

RESEARCH PAPER

Impact of NPS Fertilizer Rates on Growth and yield components of Linseed (*Linum usitatissimum* L.), Varieties in Horro Guduru Districts, Western Ethiopia

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ABSTRACT

The yield of linseed crops was low in the study area due to improper field management practices with, poor fertilizer application being a major challenge. To address this issue, a field experiment was conducted during the 2019 and 2020GC main cropping seasons at Harato and Gitilo sites to investigate the response of blended NPS fertilizer rates on the growth and yield components of linseed varieties. The factorial experiment included four blended fertilizer rates and four linseed varieties, arranged in a randomized complete block design with three replications. The analysis of variance showed that growth and yield components were significantly influenced by the main effect of linseed varieties and NPS fertilizer rates. Additionally, days to 90% physiological maturity, plant height, number of capsules per plant, seeds per capsule, dry biomass and seed yield were significantly ($p < 0.05$) affected by the interaction effect of linseed varieties and NPS fertilizer rates. The maximum seed yield was recorded for improved varieties such as Kuma (1861 kg/ha), Berene (1860 kg/ha), and Belay (1796 kg/ha) at the rate of 150 kg NPS fertilizer per hectare. In contrast, the minimum seed yield was observed for a local cultivar with no NPS fertilizer applied. Therefore, it is recommended to sow Kuma and Berene varieties and apply 150 kg NPS per hectare in similar agro ecologies for optimum results.

HIGHLIGHTS

- ① Weather condition (sites and years) influence on linseed yield.
- ① NPS fertilizers mainly recommended for oil crops.
- ① Linseed varieties vary in seed yield.
- ① Linseed varieties affected by environments.

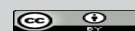
Keywords: Blended fertilizer, fatty acid, linseed, varieties, and yield

Linseed (*Linum usitatissimum* L.) is one of the oil crops cultivated in the Ethiopian highlands for a long period as a source of edible oil. The seeds are rich in nutritional quality, essential polyunsaturated fatty acids, and soluble dietary fiber (Mohammadi *et al.* 2010). The seed is used as a cash crop that generates revenue both locally and in foreign exchange (Sintayehu *et al.* 2022). Linseed seeds are well known for their saturated and unsaturated

properties of fatty acids and their ratio to each other is of great importance for human consumption and the adaptation of the plant to its environment (Suri *et al.* 2020; Wu *et al.* 2020). The growth and seed yield of linseed crops are significantly influenced by

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agronomic factors (Salah and Mohamed, 2015; Klein *et al.* 2016) altitude and weather conditions (Angelini *et al.* 2016) as well as soil types and fertility.

Nitrogen is a constitutional component of protein and a key point for amino acids, the building block of protein molecules, and DNA (Raven *et al.* 2005). It is one of the most important plant nutrients because it affects the amount of protoplasm and chlorophyll formed, which consequently increases cell size, leaf area, and photosynthetic activity (Kadar *et al.* 2004). Nitrogen levels affect plant height, the number of capsules per plant, thousand seed weight, and seed yield. Excess nitrogen application results in a reduction of seed yield by promoting vegetative growth, diseases, and lodging (Lemessa and Zerihun 2022). Linseed yield has been shown to increase with higher nitrogen application rates (Girma, 2018). Moreover, an adequate nitrogen rate encourages growth, development, and color formation in the crop (Fageria and Baligar, 2005). Therefore, using nitrogen fertilizer along with an appropriate amount of phosphorus increases linseed yields (Ahmad *et al.* 2011).

Phosphorus is a component of the complex nucleic acid structure of plants, which regulates protein synthesis (Jiao *et al.* 2013). It is important in cell division and the development of new tissue. Adding phosphorus to soil promotes root growth winter hardiness, stimulates tillering and hastens maturity (Yaping *et al.* 2016). Phosphorus deficiency in plants shows stunt growth, abnormal dark green color, and elongated roots (Yawalkar *et al.* 2002). Likewise, phosphorus is essential for plant growth and seed yield (Soethe *et al.* 2013). The application of phosphorus affects straw yield, but it increases seed yield due to a positive response on capsules per plant (Khan *et al.* 2000). Plant growth is restricted when the soil shows low levels of phosphorus (Chaudhary *et al.* 2008).

The seed yield of linseed increased by 38-46% with the application of 30 kg P₂O₅ ha⁻¹ on soils with 5.9-13.1 mg ka⁻¹ of available phosphorus at a depth of 0-30 cm (Xie *et al.* 2016).

Sulfur is mainly responsible for enhancing reproductive growth and the proportion of reproductive tissues (Sangeramsing *et al.* 2021). Sulfur is an essential element as a constituent of proteins, cysteine-containing peptides such as

glutathione, or numerous secondary metabolites in plants like the synthesis of amino acids, fatty acids, enzymes that catalyze proteolytic enzymes, vitamins, and chlorophyll formation within the cell (Kacar and Katkat, 2007). Sulfur deficiency tends to adversely affect the growth and yield of oil seed crops to an extent of 10–30% due to poor nutrition (Jat *et al.* 2008; Basumatary *et al.* 2019). Studies have shown that the application of sulfur fertilizer increased the seed, oil and protein contents (Parwar *et al.* 2023).

Linseed has a long history of cultivation by smallholder farmers in Ethiopia it is the third most important oil crop next to nuog, and sesame in the country, but the crop is traditionally cultivated for edible oil and cash crop values by small-holder farmers (Sintayehu *et al.* 2022). Out of the total grain production in the country 6.68% of the land was covered by oil crops. Linseed shared 79,042.5 ha (0.625%) of this, with a total production of 882, 029.51 quintals per hectare and the average yield potential of 13.6% in the Oromia regional state, which is higher than the national production of Ethiopia at 11.62% (CSA, 2022).

The area coverage and production of linseed crops are lower compared to other districts. The main causes for low production are due to a lack of improved seed, poor agronomic practices such as improper fertilizer use, minimum tillage, and poor site selection. In Ethiopia's agricultural system, farmers have traditionally used only di-ammonium phosphate and urea. However, the Ethiopian Soil Information System (EthioSIS) recently developed a soil map based on soil fertility which revealed deficiencies in sulfur, nitrogen and phosphorus in the study areas. To address this issue, the Ministry of Agriculture introduced blended fertilizer (NPS) containing 19% nitrogen, 38% phosphorus, and 7% sulfur. This study aims to fill the research gaps by setting the following objectives.

Specific objectives

1. To assess the response of NPS fertilizer rates on growth, yield component and seed yield of linseed varieties;
2. To evaluate the interaction effect of NPS fertilizer rates and linseed varieties on seed yield and seed yield component.

MATERIALS AND METHODS

Description of study sites

The experiment was conducted in Horro Guduru Wollega Zone, Jimma Geneti, and Horo districts during the main cropping seasons of 2019/2020 and 2020/2021. Both districts are located in the Oromia National Regional State in western Ethiopia. The Harato site is situated in Jimma Geneti Woreda at an altitude of 2300 meters above sea level (9° 27' 30" N - 9° 30' 0" latitude and 37° 7' 30" E - 37° 10' 0" E longitudes), while the Gitilo site is located in Horro Woreda at Gitilo Dale Kebele with an altitude of 2723 meters above sea level (9° 32' 30" N, 9° 35' 0" N latitude, and 37° 2' 30" E, 37° 5' 0" longitude) at 2857 meters above sea level. The mean annual rainfall at Gitilo 2100 mm and at Harato is 2211 mm 2,211 mm additionally; the mean annual minimum temperature is 17°C at Gitilo and 22°C at Harato. The mean annual maximum temperature is 20°C at the Gitilo site and 24°C at Harato study sites, respectively, according to the Shambu Meteorological substation report (unpublished). The soils in the study sites belong to the light clay textural class (Horro Guduru Wollega Zone Agriculture Office, 2018).

Experimental materials

Three linseed varieties and one local cultivar were used as experimental materials. The detailed descriptions of these varieties are listed in Appendix Table 3.

Treatment and Experimental Design

The experiment consists of sixteen treatment combinations with two factors: the first factor has four linseeds (Belay-96, Berene, Kuma, and Local Cultivar), and the second factor has four fertilizer rates (0, 50, 100, and 150 kg/ ha). The factorial experiment was arranged as a randomized complete block design with three replications. The treatments were assigned to the experimental plot randomly (Table 4).

Experimental Procedures

1. Soil sampling and chemical testing

The composite soil sample was collected from nine

points in a diagonal pattern before plowing the land and after harvesting on individual plot bases at a depth of 0–20 cm using an auger on both sites and seasons. The sample was air dried, crushed using a mortar and pestle, and passed through a 2 mm sieve (Anderson, 2010). The composite soil samples were analyzed for selected physico-chemical properties including soil pH and texture, total nitrogen, organic carbon, organic matter, available phosphorus, and available sulfur. Soil pH was measured using a glass electrode pH meter in a suspension of a 1:2.5 mixture of soil and distilled water as determined by (Bouyoucos, 1962). Soil organic carbon was determined using the method described by (Nelson and Sommers, 1996). Total nitrogen was analyzed using the Kjeldahl digestion method with sulfuric acid (Jackson, 1967).

Available phosphorus was determined by extracting it from the soil sample with a solution of 0.03 ammonium fluorides in 0.1 M hydrochloric acid following the Bray I methods (Bray I, 1945). Sulfur was analyzed turbidimetrically using calcium orthophosphate (Rowell 1994). Organic matter (OM) was estimated indirectly from the organic carbon determination with the formula $OM\% = 1.72 \times \%OC$ using the Bouyoucos hydrometer method (FAO, 2008). The soil samples were analyzed at the Holeta Agriculture Research Center soil laboratory.

2. Field managements procedures

Fine seed beds were required for uniform plant germination and growth, so experimental sites were plowed three times starting from April to the sowing dates. In mid-June, 30 kg ha⁻¹ seeds were drilled at 20 cm row spacing with a 5 cm soil depth. Blended fertilizer rates of 0, 50, 100, and 150 kg NPS ha⁻¹ were applied during the sowing period. Half of the Urea fertilizer was applied 45 days after seeding. Hand weeding was done twice at 30 days and 60 days after sowing. Data was collected at each physiological stage of the plants.

Harvesting was done manually by human power when the capsules turned brown or the seeds inside the capsules made a sound when shaken. The harvested plants were left in the field for two to three weeks until they dried or reached a constant weight. Once the seeds were separated from the straw, seed yield per plot was recorded, converted

into hectare and the clean seed was stored at ten percent moisture content in dry conditions.

Data Collection

1. Crop phenology

Days to 50% flowering: The number of days from sowing to 50% flowering was recorded when the plants in a plot produced proximately 50% of their flowers.

Days to 90% maturity: The number of days from sowing to 90% physiological maturity was recorded when the plants in the plot displayed a brown color or when the seeds made a shaking sound when shaken disturbed.

2. Growth parameters

Plant height (cm): Ten randomly selected plants within the plot area were measured from the base to the top of the stem, and their heights were averaged.

Number of branches per plant: At physiological maturity, ten branches per plant were randomly counted within the plot area, and the average was recorded.

3. Yield components and yield

Number of capsules per plant: The number of capsules per plant was determined by randomly selecting ten plants, and counting the capsules, and calculating the average.

Number of seeds per capsule: The number of seeds per capsule was randomly counted by selecting ten capsules per plant, and the average was recorded.

Thousand seed weight (g): The weight of a thousand seeds was measured in gram (using a sensitive balance) per plot at 7% moisture content.

Dry biomass (kg): The aboveground plants were weighed per plot after being air-dried for two consecutive weeks and converted to hectare basis.

Grain yield (kg): After harvesting, sun-drying, threshing and cleaning, the seed yield per plot was recorded and then converted to yield per hectare.

Harvest index (%): This was calculated by dividing the economic yield by the biological yield and multiplying by one hundred.

Data analysis

The collected data was subjected to the statistical procedure for analysis of variance (ANOVA) as described by Gomez and Gomez (1884) in SAS version 9.4 software. Before combining across seasons, the data was tested for homogeneity of error variance. When ANOVA indicated a significant difference, treatment means were compared for significant difference at a 0.05% probability level using the Duncan's Multiple Range Tests (DMRT) method.

RESULTS AND DISCUSSION

Soil Properties of Experimental Sites

The mean values of soil analysis in Table 1 indicate that the soil at the experimental sites was classified as clay loam. The pooled mean of two growing season showed that Harato had 50.79% clay soil and Gitilo had 45.29% clay soil. Clay soil is beneficial for plant growth and development due to its high nutrient and water holding capacity. The pH values (1:2.5 H₂O) at both experimental sites indicated an acidic nature, with pH ratings falling within the strongly acidic range according to source (Morphy, 1968 and London 1991).

Table 1: The pooled mean of physico-chemical properties of experimental sites soil before planting

Soil parameter	Harato site	Gitilo Site
	2019-2020/21	2019- 2020/21
pH	4.64	4.75
OC (%)	5.54	5.88
OM%	9.53	10.11
TN%	0.48	0.52
Avai (ppm)	5.31	5.35
Sulfur (mg/kg)	1.35	2.06
Particle size		
Clay%	50.79	45.29
Silt%	27.83	30.98
Sand %	21.38	23.73
Soil texture class	Clay loam	Clay loam

The soil organic carbon levels ranged from 5.54% to 5.88%, with organic matter content ranging from 9.92% to 10.11%. These high levels of organic carbon and organic matter suggest good soil structure and buffering capacity at the experimental sites, allowing for tailored nitrogen fertilizer application based on

crop type and cultivation goals as recommended by source (Berihanu 1980). The total nitrogen content at Harato (0.48%) and Gitilo (0.52%) sites was optimal for plant growth, falling within the medium range according to (London 1991). Phosphorus levels extracted using the Bray I method, were low at 5.31 ppm for Harato and 5.35 ppm for Gitilo.

Effect of NPS fertilizer rates on crop phenology of linseed

Days to 50% flowering

Days to fifteen percent flowering were significantly ($p < 0.05$) affected by the main effects of NPS and varieties. Additionally, it was significantly influenced by the interaction effects of years by NPS, and NPS by sites. During the 2020/21 the main cropping seasons, the longest time to reach 50% flowering (85.1 days) was observed at 100 kg NPS per hectare fertilizer on the Gitilo site. This was similar to the results seen at 150 kg per hectare.

On the other hand, the shortest flowering period (70.4 days) was noted at zero fertilizer rates on the Harato site in both cropping season (Table 2). Plants at zero fertilizer rates tend to complete their life cycle sooner. Both sites have different weather conditions and altitude. Higher fertilizer rates and cooler weather conditions can delay can the flowering of linseed by encouraging more vegetative growth (Teshome and Alemayehu, 2021). Similarly, study by Mizan *et al.* (2010) discovered that the time to reach fifteen percent flowering was prolonged at 200 kg NPSB ha⁻¹ in sesame varieties, but the plants began flowering earlier without any flowering. Increasing the amount of NPS fertilizer delayed the flowering period of the linseed crop in both sites and cropping seasons. Additionally, 100 kg NPS ha⁻¹ found to be was statistically equivalent to 150 kg NPS ha⁻¹ in terms of flowering dates. A study by Gelgelo and Zebene (2022) reported that excessive fertilizer and seed rates also had a delaying effect on the flowering period. Similarly, nitrogen fertilizer rates showed a significant difference in the days to 50% flowering of the linseed crop cross various sites and years (Sintayehu *et al.* 2022).

Days to 90% physiological maturity

Days to 90% physiological maturity were highly significantly influenced by the mean effects of years,

sites, varieties, and sites by varieties with ($P < 0.01$). Additionally, other factors such as NPS fertilizer rate, year by site, sites by year by NPS, and NPS by site by year had a significant effect on days to maturity ($p < 0.05$).

Table 2: Effect of NPS fertilizer rates by sites by years on days to 50% flowering dates on Harato and Gitilo sites in 2019 and 2020

Sites	Years	NPS fertilizer rate				Mean
		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	
Harato	2019	70.4 ^a	72.6 ^b	74.1 ^{bc}	75.4 ^{cde}	73.1
	2020	74.8 ^{cd}	76.5 ^{de}	78.9 ^f	80.0 ^{fg}	77.6
Gitilo	2019	74.9 ^{cd}	76.8 ^e	78.6 ^{ef}	83.1 ^{hi}	78.4
	2020	80.7 ^g	83.5 ^{hi}	85.1 ^{ij}	86.2 ⁱ	83.9
Mean		75.2	77.4	79.2	81.2	78.3
DMRT (0.05)		CV% = 2.67				

Mean within column followed by the same letters are none significant difference ($p < 0.05$), DMRT = Duncan multiple range test, CV% = Coefficient of variation.

The longest days to 90% physiological maturity (186.58 days and 187.25 days) were recorded at 150 kg NPS per hectare on the Gitilo site, during both cropping seasons. This delay in maturity could be attributed to the cool temperature of the Gitilo site as well as the adequate amount of fertilizer. Phosphorus fertilizer specifically aids in cell division, expansion and root elongation, leading to increased nutrient uptake and delayed maturity.

High rates of nitrogen fertilizer in the soil can result in luxurious vegetative growth (Bharat *et al.* 2013). Conversely, the shortest days to physiological maturity (166.25 days and 164.83 days) were recorded at zero fertilizer rates on the Harato site during both cropping seasons, with similar results for 50 kg NPS per hectare, respectively (see Table 3). This variation may be due to differences in fertilizer rates, sites and cropping seasons. The Harato site located at a mid altitude area, experience optimal temperature and rainfall during the cropping season which could contribute to the earlier maturity of plants due to less competition for nutrients (Reta *et al.* 2017 and Sintayehu *et al.* 2022). Days to physiological maturity were also significantly influenced by the interaction of NPS rates and varieties. The longest time to reach 90% physiological maturity (181.08 days and 185.75

days) was observed in the Kuma variety at 100 and 150 kg NPS per hectare, followed by the Belay variety (183.58 days) and Berene variety (184.5 days) at 150 kg NPS per hectare, respectively (Table 3). Improved varieties with longer root systems may absorb more nutrients and moisture from the soil, prolonging their vegetative growth. Conversely, the shortest time to maturity (161.06 days and 165 days) was recorded in local cultivars at 0 and 50 kg NPS per hectare, respectively (Table 3). Local cultivars with shorter root systems tend to absorb nutrients and moisture from the top soil surface, completing their cycle in a shorter period.

Furthermore, days to 90% physiological maturity of linseed were significantly affected by the interaction of varieties with sites (see Table 3). The maturity dates of linseed varieties varied between sites, with improved varieties taking longer to mature at the Gitilo site, while local cultivars matured more quickly at the Harato site.

This difference can be attributed to genotypes, altitude, and weather conditions. These results align with previous studies that have shown significant

influence of linseed genotypes (Biru and Dereje *et al.* 2014).

Effect of NPS fertilizer rates on growth parameter of linseed

1. Plant height (cm)

Plant height is a crucial characteristic of plant growth that impacts the overall growth rate of plants. The tallest plants measured came from improved varieties of Belay (85.56 cm), Berene (86.38 cm), and Kuma (87.38 cm) at a fertilizer rate of 150 kg NPS per hectare. In contrast, the shortest height (52.66 cm) was recorded from a local cultivar at 0 kg NPS per hectare. This disparity may be due to genetic factors, different fertilizer rates, and their combined effects.

A similar study by Wakjiria (2018) found that low blended fertilizer rates can be lead to stunted growth in linseed plants. Increasing NPS fertilizer rates led to an increase in plant height by 7.97%, 7.97%, and 6.37%, respectively. However, above 150 kg NPS per hectare, the height gradually declined.

Table 3: Effect of NPS rate by site by years and NPS by varieties on days to 90% physiological maturity at both site and years

Sites	Years	NPS rate				Mean
		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	
Harato	2019	166.25 ^{ab}	167.75 ^{ab}	171.83 ^{bcd}	176.67 ^{cdef}	170.63
	2020	164.83 ^a	168.00 ^{ab}	170.92 ^{bc}	174.33 ^{cde}	169.52
Gitilo	2019	177.58 ^{def}	179.92 ^{fg}	183.67 ^{gh}	186.58 ^h	181.94
	2020	172.08 ^{bcd}	177.00 ^{def}	180.92 ^{fg}	187.25 ^h	179.31
Mean		170.19	173.17	176.84	181.21	175.35
DMRT (0.05)	5.17	CV% = 3.66				
Varieties		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	Mean
Belay		172.08 ^{cde}	174.75 ^{defg}	178.67 ^{ighi}	183.58 ^{ij}	177.27
Berene		173.33 ^{cdef}	175.75 ^{defgh}	179.75 ^{ghi}	184.50 ^{ij}	178.33
Kuma		174.33 ^{defg}	177.17 ^{efgh}	181.08 ^{hij}	185.75 ⁱ	179.52
Local		161.06 ^a	165.00 ^{ab}	167.83 ^{bc}	171.06 ^{cd}	166.24
Mean		170.2	173.17	176.83	181.22	175.34
DMRT (0.05)	5.24	CV% = 3.71				
Sites		Belay	Berene	Kuma	Local	Mean
Harato		172.63 ^b	173.75 ^b	175.17 ^b	158.75 ^a	170.08
Gitilo		181.92 ^c	182.92 ^c	184.00 ^c	173.67 ^b	180.63
Mean		177.28	178.34	179.59	166.21	175.36
DMRT (0.05)	2.91	CV% = 2.99				

Mean within column followed by the same letters are none significant difference at ($p>0.05$), DMRT = Duncan multiple range test, CV%-Coefficient of variation.

This increase in height may be attributed to a sufficient nutrient supply, as nitrogen is essential for chlorophyll formation and phosphorus is involved in energy transfer for cellular metabolism and cell division (Zafar *et al.* 2020).

Similarly, a study by Ali *et al.* (2013) found that the tallest plant (88 cm) was measured at a fertilizer rate of 175-175-93.75 kg NPK per hectare, while the shortest height (42.8 cm) was observed in the control treatments. Consistent with these findings, Sangramsing *et al.* (2021) observed that high rates of nitrogen fertilizer increased the height of linseed plants. Additionally, the plant height of linseed was significantly affected by nitrogen fertilizer rate rather than phosphorus and sulfur (Girma and Tenaye, 2020), with the tallest height recorded at a rate of 150 kg per hectare compared to 50 kg per hectare (Gaikwad *et al.* 2020).

Table 4: Summarized effect of varieties by NPS and varieties by sites on plant height

	Linseed varieties				
	Belay	Berene	Kuma	Local	Mean
NPS rate					
0 kg ha ⁻¹	66.62 ^{de}	68.1 ^{de}	69.36 ^{de}	52.66 ^a	64.19
50 kg ha ⁻¹	72.96 ^f	74.23 ^f	75.24 ^f	56.58 ^b	69.75
100 kg ha ⁻¹	78.87 ^g	81.31 ^{gh}	82.31 ^h	60.49 ^c	75.75
150 kg ha ⁻¹	85.56 ⁱ	86.38 ⁱ	87.38 ⁱ	64.32 ^d	80.91
Mean	76.01	77.51	78.57	58.51	72.65
DMRT(0.05)	2.76	CV%=4.72			
Sites	Belay	Berene	Kuma	Local	Mean
Harato	77.75 ^{bcd}	79.67 ^{cd}	80.85 ^d	59.08 ^a	74.34
Gitilo	74.25 ^b	75.30 ^{bc}	76.29 ^{bc}	57.94 ^a	70.95
Mean	76.00	77.49	78.57	58.51	72.64
DMRT (0.05)=	4.55	CV%=9.75			

Mean within column followed by the same letters are non significant difference at ($p>0.05$), DMRT = Duncan multiple range test, CV%= Coefficient of variation.

Furthermore, a study by Karunakaran *et al.* (2010) showed that applying 125% of the recommended dose of fertilizers (17:34:54 kg N, P₂O₅, and K₂O per hectare) increased plant height (51.8 cm) compared to the recommended dose (48.3 cm) in Karaikal, Tamil Nadu, on coastal deltaic alluvial soils. The tallest plants (99.44 cm, 92.44 cm, and 86.67 cm) were recorded at Adami Tulu, Dugda, and Lume sites at fertilizer rates of 150, 200, and 150 kg per

hectare, respectively; while the shortest height was observed at zero fertilizer rates (Kashyap *et al.* 2018). Similarly, plant height was significantly ($p<0.05$) affected by the interaction effect of varieties by sites (Table 4), with improved varieties showing different heights at each site. This suggests that improved varieties have site-specific characteristics. The local cultivar had inferior height at both sites, while improved varieties of linseed had superior plant height.

A study by Girma and Tenaye (2020) indicated that the application of sulfur fertilizer influenced growth parameters and also reported that plant height varied due to genetics, with the tallest height of 85.47 cm recorded from the Kassa 2 variety and the shortest height of 73.67 cm from the local check on the Tabour site (Biru and Dereje, 2014).

2. Primary branches per plant

Increasing NPS fertilizer rates led to an increase in the number of primary branches per plant at both sites and during both cropping seasons (Table 5). The average minimum number of branches per plant was 7.36, while the average maximum number of primary branches per plant was 13.56 was observed at 150 kg NPS ha⁻¹ in both locations and years. This variability was attributed weather conditions, agro ecology, NPS fertilizer rates and their interaction effects.

Similarly, Gaikwad *et al.* (2020) found that the highest numbers of primary branches per plant were recorded at 150 kg ha⁻¹, while the lowest number was seen at 50 kg ha⁻¹. Previous studies by Kumar *et al.* (2011) and Yaping *et al.* (2016) also indicated that the number of branches per plant increased with application the amount of Phosphorus fertilizer to the soil. Additionally, Teshome and Alemayehu (2021) observed that the maximum number of branches per plant was achieved with 50 kg NPS ha⁻¹ and 69 kg N ha⁻¹, with the minimum branches recorded at 0 kg NPS ha⁻¹ and 0 kg N ha⁻¹.

Conversely, the number of primary branches per plant was significantly ($p<0.05$) influenced by the interaction effect of NPS fertilizer rates and sites, while increasing fertilizer rates lead to increase in the number of primary branches per plant, there was no significant different between 0 kg ha⁻¹ and 50 kg NPS ha⁻¹ at both sites (Table 5). Low

temperatures combined with a shortage of fertilizer can cause stunted growth and a lack of branches per plant. Nitrogen help is essential for cell division, expansion, and photosynthetic activity, can increase the number of branches per plant. Similarly, Kashyap *et al.* (2018) noted that a high number of branches per plant (5.12), was obtained with 90 kg of N per hectare, while the lowest number of branches per plant (4.03) was recorded at zero fertilizer rates.

Table 5: Summarized effect of NPS rates by sites by years and NPS rates by sites on number of primary branches at both sites and seasons

NPS fertilizer rates						
		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	Mean
Sites	Years					
Harato	2019	7.33a	9.23b	11.83d	14.01e	10.6
	2020	6.73a	10.6cd	11.83d	14.45e	10.89
Gitilo	2019	7.77a	11.99d	14.21e	13.83e	11.94
	2020	7.59a	9.33bc	11.57d	11.93d	10.11
Mean		7.36	10.29	12.36	13.56	10.89
DMRT (0.05)	1.28	CV% = 14.56				
=						
Sites						
Harato		7.03a	9.92b	11.83c	14.20e	10.75
Gitilo		7.68a	10.66b	12.89d	12.87d	11.03
Mean		7.36	10.29	12.36	13.54	10.89
DMRT (0.05)	0.99	CV% = 16.04				
=						

The mean within column followed by the same letters are non significant difference at ($p > 0.05$), DMRT= Duncan multiple range test, CV%= Coefficient of variation.

Yield and yield attributes

1. Number of capsules per plant

The number of capsules per plant was significantly affected by NPS rates and varieties ($p < 0.01$), with other factors such as the main effect of sites and the interaction of the NPS rate by site by year also showing significant influence on capsules per plant ($p < 0.05$) (Table 6). In most cases, the maximum numbers of capsules per plant (46.31) were recorded at 150 kg NPS ha⁻¹ on the Harato site during 2019, and (47.82) on the Gitilo site in 2020 (Table 6). This could be attributed to the nutrient levels and favorable weather conditions. However,

the minimum number of capsules per plant was observed at 0 kg NPS per plant.

Higher NPS fertilizer rates increased plant height, number of branches per plant, and capsules per plant due to increased photosynthesis accumulation in the plant. These findings are consistent with Soethe *et al.* (2013) who reported that the number of capsules per plant was significantly influenced by the interaction effect of NPS rates and supplemental nitrogen fertilizer at both sites and seasons.

Table 6: The summarized effect of NPS rate by sites by years and NPS rates by varieties on number of capsules per plant

		NPS fertilizer				
		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	Mean
Sites	Years					
Harato	2019	26.48 ^a	33.93 ^b	40.37 ^c	46.31 ^{ef}	36.77
	2020	24.55 ^a	35.23 ^b	41.33 ^{cd}	44.20 ^{de}	36.47
Gitilo	2019	27.48 ^a	36.21 ^b	43.91 ^{de}	45.60 ^{ef}	38.3
	2020	26.79 ^a	35.24 ^b	41.53 ^{cd}	47.82 ^f	37.85
Mean		26.33	35.15	41.79	45.98	37.35
DMRT (0.05)		3.03	CV% = 10.1			
		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	Mean
Varities						
Belay		24.96 ^a	33.77 ^c	40.44 ^{cd}	45.07 ^{fg}	36.06
Berene		25.78 ^a	34.37 ^c	41.51 ^{de}	46.20 ^{fg}	36.97
Kuma		25.08 ^a	33.93 ^c	41.54 ^{de}	45.65 ^{fg}	36.55
Local cultivar		29.49 ^b	38.54 ^{cd}	43.65 ^{ef}	47.01 ^g	39.67
Mean		26.33	35.15	41.79	45.98	37.31
DMRT (0.05)		2.46	CV% = 9.67			

Mean within column followed by the same letter are non significant different at ($p > 0.05$).

Similarly, Biru and Dereje (2014) noted that the application of 45 kg P per hectare was increased the number of capsules per plant by 20% compared to the control. Additionally, Biru and Dereje (2014) found that the maximum number of capsules per plant was observed at 40 kg P per hectare and 30 kg S per hectare. Also, Varanasi *et al.* (2020) also stated that a high number of capsules per plant (45.16 kg) was recorded with at the combined application of 25 kg NPS per hectare and 69 kg N hectare, while the lowest number of capsules per plant recorded

in the control group (0 kg NPS per hectare and 0 kg N per hectare).

2. Number of seeds per capsule

The minimum number of seeds per capsule 6.2 and 6.55 was recorded at 0 kg NPS ha⁻¹ on the Gitilo site during both growing seasons and on the Harato site in the 2019/20 year (Table 7). This may be due to a shortage of nutrient elements, with nitrogen fertilizer aiding in chlorophyll formation, and phosphorus aiding in seed formation. Sulfur also supports photosynthetic reactions and seed formation. Cool temperatures, along with low nutrient elements limit plant growth, resulting in few and small seeds per capsule.

Table 7: The summarized effect of NPS rate by site by year, and NPS and varieties on seeds per capsule at both sites and years

Sites	Years	NPS fertilizer				Mean
		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	
Harato	2019	6.56 ^a	7.71 ^b	8.56 ^c	9.81 ^e	8.16
	2020	7.86 ^b	8.43 ^c	8.55 ^c	8.54 ^c	8.35
Gitilo	2019	6.2 ^a	7.57 ^b	8.77 ^c	9.31 ^d	7.96
	2020	6.55 ^a	7.79 ^b	8.58 ^c	9.36 ^d	8.07
Mean		6.79	7.88	8.62	9.26	8.14
DMRT (0.05)		0.43	CV% = 6.5			
Varieties		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	Mean
Belay		6.69 ^a	7.91 ^{cd}	8.59 ^{efg}	9.29 ^{hi}	8.12
Berene		6.92 ^a	7.96 ^{cd}	8.81 ^{fgh}	9.46 ⁱ	8.29
Kuma		6.64 ^a	7.55 ^{bc}	8.37 ^{def}	9.02 ^{ghi}	7.89
Local		7.02 ^{ab}	8.08 ^{cde}	8.69 ^{fgh}	9.29 ^{hi}	8.27
Mean		6.82	7.88	8.62	9.27	8.14
DMRT (0.05)		0.54	CV% = 8.21			

Mean within column followed by the same letters are none significant difference ($P > 0.05$) DMRT = Duncan multiple range test, CV% = Coefficient of variation.

However, a high number of seeds per capsule 9.81 were counted at 150 kg NPS rates on the Harato site during the 2019 cropping season. An adequate phosphorus fertilizer rate helps nutrients move to plant roots through diffusion in the presence of optimum temperature and rainfall. Increasing NPS fertilizer rates increased the number of seeds

per capsule at both sites and growing seasons, indicating that the plant is utilizing adequate nutrient elements. Optimum NPS rates are helpful for seed bearing, full-sized seed, and embryo development (Soethe *et al.* 2013).

Additionally, the number of seeds per capsule was significantly influenced by the interaction effect of NPS rates and varieties (Table 7). This difference may be due to varietal and fertilizer effects. The maximum and minimum number of seeds per capsule was recorded on improved varieties and local cultivar at 150 kg NPS ha⁻¹ and 0 kg NPS ha⁻¹, respectively. This study indicated that applying nitrogen fertilizer beyond 100 kg per hectare can cause a severe reduction in growth and yield attributes of linseed. On the other hand Soethe *et al.* (2013) showed that a high phosphorus fertilizer rate increases the number of seeds per capsule.

3. Thousand seed weight (g)

Increasing NPS fertilizer rates increased thousand seed weight at both sites and cropping seasons. Nitrogen and sulfur fertilizers stimulate plant growth, photosynthesis and seed formation. According to Girma and Tenaye (2018) the highest thousand seed weight (3.87 g) was recorded at 100 kg NPSB ha⁻¹, while a low seed weight (3.06 g) was obtained in the control group. Similarly, Zafar *et al.* (2020) observed a maximum thousand seed weight of 6.98 g at 175-175-93.75 kg NPK ha⁻¹, with a minimum of 4.9 g in the non-fertilizer plot. These findings align with the conclusions of (Pawar *et al.* 2023). However, Zhang *et al.* (2020) found that NPS fertilizer rates did not have a significant effect on seed weight at both sites and cropping seasons.

Thousand seed weight was significantly affected by the interaction of linseed varieties with sites (Table 8). The highest thousand seed weight was recorded from improved varieties such as Belay-96 (5.85 g), Berene (5.89 g), and Kuma (6.12 g) at both sites, while the lowest seed weight was from local cultivar. This difference may be attributed to genotypic factors, as improved seeds have elongated root systems that allow them to access moisture and nutrients from deeper soil layers resulting in higher

seed weight. Manoj *et al.* (2018) also found that the seed weight of linseed varieties depended on the weather conditions and soil types of the study sites.

Table 8: The summarized effect of NPS rate by sites by years, and varieties by site by years on thousand seed weight

Sites	Years	NPS fertilizer				Mean
		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	
Harato	2019	5.82 ^{cdef}	5.68 ^{bcde}	5.85 ^{cdef}	5.84 ^{cdef}	5.79
	2020	5.22 ^{abc}	5.46 ^{abcd}	5.69 ^{bcde}	5.87 ^{def}	5.56
Gitilo	2019	4.91 ^a	5.44 ^{abcd}	5.82 ^{cde}	6.43 ^f	5.65
	2020	5.08 ^{ab}	5.46 ^{abcd}	5.87 ^{def}	6.18 ^{ef}	5.65
Mean		5.26	5.51	5.81	6.08	5.66
DMRT (0.05)	0.55	CV% = 12.3				
Sites	Years	Belay	Berene	Kuma	Local	Mean
Harato	2019	6.16 ^{cd}	6.16 ^{cd}	6.47 ^d	4.40 ^a	5.79
	2020	5.66 ^c	5.68 ^c	5.93 ^c	4.94 ^b	5.55
Gitilo	2019	5.74 ^c	5.78 ^c	6.05 ^{cd}	5.04 ^b	5.65
	2020	5.82 ^{cdef}	5.93 ^c	6.03 ^{cd}	4.81 ^{ab}	5.65
Mean		5.85	5.89	6.12	4.79	5.66
DMRT (0.05)	0.44					
CV%	9.66					

Mean within column followed by the same letters are non-significant difference at ($p > 0.05$) levels, DMRT=Duncan multiple range test, CV% = Coefficient of variation.

Seed yield (kg ha⁻¹)

The analysis of variance revealed that seed yield was significantly influenced by sites, NPS rates, and the interaction of years by sites ($p < 0.01$). Similarly, the interaction of varieties by sites, NPS rates by years by sites, and NPS rates by varieties significantly ($P < 0.05$) influenced on seed yield. The maximum seed yield (1824, and 1832kg ha⁻¹) was weighed on Harato site during 2019 and 2020 years and maximum seed yield (1781 and 1798 kg ha⁻¹) was recorded at the Gitilo sites during the 2019 and 2020 main cropping seasons at 150 kg NPS ha⁻¹, respectively. However, the minimum of 1261 kg ha⁻¹ was recorded at the Gitilo site in 2020 under 0 kg NPS fertilizer, respectively (Table 9). This variation might be due to blended fertilizer rates, sites and weather conditions. Similarly, a previous study by Marisol *et al.* (2009) reported that the seed yield of linseed increased at 200 kg N ha⁻¹ and 100 kg P₂O₅

ha⁻¹ at different sites and cropping seasons, but gradually declined as the fertilizer rate exceeded the optimum rate.

Table 9: Summarized effect of NPS fertilizer rates by years by sites, and NPS by varieties on seed yield

Sites	Years	NPS Rates				Mean
		0 kg ha ⁻¹	50 kg ha ⁻¹	100 kg ha ⁻¹	150 kg ha ⁻¹	
Harato	2019	1365 ^b	1481 ^b	1694 ^{fg}	1824 ⁱ	1591.0
	2020	1376 ^b	1553 ^{cd}	1747 ^{gh}	1832 ⁱ	1627.0
Gitilo	2019	1352 ^b	1488 ^c	1633 ^{ef}	1781 ^{hi}	1563.5
	2020	1261 ^a	1381 ^c	1591 ^{de}	1798 ^{hi}	1507.8
Mean		1338.5	1475.75	1666.25	1808.75	1572.3
DMRT (0.05) =	71.89	CV% = 5.5				
Varities		0 kg	50 kg	100 kg	150 kg	Mean
Belay-96		1341 ^{bc}	1477 ^{ef}	1665 ^g	1796 ⁱ	1569.8
B Berene		1368 ^{bc}	1493 ^{ef}	1705 ^{gh}	1860 ⁱ	1606.5
Kuma		1374 ^{bc}	1520 ^{ef}	1739 ^h	1861 ⁱ	1623.5
Local		1281 ^a	1419 ^{cd}	1552 ^f	1668 ^g	1480.0
Mean		1341	1477.25	1665.25	1796.25	1569.94
DMRT (0.05) =	65.45	CV% = 5				

Mean within column followed by the same letters are none significant difference at ($p > 0.05$) levels, DMRT = Duncan multiple range test, CV% = Coefficient of variation.

Likewise, seed yield was significantly influenced by the interaction effect of linseed varieties and NPS fertilizer rate ($p < 0.05$) (Table 9). The highest seed yield achieved with Kuma (1861 kg ha⁻¹), followed by Berene (1860 kg ha⁻¹) and Belay (1796 kg ha⁻¹) varieties at 150 kg NPS ha⁻¹, while the lowest seed yield (1281 kg ha⁻¹) was recorded for the local cultivar in the non-fertilized plot. This difference may be attributed to genotype, NPS fertilizer application, and there combined effects. Similarly, increasing NPS fertilizer rates significantly boosted the seed yield of linseed crops in various cropping seasons (Upadhyay *et al.* 2012). Overall, NPS fertilizer plays a crucial role in plant growth and development due to its positive impact on cell division, expansion, photosynthesis, chlorophyll formation, and seed development (Samvedana *et al.* 2019).

On other hand, phosphorus contributes to metabolism and energy production, enabling plants



to with stand adverse conditions Darose *et al.* 2010). Consistent with these findings, previous studies by Lilian *et al.* (2014) and Zhen-hua *et al.* (2012) indicated that the seed yield of linseed genotypes was significantly affected by nitrogen fertilizer rates. Additionally, Lanfound *et al.* (2008) reported that seed yields of linseed were influenced not only by nitrogen fertilizer rates and placement but also by soil types, moisture and linseed genotypes. These findings are supported by other authors (Jiao *et al.* 2013; Dohat *et al.* 2017).

CONCLUSION AND RECOMMENDATION

NPS fertilizer is a macro nutrient that require in large quantities to make structural components of plant cells, protein, and aid in photosynthesis. Proper application of this fertilizer increased seed yield of linseed varieties at both sites and during different cropping seasons. The Harato site yielded higher seed production compared to the Gitilo site, with differences attributed to environmental factors such as weather conditions, soil types, and altitude. The maximum seed yield of 1860 and 1861 kg per hectare was recorded with a 150 kg NPS fertilizer rate on Berene and Kuma varieties of linseed, while the minimum seed yield 1281 kg per hectare was recorded for local cultivars with 0 NPS fertilizer rates. Therefore, it is recommended to use 150 kg NPS per hectare in combination with improved Kuma and Berene varieties for the study area and similar agro-ecological regions.

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