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Physiological Variability in Linseed (*Linum usitatissimum* L.) to N Fertilization Levels and Establishment Methods and their Relationship with Seed and Oil Yield

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ABSTRACT

A field experiment was conducted during *rabi* 2021-22 to evaluate the response of linseed (*Linum usitatissimum* L.) to nitrogen under different crop establishment methods at Experimental Farm, College of Agriculture, OUAT, Bhubaneswar. The linseed cultivar, Arpita, was grown with six treatments both of nitrogen levels (0% N, 50% N, 100% N) and establishment methods (Paira/utera, conventional) in Factorial Randomized Block Design and was replicated four times. The Arpita variety showed a good performance under conventional tillage practice supplied with 40 kg N ha^{-1} in relation to its growth attributes like plant height, leaf area, leaf area index, chlorophyll content, N (23.72 kg ha^{-1}), P, K uptake, carbohydrate and total dry matter accumulation (1131.5 kg ha^{-1}). That resulted an output of 672.53 kg ha^{-1} seed yield and 203.86 kg ha^{-1} oil yield. Nitrogen harvest index (NHI-70.5%) a component of nitrogen use efficiency (NUE) was also found positively correlated with seed yield and dry matter production. The yield attributing parameters like capsules per plant (17), seeds per capsule (8.75), 1000 seed weight (4.46 g), harvested protein (7.80 g m^{-2}) and HI (33.24%) were also found in highest quantities, where conventional tillage was applied with 100% dose of nitrogen along with recommended doses of P and K. Thus, both N level as well as crop establishment method were observed to be having profound effects on seed yield, yield components with physiology of linseed. Therefore, in order to obtain high yields of linseed, the crop must receive adequate amount of N in well tilled field since this affects nutrient uptake rate, assimilation rate and physiology leading to higher seed and good quality oil yield.

Keywords Linseed, Paira, Conventional, N levels, Seed.

INTRODUCTION

Linseed, commonly known as flax, is an annual herbaceous plant belonging to linaceae family. It is one of the most important cultivated crops with high nutritional potentials like protein content and water-soluble fiber fractions and now-a-days it is mainly grown for its oil. India is the second largest (21.21%) linseed growing country in the world in

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terms of area of cultivation with productivity of 644 kg ha^{-1} (DES, Agricultural Statistics at a Glance, Govt of India 2021). It is grown under rainfed (63%), utrea (20%) and irrigated (17%) conditions (Rokade *et al.* 2015). Now, linseed is under cultivation in many states of India, viz., Madhya Pradesh, Maharashtra, Chhattisgarh, Uttar Pradesh, Jharkhand, Bihar, Odisha, Karnataka, Nagaland, Assam, West Bengal, Himachal Pradesh and Rajasthan. However, there is significant increase in the productivity of the states like Rajasthan (2006 kg/ha), Bihar (846 kg/ha), Nagaland (689 kg/ha) and Assam (517 kg/ha) is at a par with Asia (608 kg/ha) and the world (1006 kg/ha). Paira system of linseed cultivation has been in practice for efficient use of residual moisture in rice fields, where tillage is a problem. In this practice, linseed is broadcasted in the standing rice fields, when the rice crop is between flowering and dough stages. Linseed is allowed to complete its life-cycle under moisture stress, with inadequate nutrients and plant-protection measures, resulting in poor yields. To raise the yield levels, conventional systems of intensive tillage, clean cultivation, monocropping, balanced fertilizer use and rational use of irrigation water should be adopted. Improved varieties should be raised for the purpose of more productivity and good quality oil. Heavy textured soils with good water-retention capacity are ideal for this system. A dose of 20-40 kg N/ha should be applied 2 or 3 days before linseed is sown. Although, nitrogen has considerable effect on growth, development and yield of crops, yet, the effect is considerably altered by the variation in environmental conditions, season, genotype, moisture supply, source, method and quantity of fertilizer added especially in paira/utera system where presence of previous crop residues plays important role. 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 variety under different nitrogen levels and crop establishment methods on morpho-physiological growth, seed and oil yield.

MATERIALS AND METHODS

The field experiment was carried out during *rabi*'2021-22 at experimental farm, College of Agriculture, Bhubaneswar (20°15''N latitude and 85°52''E longitude, elevation of 25.9 m above mean sea level) belongs to East and South Eastern Coastal plain agro-climatic zone of Odisha and falls under the East Coastal Plains and Hills zone of the humid tropics of India. The Experimental plot soil characteristics was found low N, medium P (<30 kg P/ha, 0-15 cm layer, pH- 4.97) and normal K. The popular linseed cultivar, arpita, was broadcasted as paira/utera in medium land paddy field 10 days before harvest (DOS of paira (M_1) : 22/11/ 2021) with three treatments viz., N_0 as control, 50% N as N_1 and 100% N as N_2 as per the recommended dose of fertilizer 40:20:20:: N:P:K kg ha^{-1} and was replicated four times with zero tillage and residual moisture method. Seven days after paira sowing another set of field was sown in lines (spacing : 30 cm × 10 cm) after cultivation of land with bullock drawn MB plough and subsequent leveling as per conventional tollage practice (M_2) with adequate irrigation following same N levels and was also replicated four times to fit the entire two sets of experiment in Factorial Randomized Block Design (FRBD). The experiment was conducted for 110 days (day/night temperature of 35.4°/22.5°C, RH-7 hr/14 hr~95.2%/47.4%, 6.5-BSH, wind velocity-0.5-8.8 km/hr, 3.0-3.6 mm of evaporation). The biochemical analysis was done spectro-photometrically following anthrone method for carbohydrate analysis. Oil extraction (Sadasivam and Manickam 1992) was made by soxhlet apparatus and in rotary evaporator. The N, P and K uptake was analyzed by estimating their contents in plant dry matter after digestion of plant samples; microjheldal methods for N, vanadium yellow color method spectrophotometrically for P and flame photometer method for K. The nitrogen use efficiency including nitrogen recovery efficiency (NRE), nitrogen agronomic use efficiency (NAE), nitrogen partial factor productivity (NPFP), nitrogen harvest index (NHI) and nitrogen grain production efficiency (NGPE) were evaluated as per the formulae below :

1. $$\text{NRE} = \frac{\text{Total uptake in N plot – Total uptake in control plot}}{\text{N applied}} \times 100$$

2. $$\text{NAE} = \frac{\text{Increase in grain yield due to N (kg ha}^{-1}\text{)}}{\text{N rate (kg ha}^{-1}\text{)}}$$

Table 1. Effect of nitrogen levels and methods of establishment on Morpho-physiological parameters of plant. (M_1: Paira cropping system, M_2 : Conventional practice, N_0: No fertilizer application, N_1: 20 kg N ha^{-1} (50% N), 20 kg P_2O_5 ha^{-1} and 20 kg K ha^{-1} , N_2: 40 kg N ha^{-1} (100% N), 20 kg P_2O_5 ha^{-1} and 20 kg K ha^{-1}).

Treatments		Plant height	Leave no.	LA	LAI	Dry matter	Total chlorophyll
M_1N_0		34.55	50	0.36	0.131	333.98	1.4
M_1N_1		34.85	54.5	0.38	0.203	829.6	1.52
M_1N_2		36.1	67.75	0.41	0.338	939.4	1.75
M_2N_0		34.9	68.5	0.4	0.217	381.25	1.41
M_2N_1		37.55	75.75	0.46	0.561	960.75	1.85
M_2N_2		38.95	83.75	0.56	0.88	1131.55	1.99
SE(m) ±	M	0.464	0.827	0.013	0.013	19.022	0.032
	N	0.569	1.013	0.016	0.016	23.297	0.039
	M × N	0.804	1.433	0.022	0.023	32.947	0.055
CD 5%	M	1.399	2.493	0.038	0.04	57.329	0.095
	N	1.714	3.053	0.047	0.049	70.213	0.117
	M × N	NS	NS	NS	0.069	NS	0.165

3. $$NPFP = \frac{\text{Grain yield (kg ha}^{-1})}{\text{N rate (kg ha}^{-1})}$$

Statistical analysis

The experimental design adopted for this research work was simple Factorial Randomized Block Design (FRBD). The pre-and post-harvest observations were statistically analyzed following the RBD using Crop stat 7.2 version and Microsoft office excel 2011 version.

RESULTS AND DISCUSSION

Irrespective of different nitrogen levels in both the establishment methods, plant height was increased up to maturity. Maximum increase in growth was observed at 60 DAS in general with a percent increase of 11.6% and 7.5% over M_2N_1 and M_1N_2 respectively. The number of leaves at different stages of crop growth was found significant in both establishment methods and different nitrogen levels but their interaction was found non-significant but found correlated with seed yield (r=0.89**). Maximum growth in leaf size was observed from 45 DAS to 60 DAS and was found statistically significant within establishment methods and different nitrogen levels in linseed crop but was non-significant to their interaction (M×N) and was correlated with seed yield (r=0.98**). The leaf area index (LAI) was also followed the same trend as per leaf area development and was found significant in both the establishment method (M), different levels of nitrogen application (N) and also to their interaction (M×N). The highest LAI was recorded at 60 DAS in M_2N_2 (0.88) followed by M_2N_1 (0.56) and M_1N_2 (0.33) respectively and was correlated with seed yield (r=0.94**). The result showed that M_2N_2 had the highest dry matter accumulation of 1131.55 kg ha^{-1} followed by M_2N_1 (960.75 kg ha^{-1}) and M_1N_2 (939.40 kg ha^{-1}) with an increment of 17.7% and 20.4% in M_2N_2 over M_2N_1 and M_1N_2 respectively (Table 1). However, an increase of 14.1% of dry matter was also observed in M_2N_0 over M_1N_0 in control plots without fertilizer application and was found statistically significant within establishment methods (M) and different nitrogen levels (N) in linseed crop but was statistically non-significant to their interaction (M×N) and was correlated with seed yield (r=0.98**). There was visible plant height and leaf number differences between the control and the treatments observed at various growth stages. This was probably due to the low initial nitrogen levels in soil and might be boosted later on because of additional N application. The levels of nitrogen application were found significantly affect plant height and leaf number. Height increased steadily with increasing level of nitrogen application and plants were taller with 100% N in conventional compared to 100% N (40 kg N ha^{-1}) in paira as well as 50% N (20 kg N ha^{-1}) in conventional and paira practices and was

Table 2. Correlation coefficient analysis table showing relation of seed yield with physiological attributes. ** Signifies correlated at p value of 0.01 (p<0.01).

Treatments	Seed yield	Oil yield	Plant height	Leaf number	Leaf area	Leaf area index	Total dry matter	Total chlorophyll	Carbohydrate	N uptake	P uptake	K uptake
Seed yield	1.00											
Oil yield	0.99**	1.00										
Plant height	0.90**	0.93**	1.00									
Leaf number	0.89**	0.92**	0.97**	1.00								
Leaf area	0.98**	0.94**	0.87**	0.89**	1.00							
LAI	0.94**	0.97**	0.99**	0.97**	0.91**	1.00						
Total dry matter	0.98*	0.94**	0.82**	0.83**	0.99**	0.88**	1.00					
Total chlorophyll	0.95**	0.96**	0.96**	0.95**	0.95**	0.98**	0.92**	1.00				
Carbohydrate	0.88**	0.91**	0.86**	0.91**	0.83**	0.88**	0.80**	0.83**	1.00			
N uptake	0.99**	0.96**	0.87**	0.86**	0.99**	0.92**	0.99**	0.95**	0.81**	1.00		
P uptake	0.96**	0.97**	0.96**	0.94**	0.95**	0.98**	0.92**	0.97**	0.88**	0.96**	1.00	
K uptake	0.99**	0.99**	0.96**	0.94**	0.96**	0.98**	0.95**	0.99**	0.87**	0.97**	0.99**	1.00

positively correlated with TDM (p<0.01) and seed yield (p<0.01). Correspondingly, leaf numbers were also followed the same pattern in 100% N in both paira and conventional cropping system and was positively correlated with TDM (p<0.01) and seed yield (p<0.01) (Table 2). Ali *et al.* (2011) reported linear increase in height with increase in nitrogen with maximum height of 106.07 cm at 75 kg N/ha while the minimum of 91.77 cm was at 0 kg N/ha. The current difference with response to N fertilization compared to earlier research probably due to cultivar use (in our case cultivar Arpita was used which has erect plant type of medium plant height). N fertilization prompted faster vegetative growth hence faster increase in plant height due to rapid increase in cell size. The decrease in plant height and leaf number observed in paira practice might be leaching of nitrogen and used up by weeds and ratoon paddy because of delay in sowing date by one month due to water logging in field caused by rainfall of 82.6 mm. And overall reduction in plant height in both the practices compared to the cultivar potential of Arpita might be raise in temperature during flowering and fruiting irrespective of different N levels. Similar effect of nitrogen on linseed cultivar reported by Sharief *et al.* 2005 and Sakandar *et al.* 2011. The interaction effect of M × N found non-significant and as nitrogen could also have migrated from treatment plots to the control (Erhart *et al.* 2007). The biological yield (TDM) increased with increasing level of N within the treatments due to continue increase in photosynthetic surfaces (LA/LAI) leading to photosynthetic assimilates. Nitrogen stress (control) sufficiently decreased dry weight, LA and LAI than the treated plants but nitrogen levels and establishment methods found significant, however, their interaction had no significant effect but was positively correlated with TDM (p<0.01) and seed yield (p<0.01). The possible reason for the increase in biological yield, LA and LAI with the increasing rates of N may be that N increases vegetative growth resulting more photosynthesis hence photosynthates which increase the growth and development of crop. Additionally, the increase may be due to the higher critical N demand of linseed for biomass formation (1131.5 kg/ha). These results are in line with the results of Lilian *et al.* (2014) who reported that total dry matter accumulation was a function of assimilating organs and the photosynthetic capacity of leaf canopy (optimum LAI at 60 DAS). In our case, this is perhaps due to increase sites of photosynthetic assimilates production as the leaves increase linearly with plant height. The leaves grew on to the elongating stem and the elongated stem translated to increase biomass. The total chlorophyll content increased within 60 DAS and thereafter it decreased and was highest in M_2N_2 (1.99 mg g^{-1} FW) followed by M_2N_1 (1.85 mg g^{-1} FW) and M_1N_2(1.75 mg g^{-1} FW) with a tune of 41.13%, 31.2% and 25% over their control respectively. However, variation in total chlorophyll of 7.5% was observed between M_2N_2

Table 3. Effect of nitrogen levels and method of establishment on nutrient analysis (NPK uptake), Crude protein (%), Carbohydrate (%) of linseed plant.

Treatments		N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})	Crude protein (%)	Carbohydrate (%)
M_1N_0		2.495	0.030	0.943	4.688	3.150
M_1N_1		13.942	0.240	2.778	10.469	5.315
M_1N_2		16.366	0.281	3.811	10.938	5.500
M_2N_0		2.946	0.104	1.208	4.844	5.235
M_2N_1		19.892	0.476	4.857	12.969	5.700
M_2N_2		23.729	0.59	6.502	13.125	8.403
SE(m) ±	M	0.455	0.013	0.080	0.250	0.365
	N	0.557	0.016	0.098	0.306	0.446
	M × N	0.787	0.023	0.139	0.433	0.631
CD 5%	M	1.370	0.040	0.242	0.753	1.099
	N	1.678	0.049	0.296	0.923	1.345
	M × N	2.373	0.069	0.419	1.305	NS

and M_1N_2 and 13.7% within M_2N_2 and M_2N_1 at 60 DAS. Moreover, an increase of 52.7% and 47.3% carbohydrate in M_2N_2 was recorded over M_1N_2 and M_2N_1 respectively. The NPK uptake by plant in kg per ha was found highest in the plot treated with M_2N_2 (23.7 kg N ha^{-1}, 0.59 kg P ha^{-1}, 6.5 kg K ha^{-1}) followed by M_2N_1 (19.9 kg N ha^{-1}, 0.47 kg P ha^{-1}, 4.85 kg K ha^{-1}) and M_1N_2 (16.4 kg N ha^{-1}, 0.28 kg P ha^{-1}, 3.81 kg K ha^{-1}) and was found statistically significant in both the establishment methods (M) and the nitrogen application (N).The high amount of crude protein content was available in plant grown in M_2N_2 (13.1%) followed by M_2N_1(12.96%) and M_1N_2 (10.93%) with a tune of 1.2% and 19.7% respectively (Table 3). The crude protein content was found statistically significant to establishment method (M), N levels (N) and their interaction (M × N). Highest value of photosynthetic pigment of cultivar Arpita is recorded in M_2N_2 than M_1N_2 and is in agreement with those obtained by Fawzy *et al.* (2012). The increases may be due the rate of quenching of chlorophyll fluorescence which was markedly increase in the linseed leaf and was greater than in control. The promotion effect of chlorophyll content might be attributed by the fact that nitrogen is the constitution of chlorophyll molecule as well as main constitute of all amino acids in proteins, lipids that acting as a structural compound of the chloroplast. Addition of 40 kg N/ha to the soil affected significantly on total carbohydrate compared with 50% N kg/ha and control. Data emphasized that total carbohydrates content increase gradually with the addition of N levels as compared with control plant and found significant and positively correlated with seed yield, total chlorophyll, NPK uptake ($p<0.01$) among the treatments but the interaction found non-significant. These obtained results of N levels are in accordance with Bakry *et al.* (2013) and Karakurt *et al.* (2009). Therefore, it could be concluded from the results that nitrogen levels add a positive effect on carbohydrate content of linseed and this effect may be related to the results of increasing photosynthetic pigment. Information on nutrient uptake of crop is helpful in devising fertilizer management strategies, it was observed that increase application of N levels increased straw N content over the control but 50% N application in conventional planting showed significantly higher N uptake (23.72 kg/ha) than 100% N of paira (16.36 kg/ha). The possible reason may be competition of weeds and ratoon crop to paira linseed. The increase in straw N content of linseed with application of N could be due to the fact that N is an integral part of chlorophyll and crude protein. The above observation in the present study was in the agreement with the findings of Kutcher *et al.* (2005). Application of phosphorus (P) to linseed hastened root development and promotes deep penetration, which prevents loading and take care of plant during time of moisture stress. Our result revealed that P uptake was increased in M_2N_2 and M_2N_1 in line with the results of Gupta *et al.* (2017). Results presented in Table 3 indicated that linseed plant treated with K fertilizer (RDF) showed marked increase in shoot K uptake compared to control. However, in M_2N_2, K uptake was highest. The results were corroborated with the findings of Meena *et al.* (2011). The average number of capsules/plant was varied from 11-17 and the highest capsules number per plant was observed in the plot treated with M_2N_2 (17) followed by M_2N_1 (15.5) and M_1N_2 (15.2) with a percent of 47%, 34% and 22% over their control respectively. Less number of capsules/plant was noted in control plot of conventional practice M_2N_0 (11.5) than paira sown control treated plot (M_1N_0-12.5) and was correlated with seed yield (r=0.97**). The average number of seed/capsules was varied from 7-8 among the treatments and the highest number of seeds in a capsule was found in M_2N_2 (8.75) followed by M_2N_1

Table 4. Effect of nitrogen levels and method of establishment on seed yield and yield attributes of linseed cuv-Arpita.

Treatments		Capsule/ plant	Seed/ capsule	Test weight (1000-SW) (g)	Seed yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})	Stalk yield (kg ha^{-1})	HI (%)	Percent yield (%)	Bray's percentage yield (%)
M_1N_0		12.5	7.25	4.36	157.08	16.18	25.39	396.5	28.41	18.5	-
M_1N_1		14.75	7.75	4.37	399.55	22.62	91.6	994.3	28.65	47.06	39.31
M_1N_2		15.25	8.25	4.43	451.4	23.17	106.47	1104.1	28.88	53.17	34.8
M_2N_0		11.5	8	4.36	183	17.33	31.8	460.55	28.48	21.55	-
M_2N_1		15.5	8.25	4.44	494.1	26	128.38	1110.2	30.54	58.2	37.04
M_2N_2		17	8.75	4.46	672.53	30.39	203.86	1343.22	33.24	79.21	27.21
SE(m)±	M	0.406	0.171	0.014	21.292	1.228	9.403	26.3	0.626	2.508	
	N	0.497	0.21	0.017	26.077	1.504	11.516	32.211	0.767	3.072	
	M × N	0.703	0.297	0.024	36.879	2.127	16.286	45.553	1.084	4.344	
CD 5%	M	NS	0.517	NS	64.171	3.704	28.33	79.265	1.887	7.558	
	N	1.499	0.633	0.051	78.593	4.533	34.707	97.079	NS	9.257	
	M × N	NS	NS	NS	NS	NS	46.083	NS	NS	NS	

(8.25) and M_1N_2 (8.25) with a tune of 9%, 3% and 13% over their control respectively. The test weight was found highest in conventional practice of M_2N_2 (4.48 g) followed by M_2N_1 (4.44 g) and M_1N_2 (4.43 g) paira practice with a tune of 3%, 2% and 2% over their control respectively. However, a marginal increase of 0.7% in M_2N_2 over M_1N_2 was noted. The maximum seed yield was found in M_2N_2 (672.53 kg ha^{-1}) followed by M_2N_1 (494.10 kg ha^{-1}) and M_1N_2 (451.40 kg ha^{-1}) with a tune of 36.1% and 48.98% respectively (Table 4). As regards to seed yield, a percent increase of 16.5% was noted in control plot M_2N_0 (183 kg ha^{-1}) over M_1N_0 (157.08 kg ha^{-1}) and stalk yield was found in M_2N_2 (1343.22 kg ha^{-1}) followed by M_2N_1 (1110.2 kg ha^{-1}) and M_1N_2 (1104.1 kg ha^{-1}) with a tune of 20.98% and 21.65 % respectively. A percent increase of 16.1% was noted in control plot M_2N_0 (460.55 kg ha^{-1}) over M_1N_0 (396.5 kg ha^{-1}). The HI was increased up to 8.8 % in M_2N_2 than M_2N_1 and 15% over M_1N_2. However, the HI was found at par in both the control treatment. Linseed yield was significantly increased in M_2N_2 (672.5 kg ha^{-1}) as a result of an increased in nitrogen fertilizer rate from 0 to 40 kg N ha^{-1} (100% N). The percent seed yield was calculated as per actual yield over theoretically potential yield (849 kg ha^{-1}) of cultivar Arpita, which revealed that among all the treatments percentage yield was found highest in M_2N_2 (79.21%) followed by M_2N_1 (58.2%) and M_1N_2 (53.17%) with a tune of 36.1% and 48.9% increased respectively. Bray's percentage yield was found highest in M_1N_1 (39.31%) followed by M_2N_1 (37.04%), M_1N_2 (34.8%) and M_2N_2 (27.21%). It could be attributed to positive influences of nitrogen on seed yield enhanced rate of photosynthesis resulting to increased dry matter partitioning to reproductive parts and enhanced organ development (Lemessa and Zerihun, 2022, Hocking and Pinkerton1991). Hocking (1995) indicated that there was a positive yield response to nitrogen at 20-60 kg ha^{-1}. Similar study by Chopra and Badiyala (2016) on linseed reported that an increasing nitrogen fertilizer attained highest yield attributes and yield (610 kg/ha) and nitrogen levels was significant for seed yield. Their findings indicated lower yield potential of the linseed varieties used as compare to the variety used in this study may be related the difference in genetic potential of the varieties and growing environment. In the present study the seed yield of conventional practice superseded paira practice of linseed cultivation to levels of nitrogen fertilizer applications of 100% (40 kg N/ha) and 50% (20 kg N/ha) in a way that paira practice limit nitrogen availability to main crop and water shortages, which shortening the growing cycle. Moreover, this study confirmed to Sakatu *et al.* (2021) that nitrogen rate had a significant effect on all parameters and higher percent yield. Our study represented an increase in percent yield (79.2%) and decrease in Bray's percentage yield of 27.2%. The raise number of capsules per plant of linseed variety was due to an increasing ni-

Table 5. Effect of nitrogen levels and method of establishment on physiological parameters related to nitrogen studies (NUE) of linseed.

Treatments	NRE (kg kg^{-1})	AE (kg-kg^{-1})	NGPE (kg kg^{-1})	NPFP (kg kg^{-1})	NHI (%)
M_1N_0	-	-	-	-	62.96
M_1N_1	57.24	12.12375	21.75727	19.9775	65.83
M_1N_2	34.68	7.358125	21.84929	11.285	65.86
M_2N_0	-	-	-	-	63.05
M_2N_1	84.73	15.555	18.42999	24.705	66.64
M_2N_2	51.96	12.23813	23.63642	16.81313	70.5

trogen rate. Hussain and Zedan (2008) stated that increasing nitrogen fertilizer levels resulted in increased the number of capsules per plant, thousand seed weight, number of seed per capsule and seed yield of the linseed cultivars. Thus, an increased seed weight as a result of increasing nitrogen rate may be due to the result of sufficient supply of carbohydrate, protein, harvested protein, NPK uptake to individual capsules and found positively correlated with seed yield resulting proper growth of plant in M_2N_2 than M_1N_2. It resulted in good dry matter accumulation, in capsules which increased the weight of seeds. However, results are contradicted with the finding of Hocking and Pinkerton (1991) who reported no significant effect on thousand seed weight or number of seeds per capsule of linseed at nitrogen deficit levels. The top (33.2%) harvest index was obtained at 40 kg N/ ha in M_2N_2 which may be due to changing between vegetative and reproductive growth toward necessary vegetative growth and increased seed filling (Lemessa and Zerihun 2022). Harvest index is determined by the partitioning of photosynthesis between the grains and the vegetative plant parts which varied from 28.4 to 33.2% for two factors (N levels and establishment methods) in linseed cultivars. Oil yield was found significant among the treatments and was noted highest in M_2N_2 (203.86 kg ha^{-1}) followed by M_2N_1 (128.38 kg ha^{-1}) and M_1N_2 (106.47 kg ha^{-1}) and was also found significant among the treatments and their interaction (M × N). The highest seed oil yield at 40 kg N ha^{-1} was found in M_2N_2 and the lowest was in control. The present findings were similar to Poonia (2003); Aglave *et al.* (2009) who found an increased seed oil yield because of higher seed yield in response to increasing rate of nitrogen fertilizer. Nitrogen use efficiency decreases with increase in N supply resulting in a w^{0}aste of resources. Therefore, the NUE concept involves three major processes in plant : Uptake, assimilation and utilization of nutrients. The different components of NUE including nitrogen recovery efficiency (NRE), nitrogen agronomic efficiency (NAE), nitrogen partial factor productivity (NPFP), nitrogen harvest index (NHI) and nitrogen grain productivity efficiency (NGPE) were evaluated. The nitrogen recovery efficiency was found highest in M_2N_1 (84.73%) followed by M_1N_1 (57.24%) and M_2N_2 (51.96%) with a tune of 48% and 63% increase respectively (Table 5). The agronomic efficiency or nitrogen agronomic efficiency (kg kg^{-1}) was calculated considering seed yield over fertilizer N applied and was highest in M_2N_1 (15.5 kg seed kg^{-1} N applied) followed by M_2N_2 (12.2 kg kg^{-1}) and M_1N_1 (12.1 kg kg^{-1}) with an increase of 27% and 28% respectively. The nitrogen grain production efficiency was calculated as per seed yield upon nitrogen uptake by crop and was highest in M_2N_2 (23.63 kg kg^{-1}) followed by M_1N_2 (21.84 kg kg^{-1}) and M_1N_1 (21.75 kg kg^{-1}) with a line of 8.1% and 7.9% increased respectively. The nitrogen partial factor productivity, commonly expressed as yield per unit input was calculated and was found highest in M_2N_1(24.7 kg kg^{-1}) followed by M_1N_1 (19.97 kg kg^{-1}) and M_2N_2 (16.81 kg kg^{-1}) with an increase of 23.68% and 46.9% respectively. 50% of N fertilizer application was found more effective to partial factor productivity than 100% N application irrespective of establishment method. NPFP directly related to application of N was found positively correlated with NAE and NRE indicated proper utilization of nitrogen fertilizer for linseed crop. We found that agronomic efficiency was affected by N application and it was higher at 50% N in both the establishment methods compared with 100% N. AE is used to describe the utilization of N inputs in relation to the levels of N applied (Li *et al.* 2020). The decrease in AE at higher N rates was because the increase in yield was high at 100% N. Also, in other studies or with other plant species it was found that AE was higher at lower N rates and decreased at higher N rates (Fageria and Baligar 2005). This indicates that linseed plants were unable to absorb N when applied in excess because their absorption mechanisms might have been saturated. Similar results of AE values on safflower were also reported by Dordas and Sioulas (2008). In addition, similar trend on NRE and NPFP values noticed that determined the effect of N application on linseed yield as NGPE and NHI percentage increased with higher N rate.

CONCLUSION

We studied whether N level can affect yield, yield component, seed quality characteristics, chlorophyll content and NUE under paira and conventional establishment methods in linseed crop cultivar Arpita. N fertilization increase seed yield by an average of 36% and the yield component such as the number of capsules per plant, seeds per capsule, 1000 seeds weight and HI were increased with 100% N application compared with the control and 50% N in conventional than paira practices. Pigment concentration, carbohydrate, crude protein and NPK uptake of plant were also increased by N application compared with the control in conventional practice than paira. However, nitrogen use efficiency (NUE) matrices like NRE, NAE and NPFP were reduced at high N level compared with low N rate. This study provides new information about the response of N levels on seed yield, yield components, biomolecules and morpho-physiology of linseed under two crop establishment methods.

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