (3160 kg/ha) was produced when plots were seeded with 120 kg/ha (the second highest seed rate), while minimum grain yield (2437 kg/ha) was noted with a 60 kg/ha seeding rate (the lowest seed rate) (Shah *et al*., 2016). The main effect of nitrogen showed a significant effect on the grain yield for the combined mean and on both soil types (Table 5). Accordingly, the higher grain yields (2.54, 2.38, and 2.69 t/ha), respectively, were observed at an N level of 111 kg/ha for the combined mean and both soil types, while the lowest was recorded for the unfertilized plot for all (Table 5). In a similar experiment, the highest grain yield (4626 kg/ha) was observed at a nitrogen level of 125 kg/ha, followed by 100 kg/ha (4477 kg/ha), while the lowest grain yield (3193 kg/ha) was recorded at a nitrogen level of zero [13]. Only soil type and nitrogen interaction showed a significant effect on grain yield (Table 6). The highest grain yield was recorded at the combination of black soil with an N rate of 111 kg/ha, followed by the combination of black soil with an N rate of 88 kg/ha, which indicates that black soil was more productive than red soil. Moreover, the combination of red soil with the highest N rate also produced a higher grain yield. Similarly, red soil type produced slightly higher grain yield at lower N levels (0 and 42 N kg/ha), while black soil type produced a higher yield at higher N levels than red soil type (Table 6).

Table 5: Main effects of N rates and seeding rates on grain yield and some yield components of bread wheat under irrigation in West Shewa black and red soil types and combined mean

Treatment	**Number of spikelets per spike**			**Number of kernels per spike**			**1000-grain weight (g)**			**Grain yield (t/ha)**		
	Red soil	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**
Soil type (St)												
Red soil	-	-	18.2a	-	-	46.2a	-	-	35.13a	-	-	1.97
Black soil	-	-	13.2b	-	-	37.6b	-	-	33.66b	-	-	2.05
LSD (%)	-	-	0.627	-	-	2.681	-	-	0.682	-	-	**ns**
Seeding rate (Sr) (kg/ha)												
125	18.8	13.6	16.2	46.8	40.3	43.5	34.08b	33.37	33.73b	1.84b	2	1.92b

Treatment	**Number of spikelets per spike**			**Number of kernels per spike**			**1000-grain weight (g)**			**Grain yield (t/ha)**		
	Red soil	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**	**Red soil**	**Black soil**	**Combined**
150	17.8	13.4	15.6	45.7	36.2	40.9	35.27ab	33.85	34.56ab	1.94ab	2.03	1.98b
175	18	12.7	15.4	46.1	36.3	41.2	36.05a	33.76	34.91a	2.13a	2.13	2.13a
LSD (%)	ns	ns	ns	ns	ns	ns	1.248	ns	0.836	**0.207**	ns	**0.134**
Nitrogen rate (N) (kg/ha)												
0	17.3	11.2c	14.2b	43.5	28.4c	35.9b	35.29	33.07	34.18	1.55c	1.13e	1.34d
42	18.7	13.1b	15.9a	46.2	36.0b	41.1a	34.98	33.6	34.29	1.87b	1.85d	1.86c
65	17.8	13.7ab	15.7a	47.2	38.8ab	43.0a	35.36	33.58	34.47	2.06b	2.16c	2.11b
88	19.5	13.7ab	16.6a	49.1	40.6ab	44.9a	35.02	34.11	34.57	1.98b	2.43b	2.20b
111	17.7	14.6a	16.1a	45.2	44.1a	44.6a	35.02	33.96	34.49	2.38a	2.69a	2.54a
LSD (%)	ns	1.074	0.992	ns	7.266	4.239	ns	ns	ns	**0.267**	**0.23**	**0.173**
Mean	18.2	13.2	15.71	46.2	37.6	41.9	35.13	33.66	34.4	1.97	2.05	2.01
CV (%)	9.8	8.4	9.45	10.59	20.02	15.15	4.75	4.64	4.7	14.06	11.62	12.85
Sr*N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
St*Sr	-	-	ns	-	-	ns	-	-	ns	-	-	ns
St*N	-	-	1.4	-	-	5.97	-	-	ns	-	-	0.242
St*Sr*N	-	-	ns	-	-	ns	-	-	ns	-	-	ns

Table 6: Two-way interaction effects of N rates and seeding rates on number of spikelets per spike, number of kernels per spike, and grain yield of bread wheat under irrigation in West Shewa black and red soil types

Soil type	**N rate (kg/ha)**				
	0	**42**	**65**	**88**	**111**
Number of spikelets per spike					
Red soil	17.3b	18.7ab	17.8b	19.5a	17.7b
Black soil	11.0d	13.1c	13.5c	13.8c	14.5c
Difference	6.3	5.6	4.3	5.7	3.2
Number of kernels per spike					
Red soil	43.5abc	46.2ab	47.2ab	49.1a	45.2abc
Black soil	28.4e	36.0d	38.8cd	40.6bcd	44.1abc
Difference	15.1	10.2	8.4	8.5	1.1
Grain yield (t/ha)					
Red soil	1.55f	1.87e	2.06de	1.98de	2.38bc
Black soil	1.13g	1.85e	2.16cd	2.43b	2.69a
Difference	0.42	0.02	-0.1	-0.45	-0.31

The Grain Quality of Wheat

Hectoliter Weight/Test Weight

The hectoliter weight or test weight is regarded as the most common and easiest way of quantifying wheat. It is a measure of density or specific weight and is thought to be an indicator of grain quality, particularly potential extract yield (Burke *et al*., 2021). Normally, the higher the test weight, the higher the quality, and the lower the test weight, the lower the quality, and grain quality decreases dramatically as grain deteriorates (Bern and Brumm, 2009). The test weight of grain is affected by many factors, including moisture contents, frost damage, crop maturity, growing and harvesting conditions, drying conditions, fine material, degree of kernel damage, and variety (Yasothai, 2020).

From the combined mean, the soil type (as shown in Table 7) significantly affected the hectoliter weight, while the main effects of seeding rate and nitrogen rate showed a non-significant effect on the hectoliter weight for the combined mean and for both soil types (Table 7). From the combined mean, the highest hectoliter weight (72.83 kg/hl) was recorded for the black soil type (Table 7). Accordingly, it can be concluded that the black soil could be more favorable for producing quality seeds. Only seeding rate by nitrogen rate interaction showed a significant effect on the hectoliter weight on black soil type, where the highest (73.93 kg/hl) was recorded at the combination of 125 kg/ha seed rate with 111 kg N/ha and 150 kg/ha seed rate with 88 kg N/ha, but this was not significantly different from many of the combinations (Table 8).

In general, as stated above, the hectoliter weight is a common measure of grain quality in wheat; it measures the weight per unit volume of grain and is positively associated with nutritional value and milling quality (Pixley, 1990). According to the CODEX STAN 199 (1995), the minimum acceptable test weight for wheat is at least 68 kg/hl. Accordingly, the results of the present experiment demonstrated an acceptable test weight for both soil types, seeding rate, and nitrogen fertilizer levels, but more preferably for black soil type (Table 7).

Table 7: Main effects of N rates and seeding rates on hectoliter weight of bread and wheat under irrigation in West Shewa black and red soil types

Treatment	Hectoliter weight (kg/hl)		
	Red soil	Black soil	Combined
Soil type (St)			
Red soil	-	-	68.58b
Black soil	-	-	72.83a
LSD (%)	-	-	0.689
Seeding rate (kg/ha)			
125	68.01	72.59	70.30
150	69.40	72.71	71.06
175	68.35	73.19	70.77
LSD (%)	ns	ns	ns
Nitrogen rate (N) (kg/ha)			
0	68.88	71.71	70.29
42	68.58	72.96	70.77
65	68.61	73.10	70.85
88	68.00	73.71	70.85
111	68.86	72.68	70.77
LSD (%)	ns	ns	ns
Mean	68.58	72.83	70.707
CV (%)	2.61	2.00	2.30
Sr*N	ns	2.440	ns
St*Sr	-	-	ns
St*N	-	-	ns
St*Sr*N	-	-	ns

Table 8: Two-way interaction effects of N rates and seeding rates on hectoliter weight of bread wheat under irrigation in West Shewa black soil type

N (kg/ha)	Seeding rate (kg/ha)		
	125	150	175
0	69.00c	73.57a	72.57ab
42	72.93ab	73.37a	72.57ab
65	73.67a	72.20ab	73.43a
88	73.40a	73.93a	73.80a
111	73.93a	70.5bc	73.60a

Nitrogen Use Efficiency Parameters

Agronomic Efficiency (AE)

It helps to address the question of how much productivity improvement was gained by using nutrient input (Chapter 1, 2014). The analysis of variance indicated that the main effect of the soil type, seeding rate (from the combined mean), and seeding rate on both soil types showed a significant effect on agronomic efficiency (Table 9). On the other hand, none of the interactions showed a significant effect on agronomic efficiency, either for the combined mean or for both soil types (Table 9). From the combined mean, the highest agronomic efficiency (15.54 kg/kg) was obtained from the black soil type (Table 9). On the other hand, the highest agronomic efficiencies (13.73, 9.81, and 17.65 kg/kg) were recorded at a seeding rate of 150 kg/ha for the combined mean, red soil type, and black soil type, respectively (Table 9). Though not significant, the agronomic efficiency of applied N showed a decreasing trend on black soil types, an unpredictable trend on red soil types, and a combined mean with increasing levels of applied N (Table 9). Contrary to our result, a decreasing trend in nitrogen agronomic efficiency was reported with increasing N levels from 30 to 120 kg/ha (Arduini *et al*., 2006). In addition, Fresew *et al*., (2018) reported a decreasing trend in the agronomic efficiency of applied N with increasing levels of N for all the varieties tested. In another experiment, agronomic efficiency increased in response to added N from 23 up to 46 kg N/ha but decreased progressively as the rate increased from 46 to 92 kg/ha, justifying that increased AE at the rate of 46 kg N/ha could be due to the high yield increment per unit of N applied (Beyenesh *et al*., 2017).

Partial Factor Productivity (PFP)

It helps to address the question: How productive is this cropping system in comparison to its nutrient input? (Chapter 1, 2014). The analysis of variance indicated that the main effect of the soil type and seeding rate (from the combined mean) and the main effect of seeding rate showed a significant effect on partial factor productivity on the red soil type, while the main effect of N rate showed a significant effect on partial factor productivity for the combined mean and on both soil types (Table 9). Likewise, the interaction of seeding rate with N rate revealed a significant effect on partial factor productivity for the combined mean and on red soil type (Table 10). From the combined mean, the highest partial factor productivity (32.30 kg/kg) was obtained for black soil (Table 9). Similarly, the highest partial factor productivity (32.98 and 33.13 kg/kg) was recorded at a seeding rate of 175 kg/ha for the combined mean and red soil type, respectively (Table 9). In general, partial factor productivity showed an increasing trend, while seed rate increased from 125 to 175 kg/ha. On the other hand, the highest partial factor productivity (44.31, 44.54, and 44.08 kg/kg) was recorded at an N rate of 42 kg/ha for the combined mean, red, and black soil types, respectively (Table 9). Generally, the partial factor productivity of applied N showed a decreasing trend for the combined mean and on both soil types with an increasing level of applied N (Table 9). In agreement with this result, Panayotova and Kostadinova (2016) reported a decreasing trend of PFP from 69.8 to 25.7 kg/kg as applied N increased from 60 to 120 kg/ha. Only seeding rate by nitrogen rate showed a significant interaction effect on partial factor productivity, where the highest (48.38 and 52.54 kg/kg) was recorded for the combined mean and red soil type, respectively, at the combination of 175 kg/ha seeding rate with 42 kg N/ha (Table 10). As reviewed and reported by Panayotova and Kostadinova (2016), partial factor productivity is used as a long-term indicator of trends. Higher levels indicate a higher amount of nutrient input, while lower levels indicate a productivity-limiting deficit. Typical values of the partial factor productivity of nitrogen are about 40–80 kg/kg. Rates higher than 60 kg/kg are used in very efficiently managed systems at low nitrogen rates or low soil nitrogen supply. PFP-N (often-called nitrogen use efficiency or NUE) is changed from a high value at low N fertilization to lower values by increasing the nitrogen levels. Accordingly, our results fell within the stated range.

Table 9: Main effects of N rates and seeding rates on agronomic efficiency (AE) and partial factor productivity (PFP) of bread wheat under irrigation in West Shewa black and red soil types

Treatment	AE (kg/kg)			PFP (kg/kg)		
	Red soil	Black soil	Combined	Red soil	Black soil	Combined
Soil type (St)						
Red soil	-	-	7.37b	-	-	30.07b
Black soil	-	-	15.54a	-	-	32.30a
LSD (%)	-	-	**1.991**	-	-	**1.896**
Seeding rate (Sr) (kg/ha)						
125	7.91ab	15.88ab	11.89a	27.81b	31.61	29.71b
150	9.81a	17.65a	13.73a	29.27b	32.44	30.86ab
175	4.38b	13.09b	8.74b	33.13a	32.84	32.98a
LSD (%)	**3.535**	**3.561**	**2.438**	**3.583**	ns	**2.322**
Nitrogen rate (N) (kg/ha)						
0	-	-	-	-	-	-
42	8.24	17.28	12.76	44.54a	44.08a	44.31a
65	8.31	15.97	12.14	31.77b	33.28b	32.52b
88	5.21	14.78	10.00	22.54c	27.57c	25.05c
111	7.71	14.12	10.92	21.44c	24.26c	22.85c
LSD (%)	ns	ns	ns	**4.137**	**3.650**	**2.681**
Mean	7.37	15.54	11.45	30.07	32.30	31.18
CV (%)	56.66	27.07	36.59	14.07	11.56	12.80
Sr*N	ns	ns	ns	**	ns	*
St*Sr	-	-	ns	-	-	ns
St*N	-	-	ns	-	-	ns
St*Sr*N	-	-	ns	-	-	ns

Table 10: Two-way interaction effects of N rates and seeding rates on partial factor productivity of bread wheat under irrigation in West Shewa on combined mean and red soil type

N rate (kg/ha)	Seeding rate (kg/ha)		
	125	150	175
Combined mean			
42	43.44b	41.09b	48.38a
65	28.76d	34.76c	34.05c
88	22.97e	25.02de	27.17de
111	23.67e	22.55e	22.34e
N rate (kg/ha)	**Red soil type**		
42	41.90b	39.17bc	52.54a
65	27.89de	32.54cd	34.86bcd
88	18.47f	25.00ef	24.14ef
111	22.99ef	20.37ef	20.97ef

Partial Budget Analysis

Since there was no significant seeding rate with N rate interaction effect on grain yield, the partial budget analysis for the combined mean was done on the main effects of seeding rate and N rate using the methods suggested in CIMMYT (1988). Accordingly, the highest net benefits of 50343.00 ETB/ha with a marginal rate of return (MRR) of 422.00% were obtained at the seeding rate of 175 kg/ha, while the highest net benefits of 62354.61 ETB/ha with a marginal rate of return of 987.14% were obtained at the N rate of 111 kg/ha (Table 11). In both seeding rate and fertilizer level main effects, the MRR is highly greater than the acceptable minimum rate of return of 100% and suggests that for each Ethiopian Birr (ETB) invested in irrigated wheat production by using variety '*Kakaba*' at a seeding rate of 175 kg/ha and N fertilizer at a rate of 111 kg/ha, the producer would get ETB 4.22 for a seeding rate and 9.87 for a fertilizer rate after recovering the investment cost (Table 11).

Table 11: Dominance and marginal rate of return analysis for the effect of seed rate and nitrogen fertilization on grain yield (t/ha) of bread wheat in the West Shewa, combined over soil types

Treatments	Observed grain yield (kg/ha)	Adjusted grain yield (10% down)	Gross benefit (Birr/ha)	Total variable costs (Birr/ha)	Net benefit (Birr/ha)	Marginal rate of return (%)
Seeding rate (kg/ha)						
125	1.92	1.73	50112.00	3750.00	46362.00	-
150	1.98	1.78	51678.00	4500.00	47178.00	108.80
175	2.13	1.92	55593.00	5250.00	50343.00	422.00
Nitrogen rate (kg/ha)						
0	1.34	1.21	34974.00	0.00	34974.00	-
42	1.86	1.67	48546.00	1490.58	47055.42	810.52
65	2.11	1.90	55071.00	2306.85	52764.15	699.37
88	2.20	1.98	57420.00	3123.12	54296.88	187.77
111	2.54	2.29	66294.00	3939.39	62354.61	987.14

CONCLUSIONS

This study indicated that the main effect of seeding rate showed a significant effect on grain yield, and some of the studied parameters, while the N fertilizer level showed a significant effect on grain yield, and most of the studied parameters of the bread wheat variety '*Kakaba*' under irrigated conditions in highland areas of west Shewa. Depending on the agronomic and economic analysis results, it can be concluded that variety '*Kakaba*' at a seeding rate of 175 kg/ha and at an N level of 111 kg/ha was found to be optimal for the production of wheat under irrigation in the highlands of west Shewa. However, producers who have limited access to resources could use a seeding rate of 150 kg/ha as a second choice and N rates of 88 kg/ha, 65 kg/ha, and 42 kg/ha as the second, third, and fourth choices, respectively. Since this experiment was done only for one season, to get reliable results, the experiment should be repeated at least for one season on both soil types.

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