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Effect of Nitrogen Fertilizer Rate on Growth, Grain Yield and Yield Components of Bread Wheat (Triticum aestivum L.) Varieties at Woliso, Central Highland of Ethiopia

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Abstract: A decline in soil fertility and a lack of site-specific fertilizer recommendations are among the main factors contributing to the low productivity of wheat in Ethiopia in general and Waliso in particular. A field experiment was carried out during the 2022 cropping season at Woliso District to determine the effect of nitrogen rates on growth, grain yield, and yield components of bread wheat (Triticum aestivum L.) varieties at Woliso district, central Ethiopia. The treatments consisted of five nitrogen rates (0, 23, 46, 69, and 92 kg ha^{-1}) and three varieties. The experiment was laid out in a 3*5 factorially arranged in a randomised complete block design with three replications. Data on growth, yield, and its components were recorded and subjected to analysis of variance (ANOVA) using SAS version 9.3. The results of the analysis of variance showed that N and variety had main effects and interaction effects on leaf area, number of productive tillers per plant, number of spike length, thousand-grain weight, dry biomass yield, straw yield, and grain yield (all with $P \leq 0.05$). However, days to 50% heading, days to 90% physiological maturity, plant height, spikelets per spike, grain per spike, and harvest index were only affected ($P \leq 0.05$) by the main effects of N rates and varieties. Almost all yield parameters went down as the nitrogen rates went up, except for thousand-grain weight and agronomic efficiency. This happened up to 92 kg N ha-1. Combining the Wane variety with 92 kg N ha-1 yielded a higher grain yield of 4307.96 kg ha-1, and this combination was also economically feasible. Days to heading (r = 0.86**), days to physiological maturity (r = 0.64**), plant height (r = 0.93**), leaf area (r = 0.92**), and spike length (r = 0.95**) were significant ($P < 0.01$) and positively correlated with grain yield. The correlation between grain yield and productive tillers (r = 0.98**), the number of seeds per spike (r = 0.97**), the grain per spike (r = 0.96**), biomass yields (r = 0.98**), and the thousand-grain weight (r = -0.45**) was significant and positive. The combination of 92 kg N ha-1 with Wane variety yielded the highest net benefits (109,551.04) and marginal rate of return (2753.41). Therefore, we found that applying 92 kg N ha-1 fertiliser rates with the Wane variety was both agronomically and economically feasible for bread wheat production in the study area.

Keywords: bread wheat, growth, grain yield, nitrogen fertilizer

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1. INTRODUCTION

Wheat is one of the key cereal crops grown worldwide, contributing to global food security (FAO, 2022; USDA, 2022). Wheat contributes about 20% of the world's total energy and protein needs (Braun et al., 2010). Pradhan et al. (2015) predict a 60–110% increase in the global demand for food for humans and cattle between 2005 and 2050. Wheat production in Africa increased steadily at a rate of 0.52 million tonnes per year since 1980 to nearly 25.2 Mt in 2020. A much sharper increase in wheat imports accompanied such an increase in wheat production: since the mid-1990s, wheat imports have steadily increased at a rate of 1.45 Mt yr 1, resulting in a gap between imports and production of 21.7 Mt in 2022. The magnitude of the increase in wheat production varied across countries. For instance, Ethiopia (the largest wheat producer in Eastern Africa) saw spectacular increases in wheat production, at a rate of 0.24 Mt yr 1, since the early 2000s (FAOSTAT, 2023). Wheat contributes approximately 18% to Ethiopia's total cereal production, making it the country's second most important food staple crop. According to statistics, global wheat production rose by 31% in 2021 compared to 1994 levels, but the area increased by 29% in the same period. This indicates that high-yielding new cultivars, intensive management practices, and an increase in the area under irrigation are more likely to be responsible for the production increase than area expansion (van Ittersam and Cassman, 2013).

Wheat is the main staple food for about 36% of the Ethiopian population (CIMMYT, 2005). After teff, maize, and sorghum, wheat ranks fourth in area coverage and ranks third in total production. Despite the long history of wheat cultivation and its importance to Ethiopian agriculture, its average productivity is still very low: 2.97 t ha-1 at the national level (CSA, 2022). In all cases, this yield is significantly lower than the global average of 3.52 t ha-1 (USDA, 2022).

In Ethiopia, wheat productivity and quality are low due to depleted soil fertility (Tanner et al., 1993), low levels of chemical fertilizer usage, limited knowledge of the timing and rate of fertilizer application (Amsal et al., 1997), poor agronomic and soil management practices, and diseases. Low soil fertility, especially N deficiency, is one of the major constraints limiting wheat production in the highlands of Ethiopia (Teklu and Hailemariam, 2009).

During the rapid phase of crop development, nitrogen plays a crucial role in determining the final grain yield of wheat. This is because it is essential for high rates of spikelet initiation, improving spikelet fertility, increasing the number of grains per fertile spikelet, and forming biomass (Frank and Bauer, 1982). Walia et al. (1980) said that there was a stronger link between grain yields and the amount of nitrogen in plants during the tillering, jointing, and dough stages. They also said that the amount of nitrogen in the plant during jointing gave the most accurate estimate of the grain. Nitrogen nutrition stimulates tillering, probably due to its effect on cytokinin synthesis (Botella *et al., 1993).*

Studies done in the Nitisol zones of the central highlands of Ethiopia showed that wheat responded positively and linearly to N fertiliser in some agronomic parameters, such as plant height, number of spikes m-2, thousand grain weight (TGW), grains m-2, and grain yield (Amsal et al., 2000). A similar test in the Vertisol zones showed that the N content of wheat grain and straw went up by 36% and 57%, respectively, when the highest rate of N fertiliser (N164 kg N ha-1) was used compared to the control (Amsal and Tanner; 2001). Alcoz *et al.* (1993) reported that increased yield with N applied at the earlier growth stages was attributable to a greater number of spikes produced per unit area.

According to CSA (2022), the productivity of wheat at the Southwest Shawa Zone was 3 t ha-1, which is well below experimental yields of over 5 t ha^{-1} (Mann and Warner, 2015).

In Ethiopia, with the use of improved production technologies, grain yield ranges from 3-6 t ha-1, whereas at the research center it goes up to 5-7 t ha-1. This indicates the existence of a yield gap between the uses of improved technologies and that of farmers' attainable level (Bekele et al., 1993).

Poor fertiliser use, soil loss due to erosion, farmer's seed dependence, erratic rainfall, and a prolonged dry season are all contributing factors to this lower productivity (MOARD, 2012). Conversely, the soil-plant system may lose the highly soluble nitrogen fertiliser or render it unavailable to plants due to processes such as leaching, ammonia volatilisation, denitrification, ammonium fixation, and N immobilisation (Bock, 1984). Moreover, N is required in larger quantities than other nutrients.

The Waliso District made little effort to determine the agronomic requirements of bread wheat. Agronomic practices like low fertilizer rates, poor management practices, and the use of low-yielding varieties are the most yield-limiting factors in bread wheat production in the study area. To develop sustainable crop wheat production practices, it is essential to understand the rate of applied N for different bread wheat varieties. Therefore, the objective of this study was to improve bread wheat productivity in the central highlands of Ethiopia by determining the optimal nitrogen fertilizer application rate and identifying the best-performing varieties.

2. **2. Materials and methods**

2.1 Description of the Study Areas

The experiment was conducted at Obbe Koje Rural Kebele, Woloso District, Central Highlands of Ethiopia during the 2020 main cropping season. Waliso is located 114 km from Addis Ababa in the southwest direction on the way to Jimma. The experimental site is located at an altitude of 2090 m.a.s.l. and occupies a geographic coordinate of 80 34'685''N latitude and 38001'027''E longitudes. According to the district weather report, the total rainfall of the study area during the main cropping season (2022) was 1400 mm. The mean minimum and maximum temperatures are 10 and 25 °C, respectively. The type of soil is Nitisols.

2.2 Soil Sampling and Physico-Chemical Analysis

The soil laboratory at Jimma University College of Agricultural and Veterinary Medicine analysed the samples taken before planting. Bouyoucos (1962) used the hydrometer method to determine the soil's texture. Jackson (1962) used the Kjeldhal digestion method with sulphuric acid to analyse the total soil N. A filtered suspension of 1:2.5% soil to water was used to find the pH of the soil. A glass electrode connected to a digital pH meter, called a potentiometer (FAO, 2008), was used to do this. Organic carbon content was determined by the volumetric method (Walkley and Black, 1934).

The available P and the cations exchange capacity (CEC) of the soil were analysed at the Bedle soil laboratory. The available P content of the soil was determined following the Bray II method (Bray, 1945). The cations exchange capacity (CEC) of the soil was determined following the 1N ammonium acetate extraction (pH 7) method.

2.3 Soil Properties before Sowing

Table 1 presented the soil analysis before sowing. The experimental site's soil sample had a loam texture, with 35% sand, 48% silt, and 17% clay. Tekalign (1991) rated the pH at 5.8, indicating it was moderately acidic. Table 3. According to Fageria (2011), the normal soil pH range for wheat production is 5.5-8.2, where N availability is at its peak. This value falls within this range.

Cation exchange capacity is an important parameter of soil because it gives an indication of the type of dominant clay mineral present in the soil and its capacity to retain nutrients against leaching. Before planting, we found the soil's total nitrogen and cation exchange capacity (CEC) to be 0.114% and 11.55 mol (+)/kg, respectively. Havlin et al. (1999) and Murphy (2007) rated the soil's total nitrogen and cation exchange capacity (CEC) as low and medium, respectively. Table 1 found the organic carbon and organic matter to be 1.326 and 2.386%, respectively. Tekalign (1991) and Westerman (1990) rated the organic carbon and organic matter as low and medium, respectively, based on this data. Tekalign (1991) found the value of available phosphorous in the soil to be 4.347 mg/kg. The total amount of available P in soil was very low, according to Tekalign's (1991) rating.

Table 1: Soil Physical and chemical Properties before sowing

Parameter	Unit	Value	Rating	Reference
Particle size distribution				
Sand	(%)	35	-	
Silt	(%)	48	-	
Clay	(%)	17	-	
Texteral Class	Loam	-	-	
Ph	(%)	5.8	Moder.Acid	(Tekalign Tadesse, 199)
CEC	(cmol(+)/kg)	11.5	Low	(Tekalign Tadesse, 1991)
OC	(%)	1.326	Low	(Tekalign Tadesse, 1991)
TN(%)	(%)	0.114	Medium	(Olsen etal.,1954)
OM(%)	(%)	2.386	Medium	(Metson, 1961)
AvP	(mg/kg)	4.35	Very Low	(Metson, 1961)

CEC = Cation exchange capacity, OC = Organic carbon, OM = Organic matter, TN = Total nitrogen, Av.P = Available phosphorus.

2.4 Experimental materials

Three popular bread wheat varieties, namely, Kekeba, Kingbird and Wane, were used in the experiment. All of them are recommended for the area as they are high yielding and resistant to yellow rust. (Table 2).

Table 2: Bread Wheat Varieties used for experiment with its agronomic characteristics

Characteristics of Varieties	Kekeba	Kingbird	Wane
Year of release	2010	2015	2016
Area of adaption altitude	1300-2200	2000-2200	2000-2300
Days to maturity	90-120	90-95	120
Agro ecology	Low land & Mid land	Mid land	Mid land
On station productivity Quintal ha^{-1}	33-52	40-50	50-65

Source: Kulumsa Agricultural Research Center (KARC), Wheat breeding program (2017)

2.5 Treatments and Experimental Design

The treatments consist of three improved bread Wheat varieties (Kekeba, Kingbird, and Wane) and five nitrogen levels (0, 23,46, 69, and 92 kg N ha^{-1}) from urea (Table 3). The experiment was laid out in a randomized complete block design in a factorial arrangement. The three varieties were arranged in a factorial combination with the five levels of Nitrogen resulting in a 15 (3*5) treatments were replicated three times. Thus, there were a total of 45 experimental units. The area of each plot size was 3 m x 2 m. The spacing between plots and blocks was 0.5 m and 1 m, respectively. Each plot consisted of 15 rows with a spacing of 20 cm. Treatments were assigned randomly to experimental plots within a block.

Table 3:Treatment Combinations

Treatment No.	Varieties	N rate
1	Kekeba	0 kg ha^{-1}
2	Kekeba	23 kg ha^{-1}
3	Kekaba	46 kg ha^{-1}
4	Kekeba	69 kg ha-1
5	Kekeba	92 kg ha^{-1}
6	Kingbird	0 kg ha^{-1}
7	Kingbird	23 kg ha^{-1}
8	Kingbird	46 kg ha^{-1}
9	Kingbird	69 kg ha^{-1}
10	Kingbird	92 kg ha^{-1}
11	Wane	0 kg ha^{-1}
12	Wane	23 kg ha^{-1}
13	Wane	46 kg ha^{-1}
14	Wane	69 kg ha^{-1}
15	Wane	92 kg ha^{-1}

2.6 Experimental Procedures

2.6.1 Land preparation

The land was prepared following the conventional tillage practice by using, oxen-driven local plow (Maresha) before planting the wheat varieties. Accordingly, the field was plowed four times, a field layout was prepared and each treatment was assigned randomly to experimental plots.

2.6.2. Application of mineral fertilizer

The full rate of the Triple super phosphate 46 % P2O5 (100 kg ha^{-1}) and half of the nitrogen fertilizer were applied in basal application prior to planting for all plots and incorporated into the soil. The remaining half of urea was applied as side-dressing at mid tillering stage of the crop (35 days after emergence).

2.6.3. Sowing and Harvesting

Wheat seeds were sown by drilling along the rows in each plot placed 20 cm apart on July 18, 2020. Weeds were removed by hand weeding at early tillering, maximum tillering, and booting stages of growth. Harvesting was done manually using hand sickles at the physiological maturity of the crop.

2.7 Data Collection

2.7.1 Phenological data

Data on agro morphological traits of wheat varieties were collected on a plot and plant basis according to Dargicho et al., (2015) and descriptors for wheat.

Days of 50% heading: It was recorded as the number of days taken from the day of sowing to the date when 50% of the plants produced head .

Days to 90% physiological maturity: It was determined as the number of days from sowing to the time when the plants reached 90% maturity based on visual observation. It was visually assessed by senescence of the leaves as well as frees threshing of grain from the glumes when pressed between the forefinger and thumb.

2.7.2 Growth Parameters

Leaf Area: It was determined by measuring the length of the leaf from the base to the tip and the width of the leaf from five plants from each plant three leaves in each plot and will be determined as length x breadth x 0.8 at the flowering stage.

Plant Height: It was measured in cm from ground level to the tip of the spike excluding the awn of five randomly taken plants from the middle four rows of each plot.

Spike length: The main spikes from the five sampled plants from the central four rows of each plot were measured in cm and averaged to represent the spike length in cm (excluding own).

2.7.3 Yield and Yield Components Data

Number of Productive Tiller/plant: Number of Productive tillers per plant excluding the main plant was recorded at maturity and expressed as an average of five plants per plot.

A number of spikelets per spike: was recorded by counting the number of spikelets on each spike on the main tiller of each plant and was expressed as an average of five plants in a plot.

Number of Kernels per spike: Total number of grains in the main spike was counted at the time of harvest from five randomly taken plants and to be expressed as an average and recorded from central rows of each plot.

Biomass yield per hectare: Biomass weight was taken after harvesting from the whole plant parts, including leaves and stems, and seeds from the whole plot.

Straw yield per hectare: After threshing and measuring the grain yield, the straw yield was measured by subtracting the grain yield from the total above-ground biomass yield.

Grain yield per hectare: Grain yield was measured by harvesting the crop from 13 rows in the net middle plot area of $4.16m^2$ to avoid border effects. Then the grain yield of each treatment was adjusted to the standard moisture level by computing the conversion factor for each treatment to get the adjusted yield using the following formula (Biru, 1979):

$$\textbf{Conversion factor (C.F)} = \frac{100-Y}{100-X} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where Y is actual moisture content and X is the standard moisture content to which the yield is to be adjusted (for cereals the standard moisture content is 12.5%).

Adjusted yield = C.F*Grain yield------------------------- (2)

Harvest index(%): The harvest index was calculated as the ratio of grain plant mass to the total above-ground biomass and expressed in percentage (Singa, 1977).

Mathematically, HI = (GY / BY)*100 = where GY = Grain yield and BY = Biomass yield(Above ground biomass yield).

2.8. Statistical analysis

The data were subjected to analysis of variance (ANOVA) as per the design used in the experiment using statistical software (SAS), and interpretation was made following the procedure of Gomez and Gomez (1984). Mean separation was conducted using the least significant difference test (LSD) to evaluate the different nitrogen levels on bread wheat varieties at a 5% level of significance. The correlation analysis was performed to determine relations between phenological, growth parameter, and yield and yield components as influenced by nitrogen application rates.

3. RESULTS AND DISCUSSION

3.1 Phenological Parameter

3.1.1 Days to 50% heading

The analysis of variance indicated that days to 50% heading was statistically ($P \leq 0.05$) affected by varieties and nitrogen levels, but their interactive response was insignificant. Kingbird variety had delayed days to heading (68.5), whereas Kekeba variety had the earliest days to heading (64.6) (Table 4). This might be due to variation in genotypes. Similarly, Dabi et al. (2019.) reported that wheat genotypes differ in days to heading.

The highest nitrogen fertiliser rate (92 kg ha-1) recorded the longest days to heading (71.9), while the control treatments yielded the shortest days to heading (60). As the levels of N fertiliser increased from the lowest (0 N) to the highest (92 kg N ha-1), the days to heading also consistently increased. The behavior of increased N fertiliser, which increases the vegetative growth of crops and thereby delays the heading time, could explain this. Mekonen (2005) found that applying N fertiliser at the highest rate significantly delayed the day to heading for wheat and barley production, compared to applying it at the lowest rate. Similarly, Cock and Ellis (1992) have also reported that N fertiliser application had a significant effect on days to heading.

3.1.2 Days to 90% psychological maturity

The days to 90% physiological maturity were statistically ($P \leq 0.05$) affected by varieties and nitrogen levels, but their interactive response was insignificant. Wane appeared as a late-maturing variety (108 days), while Kekeba proved early maturing (90.5) (Table 4). Among nitrogen levels, we observed the delayed maturity day (109 and 106.1) at 92 and 69 kg ha-1 nitrogen, respectively, and the early maturity day (92) at no N at control levels (Table 4). The results align with Marschener's (1995) observation that excess N application delays crop maturity by disrupting photosynthesis during the critical reproductive phase. Moreover, excess N application to wheat reduces the sugar concentration in leaves during the early ripening stage, thereby inhibiting the translocation of assimilated products to spikelets (Tanaka, 1994).

Table 4: Main effect of Varieties and Nitrogen levels on Phenological parameters Day to heading and Day to Maturity of bread wheat at Waliso district

Varieties	Day to 50% heading	Day to 90% Maturity
Kekeba	64.6c	90.5c
King bird	68.5a	105b
Wane	66.5b	108.8a
LSD (5%)	1.5	2.81
Nitrogen level (kg ha $^{-1}$)		
0	60.1e	92.44d
23	64.3 d	98c
46	67.1c	101.66b
69	69.1b	106.1a
92	71.9 a	109a
Mean	66.5	101.33
LSD (5%)	1.94	3.6
CV (%)	3.0	3.7

Means followed by the same letters within a column for the main factors are not significantly different at ($p \leq 0.05$).

3.2 Growth Parameters

3.2.1 Leaf area at heading stage

The current study found that the bread wheat crop's leaf area had a very important (p ≤ 0.01) impact on the main effect varietal difference, N rates, and how they interacted with each other (Table 5). The combination of Wane variety and nitrogen rate 92 kg Nha-1 yielded the highest leaf area value (27.16 cm2), while the combination of Kekaba variety at 0 kg N (control) yielded the lowest leaf area value (14.72 cm2). Increasing N fertiliser rates increased the leaf area in all varieties. This implies that the application of N fertiliser can increase leaf area and that an increase in leaf area of plants contributes to the increment of solar radiation absorption. This, in turn, could lead to an increase in the process of photosynthesis and the growth of yield components. Furthermore, Iqtidar et al. (2006) and Minale et al. (2006) discovered that an increase in nitrogen rates also led to an increase in the leaf area of barley. The development of individual leaf area and total leaf area of crop plants ultimately contributed towards higher grain yield.

Table 4: Interaction effect of varieties and nitrogen levels on Leaf area of bread wheat at waliso district

Varieties	Nitrogen rates (kg ha $^{-1}$)				
	0	23	46	69	92
Kekeba	14.72i	16.60gh	18.01f	19.77e	21.97c
King bird	16.20h	18.21f	20.27de	22.25c	25.20b
Wane	17.33fg	20.85d	22.12c	25.65b	27.16a
Mean	16.08	18.55	20.13	22.55	24.78
LSD(0.01)			0.97		
CV(%)			2.85		

Means followed by the same letters are not highly significant different at (*p* ≤ 0.01).

3.2.2 Plant height

The results indicated that the main effect of both wheat varieties and nitrogen levels had a highly significant (P ≤ 0.01) difference in plant height. Table 6 shows that their interaction did not significantly impact plant height. The Wane variety produced the tallest plants (76.84 cm), while Kekeba yielded the shortest plants (72.76 cm) (Table 6). Plant height differences among various cultivars are generally due to their genetic constitution (Sial et al., 2009).

Of nitrogen levels, the tallest plants (81.07 cm) were observed at a nitrogen level of 92 kg ha-1, while the shortest plants (66.05 cm) were recorded at 0 kg (control) level of nitrogen fertilisation (Table 6). The results indicated that plant height increases as nitrogen levels increase. Increased plant height and spike length with increased nitrogen fertilization likely resulted from increased nitrogen availability, which may have favored the vegetative growth of plants. Ali et al. (2003) reported similar results of plant height increment with N rate increase. Research findings also confirmed that maximizing N fertilization increased plant height (Amanuel et al., 1990).

Table 5: Main effect of varieties and nitrogen levels on Plant height of bread wheat at Waliso district

Varieties	Plant height (cm)
Kekeba	72.72b
King bird	75.96a
Wane	76.62a
LSD (0.01)	1.49
Nitrogen level (Kgha $^{-1}$)	
0	65.76e
23	73.56d
46	76.21c
69	78.67b
92	81.30 a
Mean	75.1
LSD (0.01)	1.93
CV (%)	2.7

Means followed by the same letters within a column for the main factors are not highly significant different at (*p* ≤ 0.01).

3.2.3 Spike Length

The results showed that spike length had a highly significant (p ≤ 0.01) effect on wheat varieties, nitrogen fertilization levels, and their interactions (Table 7). The longest spike length (9.2 cm) was observed with the combination of 92 kg N ha^{-1} and Wane variety, whereas the shortest spike length (5.3 cm) was recorded with the combination of 0 kg N rates (control) treatment with Kekeba variety (Table 7). The increment in spike length with increasing N rates might be attributed to the effective role of N as an essential constituent of chlorophyll on dry matter production and spike length. In agreement with this result, Noureldin et al. (2013) reported that increasing the rate of nitrogen up to 75 kg ha^{-1} significantly increased spike length by 36.2% over the control treatment. Similarly, Ali (2011) found the maximum spike length (11.3 cm) with the application of 130 kg N ha^{-1}. Furthermore, the application of the highest N fertiliser (125 kg ha^{-1}) produced the longest spike (9.24 cm) of wheat in comparison with the control (Noureldin et al., 2013). Increasing the rate of nitrogen significantly enhanced its availability to maintain plant health, ultimately leading to an increase in spike length (Ejaz et al., 2002).

Table 6: Interaction effect of varieties and nitrogen levels on spike length of bread wheat at Waliso district

Varieties	Nitrogen rates (kg ha $^{-1}$)					
	0	23	46	69	92	Mean
Kekeba	5.3j	6.76i	7.66fg	8.03ef	8.7bc	7.29
King bird	6.46i	7.63g	8.1de	8.86ab	9.13a	8.04
Wane	6.4 i	7.16h	7.76efg	8.43cd	9.2a	7.79
Mean	6.03	7.18	7.84	8.44	9.01	
LS(0.01)				0.37		
CV(%)				2.87		

Means followed by the same letters are not highly significant different at (*p* ≤ 0.01).

3.3 Yield and Yield Components

3.3.1 Productive tillers

There was a very big (p ≤0.01) effect on the number of productive tillers per plant of bread wheat when nitrogen levels and varieties were looked at separately and together (Table 8). The combination of 92 kg N ha-1 and wane variety recorded the highest (6.4) number of productive tillers at the maturity stage, while the control treatment with kekeba variety yielded the lowest (1.16) number of productive tillers at the maturity stage.

As the nitrogen rates increased, so did the number of productive tillers. The mean number of productive tillers per plant increased to 2.77, 3.53, 4.8, and 5.76 in the application of 23, 46, 69, and 92 kg N ha^{-1} over control treatments (1.6). This could be attributed to the role of nitrogen fertilizer in accelerating plant vegetative growth, and the stimulation of tillering caused by nitrogen's effect on cytokine/protein synthesis. The results were in agreement with Abdullatif et al. (2010), who reported an increase in the number of productive tillers with nitrogen fertilization. Bereket et al. (2014) and Abdollahi et al. (2012) also reported that nitrogen fertilization has a significant effect on the number of productive wheat tillers.

Table 7: Interaction effects of Varieties and nitrogen levels on productive tillers of bread wheat at waliso district

Varieties	Nitrogen rates (kg ha $^{-1}$)				
	0	23	46	69	92
Kekeba	1.2i	2.7g	3.1f	4.3de	5.2c
King bird	1.7h	2.6g	3.4f	4.7d	5.7b
Wane	1.9h	3.0fg	4.1e	5.3bc	6.5a
Mean	1.6	2.77	3.53	4.77	5.8
LS(0.01)				0.4	
CV(%)				6.5	

Means followed by the same letters are not highly significant different at (*p* ≤ 0.01)3.3.2. Number of Spikelets Per Spike

Spikelets per spike was statistically highly significant ($p \leq 0.01$) with wheat varieties and nitrogen levels, while it was not significantly affected by interaction (Table 9). The Wane variety recorded the highest number of SPS (36.80), while the Kekeba variety recorded the lowest number (32.44) (Table 9). The number of SPS differences among various cultivars is generally due to their genetic constitution.

At a nitrogen level of 92 kg N ha-1 nitrogen application, we observed the highest number of SPS (42.76), while the nitrogen zero level (control) of nitrogen fertilisation recorded the lowest number of SPS (26). The reason for this is that the nitrogen availability met the plant's growth and development requirements at 92 kg ha-1, allowing the plants to produce more spikelets per spike. This result was statistically similar, aligning with the findings of Mosalem et al. (1997) and Sobh et al. (2000), which suggested that an increase in nitrogen levels led to a proportional increase in the number of spikelets per spike.

3.3.3. Number of Seeds per Spike

The grains per spike, an important yield component of grain yield, determine the wheat spike's yield potential. Varieties and nitrogen levels statistically significantly increased the number of grains per spike, but the interaction did not significantly affect it. The Wane variety recorded the highest number of seeds per spike (NSPS) at 59.65, while the Kekeba variety recorded the lowest number at 55.65. This result was statistically similar to the findings of Cost and Kronstad (1994), indicating that a genotypic difference in wheat affects both yield and yield components. (Table 9).

In terms of nitrogen levels, we observed the highest number of SPS (67.18) at a nitrogen level of 92 kg N ha-1 during nitrogen application, and the lowest number of NSPS (46.67) at the nitrogen zero level (control) during nitrogen fertilisation (Table 9). This can be justified with the reason that nitrogen availability satisfied the plant requirement for growth and development at 92 kg ha-1, which enabled the plants to produce a greater number of seeds per spike. The findings are in line with the data reported by Ali et al. (2003), who observed that increased application of nitrogen increases the number of grain yields per spike.

Table 8: Main effect of Varieties and Nitrogen levels on Spikelets per spike and Number of seed per spike bread wheat at Waliso district

Varieties	Spiklets per spike	Number of seed per spike
Kekeba	30.7c	55.65c
Kingbird	34.6b	57.61b
Wane	36.2a	59.65a
LSD(0.01)	1.47	0.96
Nitrogen level (kg ha^{-1})		
0	26.38e	46.67e
23	34d	53.00d
46	34.76c	58.9c
69	37.02b	62.43b
92	39.82a	67.18a
Mean	33.86	57.64
LSD(5%)	1.9	1.2
CV(%)	5.8	2.2

Means followed by the same letters within a column for the main factors are not highly significant different at ($p \leq 0.01$).

3.3.4 Biological Yield (Above ground biomass Yield)

The total above-ground biomass of the crop was highly and significantly influenced by varieties, nitrogen levels, and their interaction.(Table 10)

The interaction result shows that the highest biological yield (9299.10 kg ha^{-1}) was obtained from the Wane varietiy interacted with 92 kg N ha^{-1} nitrogen levels. The lowest biological yield (4058.5 kg ha^{-1}) was produced with kekeba variety interacting with zero (0 kg ha^{-1}) levels of nitrogen application (Table 10). Similarly, the nitrogen application enhanced the vegetative growth of the wheat crop, which ultimately increased biological yield with an increase in straw yield (Allam, 2003).

Table 9: Interaction effects of varieties and nitrogen levels on above ground biomass yield (Kg ha^{-1}) of bread wheat at waliso district

Varieties	Nitrogen rates (kg ha $^{-1}$)				
	0	23	46	69	92
Kekeba	4058.5j	4521.5j	5672.9g	6822de	7729.6de
King bird	4499.9i	5628.5g	6617.9e	7785.6c	8637.3b
Wane	4394.0i	6069.9f	7065.6c	7889.6c	9299.1a
Mean	4317.46	5406.63	6452.13	7499.06	8555.33
LSD (0.01)	277.38				
CV (%)	2.56				

Means followed by the same letters are not highly significant different at ($p \leq 0.01$)

3.3.5 Straw yield

The result regarding the straw yield of the crop was highly and significantly influenced by varieties, nitrogen levels, and their interaction. (Table 11).

The interaction effect of variety and nitrogen rates showed that the highest straw yield (4991.11 kg ha^{-1}) was recorded from wane variety at N rate of 92 kg ha^{-1} while the lowest straw yield (2952.62 kg ha^{-1}) was obtained from kekeba variety under the 0 kg N ha^{-1} (control) treatment (Table 11).

The increase in the straw yield at higher N rates might be due to increased plant height and tillering. In line with this result, Annicchiarico et al.,(2005) reported that N significantly enhanced straw yield of wheat, since N usually promotes the vegetative growth of a plant. In agreement with this result, Geleto et al.,(1996) reported straw yield increments of 24% to 29% for 120 over 60 kg N ha^{-1} from experiments conducted in central and southeastern Ethiopia.

Moreover, the result from the experiment done on Vertisols of the central highlands of Ethiopia by Selamyihun et al.,(1999) showed that straw yield of durum wheat increased significantly with each incremental dose of N from 0 to 60 kg ha^{-1}. Iqtidar et al.,(2006) also indicated N application rates of 70, 140, and 210 kg ha^{-1} resulted in significantly higher straw yield than the yields under zero N rate where the highest N rate gave the highest straw yield which was significantly differed from other rates. Furthermore, Taye et al.,(2002) reported linear and quadratic responses of straw yield to N rate with mean values ranging from 2324 to 4073 kg ha^{-1} during favorable growing seasons

Table 10: Interaction effects of Varieties and nitrogen levels on straw yield (kg ha^{-1}) of bread wheat at waliso district

Varieties	Nitrogen rates (kg ha $^{-1}$)				
	0	23	46	69	92
Kekeba	2952.62i	3156.23gh	3321.84g	3907.95e	4276.65d
King bird	3273.46gh	3593.22e	3918.66e	4464.14c	4641.85b
Wane	3138.38h	3945.50e	4220.92d	4310.73dc	4991.11a
Mean	3121.48	3564.98	3820.47	4227.60	4636.53
LSD (0.01)	162.33				
CV (%)	3.78				

Means followed by the same letters are not highly significant different at ($p \leq 0.01$).

3.3.6 Thousand Seeds Weight

The weight of 1000 grains was measured at a seed moisture content of 12.5%. The thousand seed weight of wheat was highly and significantly affected by different wheat varieties, levels of nitrogen, and their interaction. (Table 12).

When the Wane variety interacts with zero nitrogen levels, the thousand seed weight is heavier (41.0 g), but when the Kekeba variety interacts with 23, 46, 69, and 92 kg ha-

1 nitrogen levels, the thousand seed weight is lighter (30.5, 29.5, 25.83, and 24.5 g) (Table 12).

Regardless of varities, the N rates increase as the seed weight decreases. This result aligns with the findings of Gooding and Davies (1997), who found that applying nitrogen fertiliser at rates optimized for yield response does not always lead to a comparable increase in 1000-grain weight. The increased number of spikelets per spike and the vigorous vegetative growth resulting from high nitrogen application lead to competition for the carbohydrate available for grain filling and spikelet formation (Hasegawa, 1994). This results in a decrease in grain weight due to the inadequate availability of carbohydrates for each individual grain.

Table 11: Interaction effects of Varieties and nitrogen levels on Thousand Seeds Weight (g) of bread wheat at waliso district

Varieties	Nitrogen rates (kg ha $^{-1}$)				
	0	23	46	69	92
Kekeba	32.16ef	30.5gh	29.5hi	25.83j	24.5j
King bird	34.33d	33.33de	31.16 fg	30.5gh	29.5hi
Wane	41.0a	40.0a	38.16b	36.5 c	28.16 i
Mean	35.88	34.64	32.94	30.94	27.38
LS(0.01)			0.94		
CV(%)			3.01		

Means followed by the same letters are not highly significant different at ($p \leq 0.01$).

3.3.7 Grain yield

Yield is a very complex trait. It is a final product of a number of components. Thus, it is essential to detect the variables having the greatest effect on the yield and their relative contribution to its total variability. Varieties, nitrogen levels, and their interaction significantly impacted the grain yield of wheat. (Table 13)

The Wane variety recorded the highest grain yield (4307.96 kg ha1) at the 92 kg ha1 nitrogen rate, likely due to its high response to nitrogen and its efficient use. When the varieties interacted with the control (0 kg N ha-1) treatment, they recorded the lowest grain yield (1105.83) (Table 13). The findings of this study are similar to those of Channabasavanna and Setty (1994), who reported that increasing N levels increased grain yield by increasing the magnitude of yield attributes. The study found a significant and positive correlation between grain yield and productive tillers (r = 0.98**), spikelet per spike (r = 0.92**), number of seeds per spike (r = 0.97**), and biomass yield (r = 0.98**). Goodings and Davies (1997) also confirmed a close relationship between those parameters and the improvement in wheat yield.

Table 12: Interaction effects of varieties and nitrogen levels on Grain yield of bread wheat at waliso district

Varieties	Nitrogen rates (kg ha $^{-1}$)				
	0	23	46	69	92
Kekaba	1105.83j	1792.97i	2351.01g	2914.09	3452.91cd
Kingbird	1226.49j	2035.27h	2699.20f	3321.44d	3995.44b
Wane	1255.60j	2124.35h	2844.66ef	3578.89C	4307.96a
Mean	1195.97	1984.19	2631.62	3271.47	3918.77
LSD (0.01)					162.33
CV (%)			4.00		

Means followed by the same letters are not highly significant different at ($p \leq 0.01$).

3.3.8 Harvest Index

The harvest index was not affected by wheat varieties and their interaction but highly and significantly affected by nitrogen levels. Among the nitrogen levels, the highest harvest index (0.45) was obtained at 92 kg ha^{-1} nitrogen application levels. The lowest harvest index (0.27) was obtained with the control treatment (Table 14). The finding is similar to Thakur, R. B. (1993) who reported an increasing trend of harvest index to a certain level of N and a decreasing one with further increase in its rate of application.

Table 13:. Main effects of Varieties and nitrogen levels on Harvest Index of bread wheat at waliso district

Varieties	Harvest Index
Kekeba	0.39a
Kingbird	0.39a
Wane	0.39a
LSD(0.01)	NS
Nitrogen level (K g ha^{-1})	
0	0.27e
23	0.35d
46	0.40c
69	0.43b
92	0.45a
Mean	0.38
LSD(0.01)	0.015
CV (%)	4.15

Means followed by the same letters within a column for the main factors are not highly significant different at ($p \leq 0.01$).

4. SUMMARY AND CONCLUSION

Bread wheat production is heavily dependent on the available nutrients in the soil and other environmental conditions for plant growth. Information on crops' responses to N fertilizer rates and improved variety is crucial to coming up with profitable and sustainable bread wheat production. The experiment aimed to identify the optimal N-rates and variables that produced the best wheat growth, yield, and yield component. Additionally, it sought to determine the most cost-effective N fertiliser rates for bread wheat production, taking into account the current input and output price levels in the study area.

The experiment showed that N and variety had main effects and interaction effects on leaf area, number of productive tillers per plant, spike length, thousand-grain weight, above-ground biomass yield, straw yield, and grain yield ($P < 0.05$). However, days to 50% heading, days to 90% physiological maturity, plant height, spikelets per spike, and number of seeds per spike were only affected ($p \leq 0.05$) by the main effects of N levels and varieties. When the application of nitrogen rates increases, nearly all yield parameters, with the exception of thousand-grain weight and agronomic efficiency, decrease as the nitrogen rates increase, reaching up to 92 kg N ha-1. Increases in N fertiliser rates led to an increase in days to heading and maturity, leaf area, the number of tillers, plant height, spike length, spikelet per spike, the number of seeds per spike, total biomass yield, straw yield, and harvest index of bread wheat. However, an increase in N dose resulted in a decrease in the thousand-grain weight of bread wheat.

The Wane variety outperformed other bread wheat varieties in terms of leaf area, number of productive tillers, spike length and grain per spike, above-ground biomass yield, and straw yield. It also produced the highest grain yield at a nitrogen rate of 92 kg ha-1, and the combination of 92 kg N ha-1 with the Wane variety yielded the highest net benefits (109,551.04) and the highest marginal rate of return (2753.41). We can conclude from this investigation's output that applying nitrogen at a rate of 92 kg ha-1 enhanced wheat productivity and produced the maximum grain yield.

In most cases, fertilizer recommendations for crops are based on a soil test for plant-available nutrients. A major limitation is that, for the same sites, plant varieties, and management systems, the absolute plant yields may differ from year to year due to different weather conditions. Therefore, as the current study only focused on one location, one cropping season, and a limited number of bread wheat varieties, it would be premature to make a definitive recommendation. Therefore, we need to conduct further studies that replicate across seasons and locations, with the aim of recommending an agronomically optimal and economically viable approach that enhances the yields of bread wheat varieties and establishes a feasible level of N fertilizer.

5. REFERENCES

[1] Abdollahi, J., Hashemi, K., Mosavi, S., Feizias, V., Jafarzadeh ,J. and karimi, E. (2012). Effects of fall nitrogen rates on rainfed bread wheat yield and yield components in drought condition. International Research Journal of Applied and Basic Sciences, 3 (11): 2195-2204.

[2] Abdullatif, M., Asmat, U.M., sattar, A., Fiaz, H., Abbas, G. and Huss, J. (2010). Response of growth and yield of wheat to NPK fertilizer. Science international (lahore), 24 (2): 185-189.

[3] Alcoz, Frank and Haby; (1993) Nitrogen fertilizer timing effect on wheat production, nitrogen uptake efficiency, and residual soil nitrogen. Agron. J. 85:1198-1203.

[4] Ali A, Syed AAW, Khaliq T, Asif M, Aziz M, et al. (2011). Effects of nitrogen on growth and yield components of wheat (report). Sci Int (Lahore) 23: 331-332.

[5] Ali, L., Q, Mdy-Ud-Din and M. Ali. (2003). Effect of different doses of nitrogen fertilizer on yield of wheat.Int. J. Agric. Biol., 5(4), 438- 439.

[6] Alireza, A., Moselhy, E. and Zahran, M. (2015). Evaluation of yield and yield components of barley varieties to nitrogen. International Journal of Agriculture and Crop Sciences, 8(1): 52-54.

[7] Allam, A.Y. (2003). Response of three wheat cultivars to split application nitrogen fertilization rates in sandy soils. Aust. J. Agric. Sci. 1: 1-14.

[8] Amanuel G., Kuhne, R. F., Tanner, D. G. and Vlek, P. L. G. (2002). Recovery of 15- N labeled urea applied to wheat in the Ethiopian highlands as affected by P fertilization. Journal of Agronomy and Crop Science, 189: 30-38.

[9] Amsal Tarekegne and Tanner, D. G. (2001). Effects of fertilizer application on N and P uptake, recovery and use efficiency of bread wheat grown on two soil types in Central Ethiopia. Ethiopian Journal of Natural Resources, 3(2):219–244

[10] Amsal, T., Tanner, D., Taye, T. and Chanyalew, M. (2000). Agronomic and economic evaluation of the on farm N and P response of bread wheat grown on two contrasting soil types in Central Ethiopia. pp. 329. In: The 11th Regional wheat workshop for central, Eastern and Southern Africa. Addis Ababa, Ethiopia.

[11] An, D., Su, J., Liu, Q., Zhu, Y., Tong, Y., Li, J., Jing, R., Li, B. and Li, Z. (2006). Mapping QTLs for nitrogen uptake in relation to the early growth of wheat (Triticum aestivum L.). Plant and Soil, 284(1–2):73–84.

[12] Annicchirico, P., Abdellaoui, Z., Kelkoulih, M. and Zerargui, H. (2005). Grain yield , straw yield and economic value of tall and semi-dwarf durum wheat cultivars in Algeria. Journal of Agricultural Science, 143:57–64.

[13] Asnakew Woldeab, Tekalign Mamo, Mengesha Bekele and Tefera Ajema. (1991). Soil fertility management studies on Wheat in Ethiopia. In: Wheat Research in Ethiopia: A Historical Perspective. Hailu Gebre-Mariam. D.G. Tanner and Mengistu Hulluka (eds.): 137-172. IAR and CIMMYT: Addis Ababa, Ethiopia.

[14] Assaye Demelash, Tadesse Desalegn, Getachew Alemayehu, (2013). Participatory Varietal Selection of Bread Wheat (Triticum aestivum L.) Genotypes at Marwold Kebele, Womberma Woreda, West Gojam, Ethiopia.International Journal of Agronomy and Plant Production. Vol 4 (S), Pp. 3543-3550.

[15] M, Johnson MRS, Nyambilila A, Tekalign M (2015). Wheat Response to Applied Nitrogen, Sulfur,and Phosphorous in three Representative Areas of the Central Highlands of Ethiopia. In J Plant Soil Sci 8(5):1-11.

[16] Astawus Esatu, Firew Mekibib and Tadesse Dessalegn. (2018). Performance evaluation and farmer's selection criteria of improved bread Wheat varieties. African Journal of Agricultural Research, Vol. 13(44), pp. 2477-2498.

[17] Bekalu Abebe and Mamo Manchore (2016). Effect of the rate of N fertilizer application on growth and yield of wheat (Triticum aestivum L.) at Chencha, Southern Ethiopia. International Journal of Plant, Animal and Environmental Sciences 6(11): 111-122.

[18] Bekele Geleta, Amanuel Gorfu and Getinet Gebeyhu. (1993). Wheat production and research in Ethiopia constraint and sustainability, Pp. 18-25, In: D.G. Tanner, (ed.). Developing sustainable wheat production systems. The eight regional wheat workshops for Eastern, Central and Southern Africa, Kampala, Uganda.June 7-10, 1993.

[19] Bekele, H., Verkuijl, K. hugo, Mwangi, W. and Tanner, D. (2000). Adoption of Improved Wheat Technologies in Adaba and Dodola Wored as of the Bale High Lands,Ethiopia, Mexico, CIMMYT and Ethiopian Agricultural Research Organization (EARO).

[20] Bekele, M., & Shiberu, T. (2014). Adoption of improved bread wheat varieties on small scale farmers: The case of Boji Gebisa Ambo District, Oromia Regional State, Ethiopia. American Journal of Food Science and Technology, 2(3), 103–108. https://doi.org/10.12691/ajfst-2-3-5

[21] Bereket Haileselassie, Dawit Habte, Mehretab Haileselassie and Gebremedhin Gebremeskel, (2014). Effects of mineral nitrogen fertilizer on yield and nutrient utilization of bread wheat on the sandy soils of Hawzen District, Northern Ethiopia.

Agriculture, Forestry and Fisheries Journal, 3(3): 189-198.
[22] Bergh K, Chew A, Gugerty MK, Anderson CL (2012). Wheat Value Chain: Ethiopia. EPAR Brief No.204. Seattle, WA, US: Evans School of Public Affairs pp: 1-21
[23] Bergh, K., Chew, A., Gugerty, M.K. and Anderson, C.L., (2019). Wheat value chain: Ethiopia. Gates Open Res, 3.
[24] Biru Abebe. (1979). Agronomy Research Manual. Part III. Formula and Tables. Institute of Agricultural Research. Addis Ababa.
[25] Biruk Gezahegn and Demelash Kefale. (2016). Effect of nitrogen fertilizer level on grain yield and quality of malt barley varieties in Malga Woreda, Southern Ethiopia. Food Science and Quality Management, 52: 2224-6088.
[26] Bock, B.R., (1984). Efficient use of nitrogen inter cropping systems. In R. D. Hauck (Ed.), Nitrogen in crop production, 273-294. ASA, CSSA, SSSA, Madison, Wisconsin, USA.
[27] Botella, Cerda and Lips;(1993). Dry matter production, yield and allocation of carbon-14 assimilate by wheat as affected by nitrogen source and salinity. Agron.J. 85 (5): 1044 – 1049.
[28] Bouyoucos, G. J. (1962). Hydrometer Method Improved for Making Particle Size Analyses of Soils 1. Agronomy Journal, 54(5), 464 – 465 . https://doi.org/10.2134/ agronj 1962.00021962005400050028x
[29] Bray RH, Kurz LT (1945). Determination of total,organic and available forms of phosphorous in soil.Soil Sci 59(1): 39-45.
[30] Brown, B. D. and Petrie, S. (2006). Irrigated hard winter wheat response to fall, spring,and late season applied nitrogen. Field Crops Research, 96: 260-268.
[31] Central Statistical Agency (2018). Agricultural Sample Survey 2017/2018 (2010 EC), Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). V. I., Statistical Bulletin No. 586, Addis Ababa, Ethiopia.
[32] Central Statistics Agency (CSA) (2012). Agricultural sample survey 2007/2008. Report on Statistical Bulletin, 417. Addis Ababa, Ethiopia pp: 45.
[33] Channabasavanna, A.S. and R.A. Setty. (1994). Response of broadcast rice level of Nitrogen, phosphorus and time of N application.Indian J.A. 39 (30):457-459.
[34] CIMMYT (International Centre for Maize and Wheat Improvement). (2005). Sounding the Alarm on Global Stem Rust. An assessment of race Ug99 in Kenya and Ethiopia and the potential for impact in neighboring regions and beyond. Prepared by the expert panel on the stem rust outbreak in Eastern Africa. 29 May 2005.CIMMYT, Mexico.
[35] CIMMYT, (1998). From Agronomic data to farmer recommendations: An economic training manual. Completely revised ed. Mexico, D.F.
[36] Cock RL, Ellis BG. (1992). Soil management, a world view of conservation Krieger Publishing Company, Malabar, Florida p: 413.
[37] Cost, J. M. and Kronstad, W. E. (1994). Association of grain protein concentration and selected traits in hard red winter wheat populations in the Pacific Northwest.Crop Sci. J. 34:1234-1239.
[38] CSA (Central Statistical Agency). (2016). Agricultural Sample Survey 2015/2016 (2008 E.C) Agricultural Sample Survey. Volume I: Report on area and production of major crops (private peasant holdings, Meher season). Statistical Bulletin 584, Addis Ababa.
[39] CSA (Central Statistical Agency). (2017a). Agricultural Sample Survey: Volume III Report on Farm Management Practices (Private Peasant Holdings , Meher Season). Addis Ababa, Ethiopia.
[40] CSA (Central Statistical Agency). (2022). Agricultural Sample Survey 2019/2020 (2012 E.C) Agricultural Sample Survey. Volume I: Report on area and production of major crops (private peasant holdings, Meher season). Statistical Bulletin 587, Addis Ababa.
[41] Dabi, A., Mekbib, F. and Desalegn, T., (2019). Genetic variability studies on bread wheat (Triticum aestivum L.) genotypes. Journal of Plant Breeding and Crop Science, 11(2), pp.41-54.
[42] Dargicho D, Sentayehu A, Firdisa E and Ermias A, (2015). Genetic Variability in Bread Wheat (Triticum aestivum L.) Germ plasm for Yield and Yield Component Traits. Journal of Biology, Agriculture and Healthcare, 5(17): 140-147.
[43] Dixon J; HJ Braun; P Kosina; J Crouch. (2009). Wheat Facts and Futures 2009. Mexico, DF: CIMMYT.
[44] Ejaz, H., W., A., Shed, A. A., Hayat, F. and Bakht, J. (2002). Yield and yield components of wheat as affected by different planting dates, seed rates and nitrogen levels. Asian Journal of plant science., 1(5):502–506
[45] Fageria, N. K., Baligar, V, C. and Jones, C. A. (2011). Growth and Mineral Nutrition of Field Crops. 3. ed, p 530. CRC Press.
[46] FAO (Food and Agriculture Organization of the United Nations), (2012). Agricultural Production. 2009.http://faostat.fao.org (accessed 22 April 2012). FAO, Rome, Italy.
[47] FAO (Food and Agriculture Organization) (2015a). Food Balance Sheets. FAOSTAT. Rome. FAO (Food and Agriculture Organization) (2015b). Agricultural Production Statistics. FAOSTAT. Rome.
[48] FAO, (2017). The state of food and agriculture, leveraging food systems for inclusive rural transformation. Food and agricultural organization of united nations.

[49] FAO,(2023). Cereal supply and demand data may .http: //www. fao.org/fileadmin/ templates / world food food/ Reports and docs/ Cereal supply and demand data may xls
[50] Firehiwot Getachew. (2014). Effect of vermi compost and inorganic N and P fertilizers on growth, yield, and quality of bread wheat (Triticum aestivum l.) in eastern Ethiopia M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.
[51] Frank and Bauer; (1982). Effects of temperature and fertilizer N on apex development in spring wheat. Agron. J. 74:504-509.
[52] Gebreselassie, S., Haile, M. G., & Kalkuhl, M. (2017). The wheat sector in Ethiopia: Current status and key challenges for future value chain development (ZEF Working Paper Series 160, Center for DevelopmentResearch). University of Bonn.
[53] Geleto Tilahun, Tanner, D. G., Tekalign Mamo and Getnet Gebeyehu. (1996). Response of rainfed bread and durum wheat to source, level and timing of nitrogen fertilizer on two Ethiopian Vertisols: II. N uptake, recovery and efficiency. Fertilizer Research, 44(3):195–204.
[54] Gete Zelleke, Getachew Agegnehu, Dejene Abera, Shahid Rashid. (2010). Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. IFPRI, Addis Ababa, Ethiopia, 63p.
[55] Godwin, D.C. and C.A. Jones, (1991). Nitrogen dynamics in Soil-plant Systems. In:J Hanks and J.T. Richie (Eds.),Modelling plant and soil systems. Agronomy Monograph 31: 287 - 322.
[56] Gomez, K. A., & Gomez, A. A. (1984). Statistical procedures for agricultural research (2nd ed., p. 680). John Wiley and Sons Inc., New York.
[57] Gooding, M. J., and Davies, W. P. (1997). Wheat Production and Utilization System, Quality, and Environment. CAB International, USA. 355P.
[58] Goshu, D., Getahun, T. D., & Oluwole, F. (2019). Innovation opportunities for wheat and faba bean value chains in Ethiopia. FARA Research Report. Vol. 4(5).
[59] Haile, D., Nigussie, D., and Ayana, A., (2012). Nitrogen use efficiency of bread wheat: Effects
[60] Hailu, Gebre-Mariam. (1991). Wheat production and research in Ethiopia. A Historical Perspective:1-15. IAR/CIMMYT, Addis Ababa, Ethiopia.
[61] Hasegawa, T.Y. (1994). Response of spike let number to plant Nitrogen concentration and dry weight in crops.
[62] Havlin, J., Beaton, J., Tisdale, S. and Nelson, W. 1999. Soil fertility and fertilizers: An introduction to nutrient management. Prentice Hall, New York, p 499.
[63] Hei, N., Shimelis, H. A., & Laing, M. (2017). Appraisal of farmers wheat production constraints and breeding priorities in rust prone agro-ecologies of Ethiopia.African Journal of Agricultural Research, 12(12),944–952. https: // doi.org/ 10.5897/ AJAR 2016. 11518
[64] Hillette Hailu, Tekalign Mamo, R. Keskinen, E. Karltun, Heluf Gebrekidan, and Taye Bekele. (2015). Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. Agric & Food Security 4:19
[65] Hussain, I., Khan, M. A., and Khan, E. A. (2006). Bread wheat varieties as influenced by different nitrogen levels. Journal of Zhejiang University of Science, 7 (1): 70-78.
[66] Hussain, M.I., and Shah S.H. (2002). Growth, yield, and quality response of three wheat (Triticum aestivum L.) varieties to different levels of N, P, and K. Int. J. of Agri. and Bio., 4(3): 362-364.
[67] Iqbal A, Akbar N, Khan H Z, Bakar MA (2010). Influence of nitrogen fertilization on growth and yield of two wheat varieties. Crop and Environment 1: 57-58.
[68] Iqtidar, H., Ayyaz, K. M. and Ahmad, K. E. (2006). Bread wheat varieties as influenced by different nitrogen levels. Journal of Zhejiang University Science, 7(1):70–78.
[69] Jackson, M. L. (1962). Soil chemical analysis (p. 498). New Delhi, Prentice Hall of India Pvt. Ltd.
[70] Khan, A., M.T. Jan, M. Arif, K.B. Marwat, and A. Jan. (2008). Phenology and crop stand of wheat as affected by nitrogen sources and tillage systems.Pak. J. Bot. 40(3):1103-1112.
[71] Kidane Giorgis. (2015). Dry land Agriculture Production Systems in Ethiopia. National Publishers, Addis Ababa, Ethiopia.
[72] Kifle Zerga, Birhanu Tsegaye, Mekonen Gebru. (2018). Farmers participatory and selection of bread wheat Triticum Aestivum. L) varieties in cheha district, Gurage Zone, Ethiopia. Intercontinental journal of scientific and research publications, Vol 8(12)
[73] King, J., Gay, A., Sylvester-Bradley, R., Bingham, I., Foulkes, J., Gregory, P. and Robinson, D. (2003). Modelling cereal root systems for water and nitrogen capture towards an economic optimum. Annals of Botany, 91(3):383–390.
[74] Kotu, B.H., Verkuijl, H., Mwangi, W.M. and Tanner, D.G., (2000). Adoption of improved wheat technologies in Adaba and Dodola Wored as of the Bale Highlands, Ethiopia. CIMMYT.
[75] Krasowski, M.J.; Owens, J.N. (1999). "Tracheids in white spruce seedling's long lateral roots in response to nitrogen availability". Plant and Soil. 217 (1/2): 215–228. Doi10.1023/A:1004610513572 (https://doi.org/10.1023%2FA%3A1004610513572).
[76] Mann M. and J. Warner. (2015). Ethiopian Wheat Yield and Yield Gap Estimation: A Small Area Integrated Data Approach. International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia

[77] Marschener. (1995). Mineral nutrition of higher plants. 2nd ed. Academic press, London. 398p.
[78] Mekonnen Asrat. (2005). Response and uptake of barley (Hordeum irregulare L.) to different rates of Orga-P And nitrogen fertilizers on Nitisols of Gozamin District, Ethiopia. MSc Thesis, Haramaya University, Ethiopia
[79] Metson, A. J. (1961). Methods of chemical analysis for soil survey samples. Soil Bureau 171 Bulletin No. 12, New Zealand Department of Scientific and Industrial Research, pp. 168–175. Government Printer: Wellington, New Zealand.
[80] Minale Liben, Alemayehu Asefa, Tanner and Tilahun Tolessa; (2006). The response of bread wheat to N and P application under improved drainage on Bichena Vertisols in North- Western Ethiopia. In: The Tenth Regional Wheat Workshop for Eastern, Central and Southern Africa, CIMMYT, and Addis Ababa, Ethiopia.
[81] Minale Liben, Alemayehu Assefa, D.G. Tanner and Tilahun Tadesse. (1999). The response of bread wheat to nitrogen and phosphorous application under improved drainage on Bechena Vertisol in North Western Ethiopia. PP 298-303. In: The tenth Regional wheat Workshop for Eastern, Central and Southern Africa Addis Ababa, Ethiopia: CIMMYT
[82] Ministry of Agriculture and Natural resources (MoANR) (2016). Crop Variety Register. Issue No. 19. Addis Ababa, Ethiopia
[83] Minot NJ; Warner S Lemma; L Kasa; A Gashaw; S Rashid. (2015). The Wheat Supply Chain in Ethiopia: Patterns, trends, and policy options. International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia
[84] Minot, N., & Sawye, B. (2012). Agricultural production in Ethiopia: Results of the 2012 ATA baseline survey. International Food Policy Research Institute.
[85] MoARD (Minister of Agriculture and Rural Development), 2012. Crop variety registration. Addis Ababa,Ethiopia.
[86] Mosalem, M. E.; M. Zahran, M. M. EL-Menofi and A. M. Moussa. (1997). Effect of sowing date, seeding rate and nitrogen level on wheat production: 2- Yield and yield components. First Ann. Conf. Sept. 1-3, NRC, Giza, Egypt.
[87] Muhammad A, Zahir S, Hidayat U, Bushra K (2016). Yield response of wheat to nitrogen and potassium fertilization. Pure Appl Biol 5(4):868–875
[88] Murphy, H. 92007). A report on fertility status and other data on some soils of Ethiopia.Collage of Agriculture HSIU. Experimental Station Bulletin No. 44, Collage of Agriculture: p 551.
[89] Negassa, A., Shiferaw, B., Koo, J., Sonder, K., Smale, M.,Braun, H. J., Gbegbelegbe, S., Zhe Guo, D. H., Wood, S., Payne, T., & Abeyo, B. (2013). The potential for wheat production in Africa: Analysis of biophysical suitability and economic profitability. International Maize and Wheat Improvement Center (CIMMYT).
[90] Nevo, E., Korol, A. B., Beiles, A. and Fahima., T. (2002). Evolution of wild emmer and wheat improvement: population genetics, genetic resources, and genome organization of wheat's progenitor, Triticum dicoccoides. Springer Science and Business Media. Nitrogen use efficiency of wheat as affected by preceding crop, the application rate of nitrogen and crop residues. Australian Journal of crop science AJCS 4(5):363-368 (2010)
[91] Norman P. A. Huner; William Hopkins (2008-11-07). "3 & 4". Introduction to Plant Physiology 4th Edition. John Wiley & Sons, Inc. ISBN 978-0-470-24766-2.
[92] Noureldin NA, Saudy HS, Ashmawy F, Saed HM (2013). Grain yield response index of bread wheat cultivars as influenced by nitrogen levels. Ann Agric Sci 58:147-152.
[93] Obsa Chimdesa and Yeared Tesfaye. (2017). Participatory Variety Selection of Improved Bread Wheat Varieties for High Land Guji Zone, Southern Ethiopia.Journal of Biology, Agriculture and Healthcare. Vol.7(7).
[94] Olsen, S. R., Cole, C. V, Watandbe, F. and Dean, L. (1954). Estimation of Available Phosphorus in Soil by Extraction with sodium Bicarbonate. United States Department Of Agriculture; Washington.
[95] Parker, R. (2000). Introduction to plant science. (5th Edition). U.S.A.
[96] Rileyr, W. J.; Ortiz-Monasterio, I.; Matson, P. A. (2001). Nitrogen leaching and soil nitrate, nitrite, and ammonium levels under irrigated wheat in Northern Mexic.Nutrient Cycling in Agroecosystems. v. 61, n. 3, p. 223- 236.
[97] Roy R.N., Finck, A., Blair, G. J., Tandon, H. L. (2006). Plant nutrition for food security: A guide for integrated nutrient management. FAO Fertilizer and Plant Nutrition Bulletin 16. Food and Agriculture Organization of the United Nations, Rome, Italy, 368 p.
[98] Selamyihun Kidanu, Tanner, D. G. and Tekaleng Mamo. (1999). Effect Of nitrogen fertilizer applied to tef on the yield and N response of succeeding tef and durum wheat on A highland Vertisol. African Crop Science Journal, 7(1):35–46.
[99] Shewry, P. R. (2009). Wheat. Journal of Experimental Botany, 60(6):1537–1553 2016. Agriculture organization of the United Nations. Statistical database.
[100] Shrivastava, B.K., Singh, M.P. and Jain, S.K. (1992). Effect of spacing and nitrogen levels on growth, yield and quality of seed crops of radish. Seed Research Technology, 20: 85–7
[101] Sial, M. A., M. U. Dahot., M. A. Arain., G. S. Mark hand., S. M. Mangrio., M. H. Naqvi., K. A. Laghari and A. A. Mirbahar. (2009). Effect of water stress on yield and

yield components of semi-dwarf bread wheat (Triticum aestivum. L). Pak. J. Bot. 41(4): 1715 – 1728.
[102] Singa, S. K. (1977). Food legume distribution, adaptability and biology of yield. FAO Plant Production and Plant Protection Paper, 3, 124.
[103] Sobh, M.M., M.S. Sharshar and Soad A. El-Said, (2000). Response of wheat to nitrogen and potassium application in a salt affected soil. J. Product & Dev., 5(1): 83-98
[104] Sowers, K.E., B.C. Miller, and W.L. Pan. (1994). Nitrogen efficiency of split nitrogen applications in soft white winter wheat. Agron. J. 86: 942-948.
[105] Swan, H.S.D. (1971a). Relationships between nutrient supply, growth, and nutrient concentrations in the foliage of white and red spruce. Pulp Pap. Res. Inst. Can., Woodlands Pap. WR/34. 27 p.
[106] Tadesse, W., Bishawand, Z., & Assefa, S. (2018). Wheat production and breeding in Sub-Saharan Africa challenges and opportunities in the face of climate change. International Journal of Climate Change Strategies and Management, 11(5), 696–715. https://doi.org/10.1108/IJCCSM-02-2018-0015
[107] Tanner, Amanuel Gorfu and Asefa Taa; (1993). Fertilizer effects on sustainability in the wheat-based small-holder farming systems of southeastern Ethiopia. Field Crops Res. 33: 235-248.
[108] Tanaka, A. (1994). Plant characters related to Nitrogen response in rice. The mineral nutrition of the rice plant, Proceedings of the rice plant.Vol. 2.Food and Agriculture Policy Research Center, Tokyo.pp 334 - 439.
[109] Taye B., Yesuf, A., Sahlemedhin, S., Amanuel, G., Mohammed, H., Tanner, D. and Tesfaye, T. (2002). Optimizing Fertilizer Use in Ethiopia. Correlation of Soil Analysis with Fertilizer Response in Hetosa Wereda, Arsi Zone. EARO/SG-2000 Collaborative Research.
[110] Tekalign Tadesse. (1991). Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis Manual: Plant Science Division Working Document No. 13. International Livestock center for Africa. Addis Ababa, Ethiopia.
[111] Teklu E, Hailemariam T (2009). Agronomic and Economic Efficiency of Manure and Urea Fertilizers Use on Vertisols in Ethiopian Highlands. Agricultural Science in China 8(3):352-360.
[112] Tesfaye T. (2010). An overview of tef and durum wheat production in Ethiopia.
[113] Thakur, R. B. (1993). Performance of summer rice (Oryza sativa) to varying levels of nitrogen.Indian.J. Agron. 38 (2): 187 - 190.
[114] Tulema, B., (2005). Integrated plant nutrient management in crop production in the central Ethiopian highlands (Doctoral dissertation, Norwegian University of Life Sciences).
[115] USDA (2023). The Foreign Agricultural Service (FAS) updates its production, supply and distribution (PSD) database for cotton, oilseeds, and grains Foreign Agricultural Service/Global Market Analysis. USDA, Washington
[116] Van Beek, Elias, Yihenew, Heesmans, Tsegaye, Feyisa, Tolla, Melmuye and Gebremeskel Mengist. (2016). Soil nutrient balances under diverse agro-ecological settings in Ethiopia. Nutr Cycl Agroecosyst (2016) 106:257–274.
[117] van Ittersum, M.K. and Cassman, K.G. (2013). Yield Gap Analysis-Rationale, Methods and Applications. Introduction to the Special Issue. Field Crops Research, 143, 1-3.
[118] Walia, Singh and Singh; (1980). Growth and nutrient uptake behavior of dry land wheat influenced by N fertilization. J. Indian Soc. of Soil Sci. 28(1): 91-97. Argon. 85 (5): 1044 – 1049.
[119] Walkley, A. J., & Black, I.A.(1934). Estimation of soil organic carbon by the chromic acid titration method. Soil Science, 37,29-38.https://doi.org/10.1097/00010694 - 193401000-00003
[120] Westerman, R.L. (1990). Soil testing and plant analysis. Soil Science Society of AmericKa, Inc. Madison,Wisconsin, USA.
[121] White, E.M. and Wilson, F.E. (2006). Response of grain yield, biomass and harvest index and their rates of genetic progress to nitrogen availability in ten winter wheat varieties. 45: 85-101.
[122] White, J.W., D.G. Tanner, and J.D. Corbett. (2001). An Agro-Climatological Characterization of Bread Wheat Production Areas in Ethiopia. NRG-GIS Series 01-01. Mexico, D.F.: CIMMYT.
[123] Wogene Solomon and Agena Anjulo. (2017). Response of Bread Wheat Varieties to Different Levels of Nitrogen at Doyogena, Southern Ethiopia. International Journal of Scientific and Research Publications, 7(2):452–59.
[124] Woldeab, A. and Mamo, T., (1991). Soil fertility management studies on wheat in Ethiopia.
[125] Workineh Assefa, Nega Yemane and Habte Dawit. (2015). Planting density, and nitrogen and phosphorus fertilization effect on different bread wheat (Triticum aestivum L.) genotypes in Southern Tigray, Ethiopia. World Journal of Medicine and Medical Science Research, 3(2):20–28.
[126] Worku M, Bänziger M, Erley GSAM, Friesen D, Diallo AO, Horst WJ. (2007). Nitrogen uptake and utilization in contrasting nitrogen efficient tropical maize hybrids. Crop Sci. 2007; 47(2):519–28.
[127] Yetsedaw Aynewa, Tadesse Dessalegn and Wondimu Bayu. (2013). Participatory evaluation of malt barley (Hordeum vulgare L.) genotypes for yield and other agronomic traits at North West Ethiopia. 2(8): 218 -222.
[128] Zewdie, L., Tanner, D.G., Elias, E.M., Gorfu, A., Tarekegne, A.T., (1990). The relative importance of yield limiting factors on bread wheat in the Ethiopian

highlands. CIMMYT Regional Wheat Workshop for Eastern, Central and Southern Africa, Addis Ababa, Ethiopia.

[129] Zewdu Yilma and Tanner, D. G. (1994). Response of bread wheat to rate and timing of nitrogen application in a marginal rainfall zone in Ethiopia. African Crop Science Journal, 2(3):291–299.