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Yield and oil response of linseed (*Linum usitatissimum* L.) to nitrogen application

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Abstract The finding revealed that there was highly significant (P<0.01) difference of the main effect of linseed variety on biomass yield, **s**eed oil yield were highly significant (P<0.01) for the main effect of nitrogen fertilizer level. While, percent oil content of seed was significantly (P<0.05) influenced by interaction effect of both factors. Thus, the highest (8846 kg ha^{-1}) and lowest (7090 kg ha^{-1}) biomass yield and the maximum (1964 kg ha^{-1}) and minimum (1132 kg ha^{-1}) seed yield were obtained from application of 46 kg N ha^{-1} and control, respectively with 83.2% advantage. However, the highest percent seed oil content (38.3%) was obtained from Bekoji-14 variety with control and the lowest (35.1%) were obtained from Kulumsa-1 with 46 kg N ha^{-1} interaction effect, this indicating the oil content declined at higher nitrogen rate. The maximum and minimum seed oil yield was obtained from 46 kg N ha^{-1} (695.9 kg ha^{-1}) and control treatment (422 kg ha^{-1}, respectively. Kulumsa-1 variety was the best performance for studied characters. Regression analysis of linseed variety and nitrogen fertilizer rate on seed yield showed a positive linear response implying an increasing trend at every amount of treatment added while in contrast the regression line for percent seed oil content was linear negatively declined. The result revealed that maximum net benefit of 60,097 EB (Ethiopian Birr) ha^{-1}was obtained from application of 46 KgN ha^{-1} and Kulumsa-1 or Bekolji-14 with marginal rate of return of 6866% as economically profitable in the study area.

Keywords: Interaction plot, Nitrogen rate, Percent oil content, Profitability, Regression coefficient

Introduction

Oilseeds are the second biggest export earner of Ethiopia following coffee and an estimated three million small holders are involved in oil production. One third of the Ethiopian oilseed production is sesame seed followed by linseed and Noug (Wijnands *et al*., 2009). Linseed (*Linum usitatissimum* L.) is an oil crop which belongs to Linaceae and widely distributed in temperate and subtropical areas of the world (Tadesse *et al*.,

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2010). The crop was originated in east of the Mediterranean region (Adugna *et al.,* 2004). Linseed is widely distributed in different countries like Canada, Argentina, China, India, U.S and Ethiopia (Madhusudhan, 2009). Linseed crop is the only cultivated species of the genus *Linum*, (Zohary and Hopf, 2000) and performs best between 2200 to 2800 meters above sea level altitude (Reta and Niguse, 2017). However the major growing regions in Ethiopia are located at altitudes between 1800-2800 meters above sea level and mainly used for local consumption and market (Adefris *et al.,* 1992). Some researchers indicated that linseed has been cultivated since 3,000 years ago by Agaw people of Ethiopia (*Abyssinia*) (Westphal, 197). Linseed is mainly cultivated in many parts of world for fiber, oil and medicinal purposes (Kajla *et al*., 2015).

Linseed is mainly cultivated for its seed and oil use which makes it important for oil production and in food industries as it contains essential polyunsaturated fatty acids, such as linoleic fatty acid and high soluble dietary fiber which have additional health benefits (Mohammadi *et al.,* 2010). It is the multipurpose oilseed plant and source of valuable feed and seed (Farag *et al.,* 2021; Zuk *et al.,* 2015). Linseed contains high polyunsaturated fatty acids (PUFA) which are known as healthy fats. It is also rich in soluble and insoluble fibers and lignin, making it useful as a dietary supplement. As a result, intake of linseed in daily diet is supposed to reduce the risk of cardiovascular diseases, stroke and anticancer effects (Jhala and Hall, 2010).

However, linseed reported to be low productivity may be due to various reasons like moderate response to fertilizers application, use of low yielding local varieties, susceptible to fungal diseases and damage by pests, poor seed germination, plant mortality and low competition with weeds (Worku *et al.,* 2012). Nitrogen is the most important constituent of protein, enzymes and chlorophyll and involved in all processes associated with protoplasm, enzymatic reactions and photosynthesis that play a key role in oil production (Franzen, 2004) growth and yield related traits in linseed is influenced by nitrogen application. Nitrogen has considerable influence on yield of crops, the effect can be significantly changed by environmental variation, genotype and amount of fertilizer added. The optimum rate of fertilizer for linseed varied depending on the location and year (Berti *et al*., 2009).

Research results showed that linseed yield increased as nitrogen fertilizer rates increased to 2000 kg ha^{-1} (Berti *et al.,* 2009). Sharma *et al* . (2007) stated that an increasing nitrogen levels promotes vegetative growth, delaying grain fill and physiological maturity; other mechanisms such as protein and starch are stored in the seed diluting the percent oil content. In Ethiopia, research on linseed has started since 1960’s to develop high yielding and better quality varieties together with their improved management practices.

With this effort, there were more than 12 improved linseed varieties which have been nationally released (Worku *et al.,* 2012). In addition, the yield potential of the same varieties were about 2.0 tons per hectare with standard percent oil content (~38.6 %) (Abebe *et al.,* 2011). Furthermore, the recent data (Ethiopian central statistical agency) indicated linseed is currently produced on about 69,149.87 hectares of land with a total annual production of 79,694.9 tons (CSA, 2020) indicating about 1.2 tons per hectare. But the yield improvement since 2010 was constantly low which it urges to do research to increase yield. Evaluation of the current linseed varieties for their oil content and yield performance under different nitrogen fertilizer application would be useful to generate important information which would contribute to the productivity of the crop and oil content.

Despite linseed is one of important oil crops in Ethiopia which has been widely used in domestic consumption and export purpose, its national average yield is very low. Furthermore, information on oil content of the seed is useful. With regard to linseed production, recently in study areas its production is diminishing due to the competition from other major cereal crops which have more technologies and promotions. Linseed requires research attention to improve its production and there was no adequate information available as to the responses of some linseed varieties to nitrogen fertilizer application. Therefore, this study was investigated the responses of linseed varieties under different nitrogen levels on oil content, yield and yield components of linseed.

Materials and methods

Description of study area

The research was conducted in Horro District, Western Ethiopia during 2019 main cropping season. The area was 334 km away from Addis Ababa at 09^{0}32’299’’N latitude and 037^{0} 03’911’’E longitude with an altitude of about 2800 masl. The area receives rainfall 317 to 1092.8 mm (February to May) and 1543.7 mm (June to September). The mean annual maximum and minimum temperature were 23.5 ℃ and 11.9 ℃. The mean relative humidity was 62.8% (National Meteorology Agency: http://www.ethiomet.gov.et/) (Figure 1).

Experimental treatment and design

The treatments consisted of three linseed varieties (Bekoji-14, Jeldu, Kulumsa-1) which were released by Holeta Agricultural Research Centre and five levels of nitrogen fertilizer (*viz* 0 kg Nha^{-1}, 11.5 kg N ha^{-1}, 23 kg N ha^{-1}, 34.5 kg N ha^{-1} and 46 kg N ha^{-1}) were arranged in 3x5 factorial combination in randomized complete block design which replicated thrice. A spacing of 1.5m and 1m was used between blocks and plots, respectively. The plot size was 3m x 2m = $6m^2$. Each plot had 15 rows with the space of 20cm. Sample was measured from the central 11 rows of each plot.

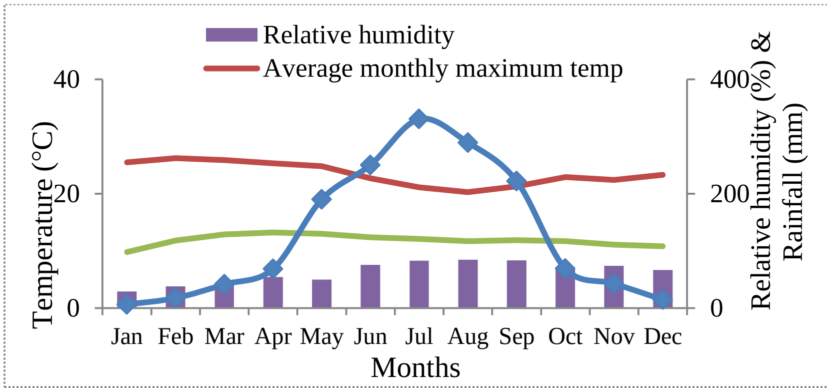

Figure 1. Average monthly rain fall, temperature (℃) and relative humidity (%) of study area during 2019

Experimental procedures

The seed were planted into rows with the seed rate of 25 kg ha^{-1} at the depth of 3-5cm on fine seedbed on July 4, 2019. The Urea nitrogen fertilizer was applied according to the recommended rates in splits, the first half at sowing in furrows and the remaining half by top-dressing at tillering stage (39 days after sowing. Beside this, the recommended rate of phosphorus (23 kg ha^{-1}) was applied uniformly in the form of TSP (46% P_2O_5) to all plots during planting. Harvesting was done at 90% physiological maturity (when capsules had turned brown and seed rattled in the capsules when shaken).

Seed yield, dry seed yield from the gross area of $6m^2$ of each plot was recorded after at 7% constant moisture level and finally, converted into per hector. Harvest index was calculated as the ratio of economical yield to dry biomass yield per plot and multiplied by 100. Percent seed oil content (%) is the proportion of oil in the seed to total oven dried seed weight as determined by a nuclear magnetic resonance spectrometer (NMRS). 22g was prepared from 25g of submitted seed sample after dried in an oven for two and half hours at 130°C; cooled for 30 minutes. Then oil content was determined using nuclear magnetic resonance (NMR). Seed oil yield is amount of oil in kg $ha^{-1}$was obtained multiplying seed yield per hector by the corresponding oil content (%) and divide by 100.

Soil analysis before planting and after harvesting

One composite soil sampler replication, each made from seven sub-samples that collected from the depth of 0-30cm before planting. Then, the composite soil samples were dried, ground by a pestle and a mortar and then filtered in a 2 mm wire mesh for its suitability to examine some soil physicochemical properties before planting and after harvesting. Accordingly, organic carbon was determined according to (FAO, 2008) guide for plant nutrient analysis using wet digestion in volumetric method (Walkley and Black, 1934). While Kjeldhal bremner and Mulvancy method was applied to analyze the total nitrogen using sulphuric acid (Jackson, 1967). Determining pH of the soil was done using the methods of 1:2.5 H_2O (weight/volume) soil samples to water solution ratio (FAO, 2008) by attaching a glass electrode to digital pH meter. The cation exchange capacity was determined by ammonium acetate-extraction method after saturating the soil within ammonium acetate (Chapman, 1965). The available phosphorus was estimated as Bray II method (Olsen e*t al.*, 1954) and particle size distribution was determined by hydrometer method (FAO, 2008) by grouping soil sizes in percentage of sand (0.05-2 mm), silt (0.002-0.05 mm) and clay (<0.002 mm) fractions in soils.

Economic analysis

The profitability of application of rates of fertilizer to linseed variety was analyzed using (CIMMYT, 1988) procedures. According to this method, the average yield is considered for analysis after adjusting down wards by 10% to standardize the yield difference existing between the research station and farmer’s field from the same treatment. Besides, the average seed yields of varieties and nitrogen treatments were subjected to economic analysis depending on the same procedures including the variable total costs of fertilizer and labor cost. The linseed yield and Urea value were considered at average open market price Ethiopian Birr (ETB) kg^{-1} for economic analysis during planting time and harvesting. The labor cost was valued per person per day in the determination of the variable costs.

Data analysis

The analysis of variance was done according to Gomez and Gomez (1984) using GLM procedures of SAS (2004) software version 9.3 and significance test was done at 5% and 1% probability levels. The interaction plot (-) function of R statistical software (R i386 3.2.3 version) (R Software, 2015) was applied for graphical display of the main and interaction effects existing between linseed varieties and nitrogen rates used.

Results

Soil analysis before planting

The results of the soil analysis showed a textural class of sandy clay loam with average sand (62 %), clay (23%), and silt (15%) (Table 1). The pH (5.01) and the cation exchange capacity (17cmol (+) kg^{-1}) of the soil were obtained. Moreover, the soil had total nitrogen (0.093%) and 7.75 mg kg^{-1} available phosphorus (Table 1).

Table 1. Physico-chemical properties of experimental soil before sowing

Parameter	Unit	Value
OC	%	1.98
Total N (%.)	%	0.093
pH	%	5.01
Av. P	mg kg^{-1}	7.75
CEC	cmol(+)/kg	17
Texture	%	Sand=62, Silt=15 & Clay=23
Textural class		Sandy Clay Loam

Where: CEC=Cation exchange capacity, Tot.N=Total nitrogen, Av. P=Available phosphorous and OC=Organic carbon.

Physico-chemical properties of experimental soil after harvest

The result indicated that there was no significant variation for total nitrogen values between treatment combinations. The total nitrogen content of the soil before planting was 0.093% while after harvesting ranged from 0.089 to 0.165%. The available phosphorous of the soil before planting was 7.75 mg kg^{-1} and after planting varied from 8.1 to 10.9 mg kg^{-1} (Table 2).

Yield and yield components of linseed varieties to nitrogen fertilizer application

The data analysis result indicated that thousand seed weight, harvest index and seed oil yield were highly significant ($P<0.01$) for the main effect of nitrogen fertilizer level. Biomass yield and seed yield were highly significant ($P<0.01$) affected by the main effect of nitrogen and linseed variety. Number of capsule per plant and number of seed per capsule were highly significantly ($P<0.01$) influenced by main effect of nitrogen and significantly ($P<0.05$) affected by main effect of varieties. However, non-significant interaction effect of linseed varieties and nitrogen rate were observed for all studied characters, except for percent oil content of seed (Table 3). It is clearly displayed that the trend and pattern of the interaction existing between the combinations of different levels of both factor levels, interaction plot was drawn using R statistical software.

Table 2. Physico-chemical properties of experimental soil after harvesting

Treatment		Soil Parameter					Soil Texture (%)			
Varieties	N (kg ha^{-1})	pH (1:2:5 H_2O)	Av. P(mg/ kg)	Tot.N (%)	OC (%)	CEC cmol(+)/kg	Sand	Silt	Clay	Textural Class
Bekoji-14	0	5.10	8.7	0.089	1.91	16.03	60	16	24	Sandy clay loam
	11.5	5.21	10.9	0.094	2.10	16.13	59	16	25	Sandy clay loam
	23	5.34	10.9	0.120	2.18	19.42	59	15	26	Sandy clay loam
	34.5	5.42	10.1	0.123	2.76	20.25	60	15	25	Sandy clay loam
	46	5.64	9	0.165	2.94	20.78	60	16	24	Sandy clay loam
Jeldu	0	5.07	8.2	0.090	1.99	16.32	61	16	23	Sandy clay loam
	11.5	5.18	10.9	0.103	2.28	16.71	60	17	23	Sandy clay loam
	23	5.25	10	0.113	2.90	16.80	59	15	26	Sandy clay loam
	34.5	5.47	10.6	0.128	2.96	16.92	59	16	25	Sandy clay loam
	46	5.52	10.7	0.108	3.10	17.56	59	16	25	Sandy clay loam
Kulumsa-1	0	5.09	8.1	0.098	1.97	16.14	61	17	22	Sandy clay loam
	11.5	5.16	10.0	0.110	2.13	16.35	58	17	25	Sandy clay loam
	23	5.24	10	0.121	2.48	17.02	59	16	25	Sandy clay loam
	34.5	5.30	9.1	0.132	2.65	17.43	59	15	26	Sandy clay loam
	46	5.49	8.9	0.139	2.73	18.21	60	17	23	Sandy clay loam

Where: CEC=Cation exchange capacity, Tot.N = Total nitrogen, Av.P=Available phosphorous and OC= Organic carbon.

Table 3. Mean square values of ANOVA for yield and yield component characters of linseed varieties tested at different nitrogen fertilizer levels

Source of Variation	Mean squares								
	Df	NCP	NSC	BY	SY	TSW	HI	POC	SOY
Rep.	2	6.6	1	156869.8	5496	0.004	2.8	0.2	799
V	2	11.4^{*}	1.5^{*}	1296937.2^{**}	58847.4^{**}	0.002^{ns}	2.8^{ns}	9.1	2323.2^{ns}
N	4	249.5^{**}	18^{**}	4871402.2^{**}	1046748.9^{**}	0.345^{**}	58.8^{**}	5	115309^{**}
V*N	8	2^{ns}	0.3^{ns}	100296.5^{ns}	19813.4^{ns}	0.002^{ns}	4^{ns}	9.1^{*}	7206.7^{ns}
Error	28	3.3	0.3	176361.6	10117.2	0.006	2.5	1	1387.9

*, ** significance test at 5% and 1% probability levels, NS = Non significant, Df =Degree of freedom, Rep = Replication, N = Nitrogen level, V = Linseed varieties, N*V = Nitrogen by varieties interaction, NCP=Number of capsules per plant, NSC = Number of seeds per capsule, BY=Biomass yield, SY=Seed yield, TSW=Thousand seed weight, HI= Harvest index, POC=Seed percent oil content, SOY=Seed oil yield.

Number capsules per plant

The result showed that there was no much variation resulted on the number of capsules per plant when nitrogen rate increased from nil to 11.5 kg N ha^{-1} but further increased the nitrogen rate from 11.5 to 46 kg N ha^{-1} had significantly increased the number of capsules per plant. Accordingly, the number of capsules produced by the plants treated with 34.5 and 46 kg N ha^{-1}was more than that of plants with the control treatment by 4.5 and 13%, respectively.. Thus, the minimum (27) and maximum (40) number of capsules per plant was achieved from control plot and 46 kg N ha^{-1} application, respectively. Regarding varieties, the minimum (30.3) and maximum (32) number of capsules per plant were recorded from Kulumsa-1 and Bekoji-14 variety, respectively (Figure 2).

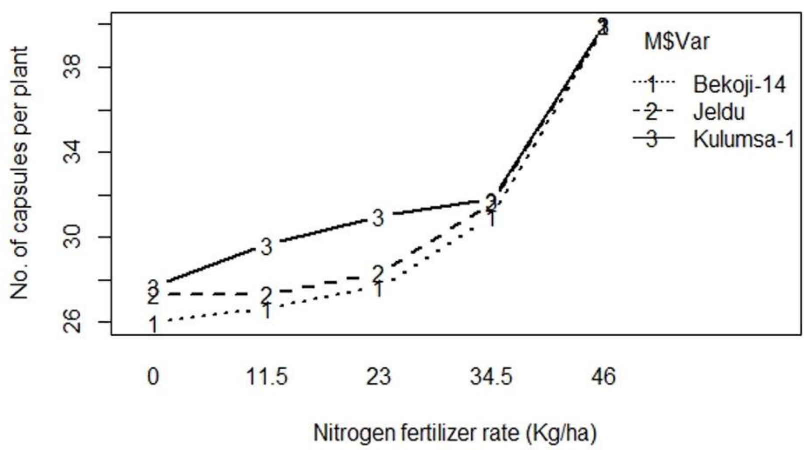

Figure 2. The interaction plot of the linseed variety and nitrogen fertilizer levels on number of capsules per plant

Number of seeds per capsule

An increase of the rate of nitrogen fertilizer rate increased the number of seeds per capsules. Hence, the minimum (6.4) and maximum (9.9) number of seeds per capsule was achieved from control plot and 46 kg ha^{-1}, respectively, resulting an increment of 54.7%. However, regarding the main effect of variety, the minimum (7.4) number of seeds per capsule was obtained from Jeldu variety and maximum (8) was recorded from Kulumsa-1variety (Figure 3).

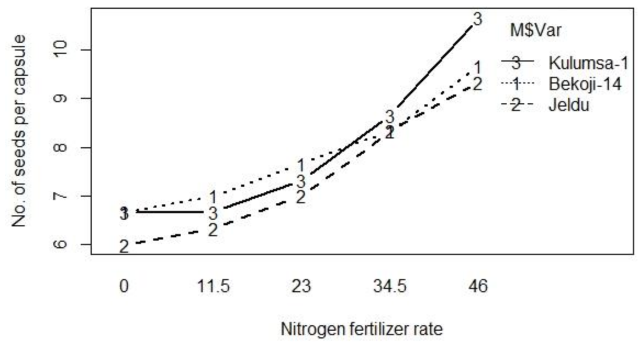

Figure 3. The interaction plot of the linseed variety and nitrogen fertilizer levels on number of seed per capsule

Thousand seed weight

An increment of thousand seed weight with the increasing nitrogen levels from nil to 11.5 and 23 kg N ha^{-1} was non-significantly differed. However, it was significantly increased when fertilizer level changed from 23 to 34.5 and 46 kg N ha^{-1} (Figure 4). Moreover, the result illustrated in Figure 4 clearly indicated there was linear increase of thousand seed weight of varieties as fertilizer rate increased. The lowest (4.8g) and highest (5.2g) thousand seed weight were obtained from a treatment without nitrogen application and those treatments treated with 46 kg N ha^{-1}, respectively. Therefore, a treatment supplied with 46 kg N ha^{-1}, exceeded control by 0.4g thousand seed weight per plot (Figure 4).

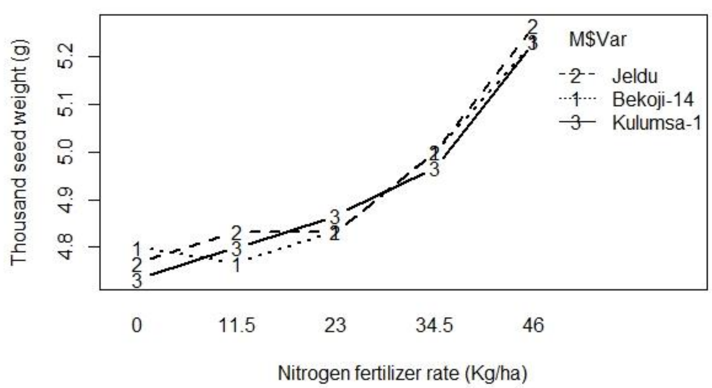

Figure 4. The interaction effect plot of the linseed variety and nitrogen fertilizer levels on thousand seed weight

Biomass yield

The graph showed that biomass yield of linseed had linearly increased when the rate of nitrogen increased and the highest biomass yield was obtained from combination of Kulumsa-1 with 46 kg N ha^{-1} fertilizer. The minimum (7090 kg/ha^{-1}) biomass yield of linseed was obtained from control while the maximum (8846 kg ha^{-1}) 46kg N ha^{-1} rate, however, biomass yield produced at 34.5 and 46kg N ha^{-1} exceeded the biomass yield which gained from control treatment by 24.8 % (Figure 5).

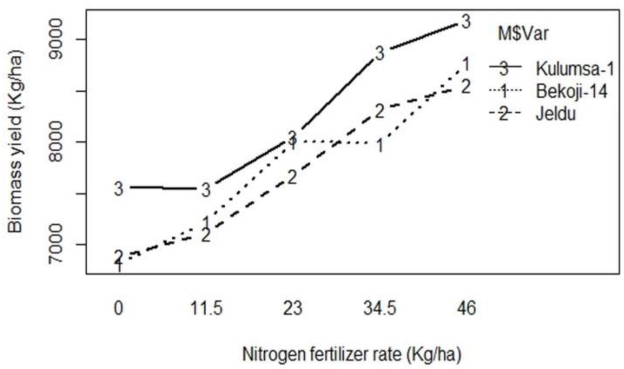

Figure 5. The interaction plot of the linseed variety y and nitrogen fertilizer levels on biomass yield

Seed yield

The result revealed that an increased level of nitrogen from 11.5 to 46 kg N ha^{-1} had significantly affected on increasing seed yield. The minimum (1132 kg ha^{-1}) and maximum (1964 kg ha^{-1}) seed yield were obtained from control and 46 kg N ha^{-1}, respectively, showing 73.5% more seed yield as compared to control. Regarding varieties, the result showed that the maximum seed yield was obtained from Kulumsa-1 variety (1539 kg ha^{-1}) while minimum (1414 kg ha^{-1}) seed yield was from Jeldu variety (Figure 6) indicating a yield advantage of 8.8%.

Harvest index

The graph of harvest index displayed that main effect of nitrogen rate showed increased at the maximum nitrogen level 46 kg N ha^{-1} than the rest treatments. Thus, the highest harvest index (22.3%) was recorded at 46 kg N ha^{-1}application as compared to the control treatment which gave the lowest harvest index (16.1%) (Figure 7). Generally, the mean harvest index values ranged from 16.1 to 22.3% (Figure 7).

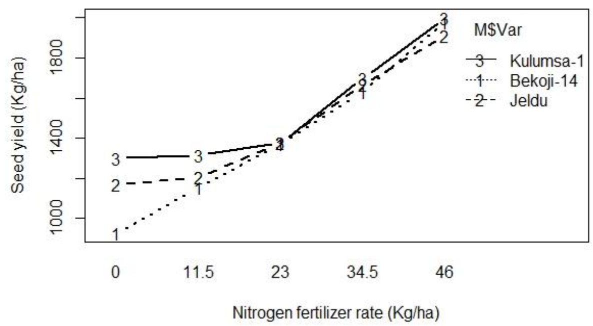

Figure 6. The interaction plot of the linseed variety and nitrogen fertilizer levels on seed yield

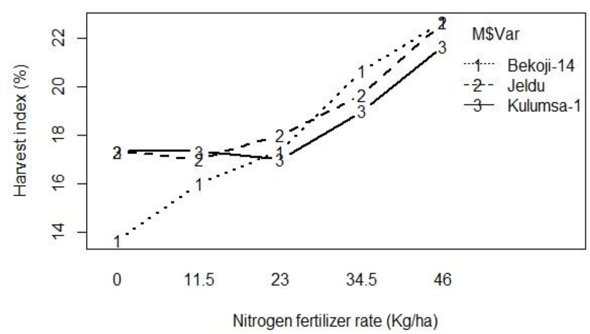

Figure 7. The interaction plot of the linseed variety and nitrogen fertilizer levels on harvest index

Oil content analysis

Seed oil yield

The final objective of oilseed crop production was the oil yield, which was the product of seed yield and seed oil content. An increased oil yield per area was achieved from increased seed yield. An increasing levels of nitrogen fertilizer from 11.5 to 46 kg N ha^{-1}significantly increased seed oil yield (Figure 8). In this study, the minimum and maximum seed oil yield was obtained from control treatment (422 kg ha^{-1}) and 46 kg N ha^{-1}(695.9 kg ha^{-1}), respectively, which revealed an increment of 273.8 kg ha^{-1} advantage over control and/or 64.9% improvement in seed oil yield (Figure 8).

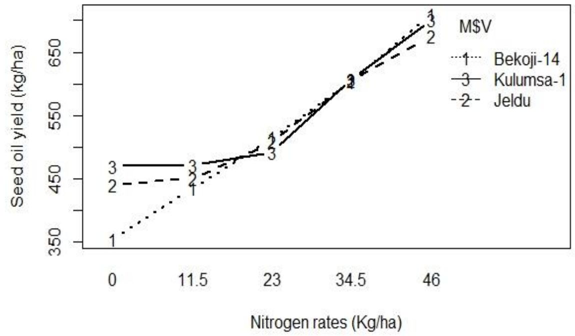

Figure 8. The interaction plot of the linseed variety and nitrogen fertilizer levels on seed oil yield

Percent oil content of the seed

Percent seed oil content was significantly decreased at increasing rate of nitrogen from zero to 46 kg ha^{-1} while an interaction effect of 46 kg N ha^{-1} with Kulumsa-1 variety which resulted to lowest percent seed oil content (35.1%). However, the highest percent seed oil content (38.3%) was obtained from the interaction of control with Bokoji-14 variety. Generally, the effect of nitrogen on seed percent oil content was consistently higher values found in control while the lowest at 46 kg N ha^{-1} in each variety. Thus, linseed grown without nitrogen fertilizer application presented the highest percent seed oil content (Figure 9).

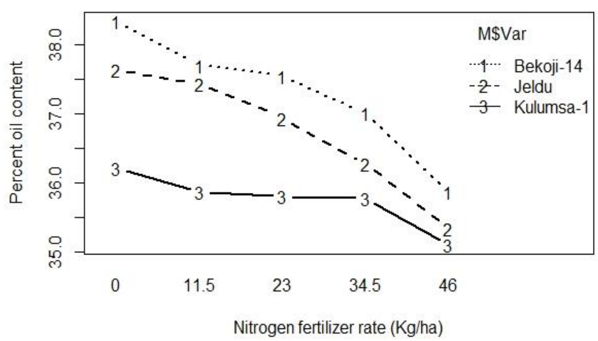

Figure 9. Interaction plot of linseed varieties and nitrogen fertilizer rates on percent oil content

Comparison effect of both factors on seed yield and percent seed oil content

Seed yield: Regression analysis of the effect of linseed variety (Var) and nitrogen fertilizer level (N) on seed yield were done. Thus, the regression plot illustrated in Figure 10 showed a linear response of linseed varieties to every all applied nitrogen fertilizer. The regression coefficient of both factors was high in the contribution of nitrogen fertilizer which is greater than varietal effect. And the regression equation is written as Y=1073.20 +124.73Var +831.44N.

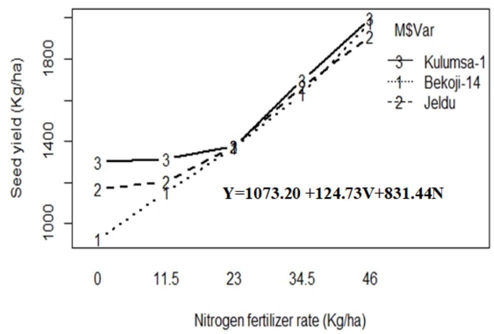

Figure 10. Seed yield trend of linseed varieties to change in nitrogen fertilizer

Percent oil content of the seed: The regression analysis of both variety (Var) and nitrogen fertilizer levels (N) on percent oil content of seed were linear but negative showing a declining trend (Figure 11). Therefore, using the regression coefficients of both factors, the regression equation is written as: Y (percent oil content) = 38.09-1.54Var -1.96N.

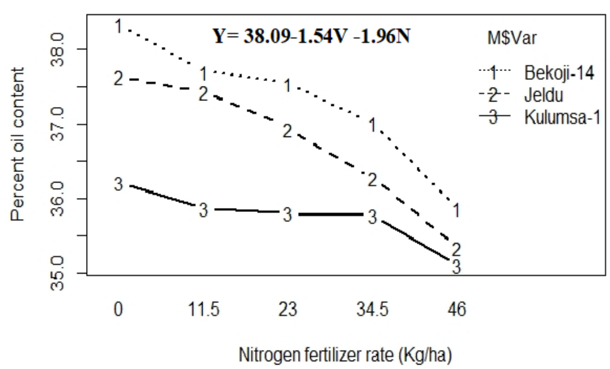

Figure 11. Percent seed oil content trend of linseed varieties to change in nitrogen fertilizer

The economic feasibility analysis

The economic analysis results for different nitrogen fertilizer levels and linseed varieties were shown in (Table 4). The finding identified the highest net benefit of 60,097 Ethiopian Birr per hectare (ETB ha^{-1}) with marginal rate return of 6866% and value to cost ratio of 33.97 ETB per unit of investment which achieved at 46 kg N ha^{-1} rate for linseed production, and followed by net benefit of 50,876 ETB ha^{-1} with marginal rate return of 4567% and value to cost ratio of 31.12 ETB per unit of investment from application of 34.5 kg N ha^{-1}. The lowest net benefit of 35658 ETB $ha^{-1}$was obtained from control for linseed production (Table 4).

Table 4. Assessment of economic profitability of application of linseed variety with nitrogen rates

N (kg/ha)	Average Seed Yield (kg ha^{-1})	Adjusted Seed yield (kg ha^{-1})	Gross Field Benefit (ETB ha^{-1})	Total cost (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	Value to cost ratio (ETB)	MRR (%)
0	1132	1018.8	35658	0	35658	-	-
11.5	1226	1103.4	38619	853	37766	44.27	247
23	1376	1238.4	43344	1438.5	41906	29.13	707
34.5	1667	1500.3	52511	1634.9	50876	31.12	4567
46	1964	1767.6	61866	1769.2	60097	33.97	6866

Linseed price 35 ETB kg^{-1}, Price of urea 12.8 ETB kg^{-1}, Labor price=36 ETB man per day and MRR=Marginal rate of return.

Discussion

The result of soil analysis of the study area was with medium clay content (20-30%) according to Hazelton and Murphy (2007) who showed better water and nutrient holding capacity and infiltration of the soil. The pH of the soil was 5.01 which is within the suitable range assumed satisfactory for the growth of the crop (Adugna, 2007) while according to Motsara and Roy (2008) rating the pH of the soil was strongly acidic. Moreover, based on the ranking given by Landon and Manual (1991) the result revealed that the organic carbon content (1.98%) was within very low range which showed low potential to add nitrogen through mineralization. Furthermore, a total nitrogen (0.093%) in study area was very low (Bashour and Sayegh, 2007). Hence, the analysis result indicated the need for nitrogen fertilization. An increased total nitrogen content of the soil after harvesting in the study area was mainly due to soil mineralization of organic nitrogen. While available phosphorus of the soil was in low range (7.75 mg kg^{-1}) and soils having available phosphorus between 5 to 9 mg kg^{-1} which categorized as low (Cottenie, 1980). The phosphorous amount after harvesting showed an accumulation in seed and straw to some extent which may be responsible for such increased in availability of phosphorous of the soil. Moreover, the loss of phosphorous through leaching was low and taken by the crop was high. Thus, the highest mean of available phosphorous of the soil in the study area could be attributed to higher rate of addition of organic nitrogen into the soil.

The raise number of capsules per plant of linseed variety was due to an increasing nitrogen rate Sharief *et al.* (2005), Yasari and Patwardhan (2006), Hussain and Zedan (2008) stated that increasing nitrogen fertilizer levels resulted in increased the number of capsules per plant, thousand seed weight, number of seeds per capsule and seed yield of linseed cultivars. Thus, an increased seed weight as a result of increasing nitrogen rate may be due to the result of sufficient supply of carbohydrates to individual capsules and less competition resulted vigorous growth of the plants. It resulted in good dry matter accumulation in the capsules which increased the weight of seeds. However, results are contradicted with the findings of Hocking and Pinkerton, (1991) which reported no significant effect on thousand seed weight or number of seeds per capsule of linseed at nitrogen deficit levels.

Furthermore, an increasing rate of nitrogen also significantly increased the biomass yield (8846.4 kg ha^{-1}) indicating nitrogen fertilization increased the dry matter partitioning into the leaves, flowers, stems and at anthesis, capsule, vegetative components and seeds at maturity (Legesse, 2010). Besides, the enhanced effect of nitrogen on biomass yield could be attributed to rapid expansion of leaves which could intercept and utilize more light energy in the production of food during the process of photosynthesis. It increased production of phtosynthate would have contributed to increased plant growth and development which had direct and indirect influence on yield and its components.

Linseed yield was significantly increased (1964 kg ha^{-1}) as a result of an increased in nitrogen fertilizer rate from zero to 46 kg N ha^{-1}. It could be attributed to the positive influences of nitrogen on seed yield enhanced rate of photosynthesis resulting to increased dry matter partitioning to reproductive parts, and enhanced organ development (Hocking and Pinkerton, 1991). Hocking(1995) indicated that there was a positive yield responses to nitrogen at 20-60 kg ha^{-1}. The yield increments could be due to the synergetic effect of N fertilizer and the suitability of the improved linseed variety to the growing agro-ecology (Alemu *et al.,* 2020). Similar study by Chopra and Badiyala (2016) on linseed reported that an increasing nitrogen fertilizer attained highest plant stand, growth, yield attributes and yield (610 kg/ha) was obtained at highest rate of 30 N kg/ha while the interaction of varieties and nitrogen levels was significant for seed yield. Their findings added at 30 kg N/ha application *Baner* variety behaved statistically similar to *Bhagsu* with a seed yield increment of 45.4 and 43.1%, respectively over *'Surbhi'* grown with the same nitrogen level which indicated lower yield potential of the linseed varieties used as compared to the varieties used in this study but their response to fertilizer application was very high than our study may be related the difference in the genetic potential of the varieties and the growing environment. Moreover, this study conformed to Sakatu *et al*. (2021) that nitrogen rate had a significant effect on all parameters which considered to except seed oil content and higher seed yield (1734.9 kg/ha) obtained by the application of 46 kg N/ha.

The top (23.3%) harvest index was obtained at 46 kg N ha^{-1} which may be due to changing between vegetative and reproductive growth towards necessary vegetative growth and an increased seed filling (Hocking *et al.*, 1987). Harvest index is determined by the partitioning of photosynthesis between the grains and the vegetative plant parts. The average harvest index value recorded in this study was within the described by Grant *et al.* (1999) who reported which varied from 15 to 55% for three linseed cultivars grown at several sites in Canada.

The decrease in percent seed oil content at an increasing nitrogen availability may be because of a dilution effect of oil in heavier seeds produced under high nitrogen (Khaliq, 2004). In another experiment, application of nitrogen rate did not cause any significant change on percent seed oil content (Sakatu *et al*., 2021) while in the present study the percent oil content declined. This finding is in line with Agegnehu and Honermeier (1997) who reported that increasing nitrogen application had decreased the oil content of flax from 41 to 39%. Similarly, Ali and Ullah(2012) reported that the reduced oil percentages with increased nitrogen application. This might be due to high accumulation of proteins in plants as a result of increased availability of nitrogen which in turn reduced the availability of carbohydrates for polymerization into fatty acids, which, in turn, lowers the oil content of the seeds. This result also agrees to Cheema *et al.* (2001) and (Berti *et al*., 2009) who reported that nitrogen fertilizer acting a vital role in increasing crop yields and seed oil yield. The highest seed oil yield (695.9 kg ha^{-1}) at 46 kg N ha^{-1} in this study is similar to Poonia (2003); Ozer *et al.*(2004); Aglave *et al.* (2009) who found an increased seed oil yield in response to increasing rate of nitrogen. This result also conforms to the finding of Cheema *et al.* (2001) and (Berti *et al*., 2009) who reported that nitrogen fertilizer acting a vital role in increasing crop yields and seed oil yield. Patel *et al*. (2017) indicated application of 90 kg N ha^{-1} on linseed exhibited superior in terms of fiber, seed and oil as well as higher gross return, net income and benefit to cost ratio.

From the economic point of view this finding was discovered that application of 46 kg N ha^{-1} was economically profitable for linseed production than the rest treatment levels. In contrary, Reta (2015) reported that the highest net benefit (31980 ha^{-1} ETB) was recorded for the treatment that received 23 kg N ha^{-1}), followed by 46 kg N ha^{-1} (30042 ha^{-1}ETB).

Regression analysis of linseed variety and nitrogen fertilizer rate on seed yield showed linear response indicating at every increase in the level of nitrogen fertilizers rate, the seed yield of linseed varieties increased. In contrast, the regression analysis for percent of seed oil content revealed both variety and nitrogen fertilizer levels that had negative linear regression coefficients indicating a declining percent of seed oil content at an increasing nitrogen fertilizer application. Hence, in each level of fertilizer increment, there was proportionally declined in percent seed oil content of linseed varieties. This research revealed that the highest net benefit of 60,097ETB ha^{-1} with marginal rate return of 6866% was obtained from application of 46 kg N ha^{-1} with Kulumsa-1 and Bokoji-14 linseed in the study area.

In conclusion, the study indicated that the main effect of linseed variety and nitrogen fertilizer rate had significantly varied for most yield and yield components as well as percent oil content of seed whereas the interaction effect of both factors showed significant difference but the interaction effect of both factors showed significant difference for percent oil content of seed. Thus, an increase in nitrogen fertilizer levels has resulted in an increasing trend for yield and yield components of linseed in which the maximum seed yield (1964 $kgha^{-1}$) was obtained from Kulumsa-1 variety with 46 kg N ha^{-1} application. The highest percent seed oil content (38.3%) was obtained from the interaction of control with Bokoji-14 variety indicating an increasing rate of nitrogen rate has declining tendency of percent seed oil content. While the maximum (695.9 kg ha^{-1}) seed oil yield was obtained from 46 kg N ha^{-1} as compared to minimum (422 kg ha^{-1}) seed oil yield from control. The regression analysis revealed that the effect of nitrogen fertilizer was significantly higher than varietal effect. Finally, the finding suggested that maximum net benefit of 60,097 ETB ha^{-1} with marginal rate return of 6866% was obtained from application of 46 kg N ha^{-1} fertilizer as economically profitable for linseed production in study area. .

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