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ORIGINAL ARTICLE

Performance of Linseed (*Linum usitatissimum* L.) Under Different Fertilizer Rates and Weeding Frequencies in South-Eastern Highlands of Ethiopia

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ABSTRACT

The effect of fertilizer rates and weeds control on yield and yield components of linseed (Linum usitatissimum L.) were studied in South-Eastern highlands of Ethiopia during the 2009/10 and 2010/11 main cropping seasons. Split plot design with three replications was used. The main and sub plots were assigned to four weeding frequencies (W1=no weeding,W2= once weeding at 30 to 35 days after sowing, W3=once weeding at 55 to 60 days after sowing, W4=twice weeding at W2 and W3) and eight fertilizer rates (F1=No fertilizer, F2=11.5/11.5 kg/ha N and P_2O_5, F3=11.5/23 kg/ha N and P_2O_5, F4=23/11.5 kg/ha N and P_2O_5, F5=23/23 kg/ha N and P_2O_5, F6=23/34.5 kg/ha N and P_2O_5, F7=34.5/23 kg/ha N and P_2O_5, F8=34.5/34.5 kg/ha N and P_2O_5), respectively. Diamonium Phosphate (DAP) and Urea were used as a source of P_2O_5 and N, respectively. Linseed variety 'Tolle' was used and sown at a seed rate of 25 kg/ha. Results indicated that tiller numbers, pod numbers and final seed yield of linseed were significantly influenced by the effects of N and P fertilizers and weeds control treatments. The present results showed that W4F5 treatment produced 58% seed yield advantage over the control (W1F1) in combined years over locations. Similarly, W4F6 produced seed yield advantage of 57% over the control in combined years over locations. Moreover, the study revealed that W4F5 treatment resulted in 9%, 38% and 43% increment in number of tillers/plant, number of pods/plant and seed yield/plant, respectively compared to the control (W1F1). Furthermore, W4F6 treatment resulted in 18%, 48% and 43% increment in number of tillers/plant, number of pods/plant and seed yield/plant, respectively compared to the control. Thus, treatments W4F5 to W4F6 were superior in weed control and N and P management practices for linseed production in South-Eastern highlands of Ethiopia. Likewise, twice hand weeding alone brought 53% seed yield increment compared to the unweeded check. Besides, twice hand weeding resulted in 13%, 45% and 38% increment in number of tillers/plant, number of pods/plant and seed yield/plant, respectively as compared unweeded check. Results have shown that dominant broad leaved and grass weeds vary across locations. The economic analysis indicated that highest net benefits were obtained from twice hand weeding and application of 23/23 kg/ha N/P_2O_5 to 23/34.5 kg/ha N/P_2O_5.

***Keywords*:** Fertilizer, Linseed, Weeding

INTRODUCTION

Linseed, *Linum usitatissimum* L., is an oil seed crop in the family Linaceae. Evidence of use by humans' dates back to about 8,000 B.C. in the Fertile Crescent (Adugna, 2007; Vaisey-Genser and Morris, 2010). Typically linseed consists of approximately 40% fat, 28% dietary fiber, 21% protein, 4% ash, and 6% carbohydrates (Vaisey-Genser and Morris, 2010). Linseed has wide uses: it is a source of food, feed, fiber, oil, medicine, industrial raw material and export commodity. Linseed possesses a very healthy fatty acids (linoleic-Omega 6 and alpha-linolenic acids or Omega 3). Linseed cake is rich in microelements, vitamins, dietary cellulose, proteins (up to 38%) (Altai, 2010). Linseed oil has been used as a drying agent for paints, varnishes, linoleum, lacquer and printing ink. Medicinal uses of linseed include promotes heart health, lowers cholesterol, protects against strokes, lowers blood pressure, used for constipation and helps guard against breast cancer and other cancers (Budwig, 1994; Connor, 2000). Ethiopia is the fivth largest producer of linseed in the world next to Canada, China, USA and India (Adugna, 2007). In 2012/13 Ethiopia allocated 106 thousand hacters of land for linseed and produced 0.104 million tons (FAOSTAT, 2013). Likewise, Arsi Zone alone allocated about 21.4 thousand hacters of land and produced 29.6 thousand tons of linseed (CSA, 2013).

Despite numerous uses of linseed, large areas allocation, and many years production tradition linseed productivity is very low in Ethiopia (0.95 t/ha) (CSA, 2013). Linseed production in Ethiopia is characterized by low input, low yield and poor product quality mainly due to attitude and poor management practices such as lack of proper weed management system, poor seed and field hygiene, poor seed bed preparation, inadequate plant nutrition, inappropriate seeding rate, improper threshing ground and improper cleaning. The use of improved varieties along with good agronomic practices could give seed yield as high as 2.2 t/ha on research fields and reports indicated that model farmers have obtained seed yield as high as 2.0 t/ha (KARC, 2012). Weeds are plants that are competitive, persistent, and pernicious (Ross and Lembi, 1985). In general, weeds cause loss of crop yield, loss of crop quality, stumble export, limit the choices of crop rotation sequences and cultural practices, harbor other crop pests, interfere with crop harvesting, necessitate extra cleaning and processing procedure, and lead to increased transportation cost. Crops vary widely in their ability to compete with weeds. In general, the competitive ability of a crop is related to its ability to access resources including light, water and nutrients (Buhler, 2002). Specific characteristics that tend to influence a crop's competitive ability include: rapid germination and emergence, rapid biomass accumulation and ground cover, leaf characteristics like leaf area index, flag leaf length and angle, canopy structure – ability to intercept light, tillering capacity, and height. In fact, linseed cannot compete effectively with weeds, particularly up to two months after sowing; therefore, early removal of weeds is important before flowering and a yield reduction of up to 56% can be incurred depending on the infestation level (Rezene, 1992).

Hence, weed control measure is a major and unavoidable operation for linseed production. Hand weeding is still by far the most widely practiced cultural weed control technique in field crop production throughout the country mainly due to the prohibitive costs of herbicides, and fear of toxic residue coupled with lack of knowledge and clothings for their use at subsistence farmers' level.

Mean while, plants need certain nutrients to grow and prosper. On the other hand, primary macronutrients namely N, P, and K can virtually be found in every brand of fertilizer on the market. In fact, many natural soils are deficinet in certain nutrients that then must be supplied through fertilizer, either organic or inorganic.

In Ethiopia, linseed is being produced under rainfed, low input and poor management practices. Linseed requires 40 to 90 kg N/ha and 20 to 50 kg P_2O_5/ha in India (Ahlawat, 2012). Concerning fertilizer utilization for linseed production, 89% of the linseed farmers of Arsi and West Arsi zones apply neither organic (manure, compost, etc.,) nor inorganic fertilizer (DAP, Urea, etc.,) (Abebe *et al*, 2011). Only 7% of farmers apply 11 to 20 kg/ha DAP. On the other hand, national fertilizer recommendation for linseed production in Ethiopia is 23/23 kg/ha N and P_2O_5 (30 kg/ha Urea and 50 kg DAP, respectively). Weeds can be a serious problem in linseed if left uncontrolled. Because linseed does not shade the ground as much as cereal grains, weeds have an excellent chance to develop (Flax Council of Canada, 2010). Some weeds are luxury users of nitrogen and will rob the linseed crop of needed soil nutrients. Weeds not only compete with the growing linseed crops to reduce yields, but also cause losses from dockage in seed shipments. Yet, majority of linseed farmers in Arsi and West Arsi zones neither hand weed nor spray herbicides to control weeds on linseed fields (Abebe *et al*, 2011). Only limited number of farmers carry out late and selective hand weeding for broad leaved weeds leaving grass weeds to compete with the crop. Even some farmers allow their sheep in side linseed fields assuming that they could selectively graze on grass weeds.

Therefore, the objectives of the study were: to investigate the effects of weeding frequencies and fertilizer rates on linseed seed yield and yield components.

MATERIALS AND METHODS

Experimental sites: The research was conducted at Kulumsa ($8^0$02' N latitude and $39^0$10' E longitude), Bekoji ($7^0$05'N latitude and $39^0$30'E longitude), Asasa ($7^0$08'N latitude and 39⁰13'E longitude) and Kofele (7⁰17'N latitude and 38⁰83'E longitude) research stations located in the South-Eastern highlands of Ethiopia with an altitude ranging from 2200m (Kulumsa) to 2780m (Bekoji). Mean annual rainfall ranges from 830mm (Kulumsa) to 1211mm (Kofele). Besides, mean annual minimum temperature varies from 5.8 (Asasa) to 10.5 (Kulumsa) degree celicus and mean annual maximum temeperature varies from 18 (Kofele) to 23.6 (Asasa) degree celicus. Chernozens, Nitosol, Euric Nitosol and Luvisol are soil type characters of Asasa, Bekoji, Kofele and Kulumsa sites, respectivley. Soil samples were taken during planting and after harvesting from the experimental fields and analyzed for soil pH, available P and total N in the soil and plant analysis laboratory of Kulumsa Agricultural Research Center (KARC) (Table 1 and 2).

Table 1. Soil characteristics (0-20cm depth) of the experimental sites (Before planting)

Location	pH	P (ppm)	Total N (%)
Kulumsa	5.78	19.63	0.17
Bekoji	5.30	16.25	0.24
Asasa	5.13	31.00	0.16
Kofele	5.08	15.13	0.30
Mean	**5.33**	**20.47**	**0.22**

Table 2. Soil characteristics (0-20cm depth) of the experimental sites (After harvesting)

Location	pH	P (ppm)	Total N (%)
Kulumsa	5.95	21.0	0.166
Bekoji	5.20	14.2	0.216
Asasa	5.83	23.3	0.158
Kofele	4.80	13.21	0.276
Mean	**5.44**	**17.93**	**0.204**

Experimental treatments, design and data collection:

The experiment was conducted during the 2009/10 and 2010/11 main cropping seasons. The experimental fields were ploughed once and disced twice prior to planting using mold-board and disc ploughs, respectively. Split plot design with three replications was used. The main and sub plots were allocated to four weeding frequencies (W1=no weeding,W2= once weeding at 30 to 35 days after sowing, W3=once weeding at 55 to 60 days after sowing, W4=twice weeding at W2 and W3) and eight fertilizer rates (F1=No fertilizer, F2=11.5/11.5 kg/ha N and P_2O_5, F3=11.5/23 kg/ha N and P_2O_5, F4=23/11.5 kg/ha N and P_2O_5, F5=23/23 kg/ha N and

P_2O_5, F6=23/34.5 kg/ha N and P_2O_5, F7=34.5/23 kg/ha N and P_2O_5, F8=34.5/34.5 kg/ha N and P_2O_5), respectively. Diammonium phosphate (DAP) and Urea were used as a source of P_2O_5 and N, respectively. The linseed variety '*Tolle*' was used and sown at a seed rate of 25 kg/ha. Each experimental plot consisted of six rows of 5 m long with spacing of 20 cm between rows. The distance between replications was 2 meters. Recommended cultural practices were properly followed in order to sucessfully grow the crop. Sowing was done from second week of June to first week of July each season. As a crop rotation linsed followed either wheat or barley in both years. Data was collected both on plot and 10 plant basis on 11 parameters namely stand percentage, days to 50% flowering and 90% maturity, plant height, lodging%, severity of three major linseed diseases (wilt (*Fusarium oxysporum*), pasmo (*Mycosphaerella linicola*) and powdery mildew (*Erysiphe cichoracearum*)), 1000-seed weight, oil content (%) and seed yield. Weed data was taken on plot basis. Average of four quadrants weed flora count was taken per plot in diagonal basis using 0.25m^2 quadrant. After threshing seeds were cleaned, weighed and adjusted to 7% moisture content. The total seed yield recorded on plot basis was converted to kg/ha for statistical analysis. The data collected were subjected to analysis using MSTATC and SAS soft wares (SAS, 2004). Moreover, partial budget analysis was performed in order to evaluate the economic feasibity of the treatments (CIMMYT, 1988) where variable cost of fertilizer and weeding was used for partial budget analysis. Price fluctuations during the production season were considered. Marginal Rate of Return (MRR), which refers to net income obtained by incurring a unit cost of input, was calculated by dividing the net increase in yield of linseed due to the application of each input to the total cost of each input applied at each rate. This enables us to identify the optimum rate of fertilizer and weeding frequency for linseed production.

RESULTS AND DISCUSSION

Weed Flora

Broad leaved and grass weed species were recorded and major weed flora were listed below along with their density for three locations (Table 3). Results have shown that dominant broad leaved and grass weeds vary across locations. Fortunately, *Convolvulus arvensis* L. was quite dominant broad leaved weed species at Kulumsa comprising 65% of weeds density. However, *Corrigiola capensis* was the dominant broad leaved weed followed by *Taraxacum spp.* and *Daucus carrota* at Bekoji. On the other hand, at Kofele major broad leaved species were *Galinsoga parviflora, Plantago lanceolata* L. and *Polygonum spp*. Considering grass weed species *Setaria faberii*, *Phalaris paradoxa* and *Eragrostis spp.* were the dominat species at Kulumsa, Bekoji and Kofele, respectively (Table 3). Hence, listed weed species were among the most important linseed yield limiting factors in these areas that need to be controlled by employing integrated weed management options.

Linseed is weak especially at early growth stage and a poor competitor to weeds as compared to other oil crops. The critical period of weed competion in linseed varies from three to eight weeks or from early estabilishment to early flowering stage. Getinet and Nigussie (1997) reported that linseed should receive an early (3-4 weeks after sowing) weeding to be followed by a one mid season one.

The combined analysis of variance over locations and years revealed that significant ($P \leq 0.05$) main effects occurred for all traits evaluated namely day to flowering, days to maturity, powdery mildew, pasmo and wilt diseases, plant height, number of tillers/plant, number of pods/plant, seed yield/plant, stand percentage and seed yield/plot for weeding frequencies and on all traits considered except pasmo and wilt diseases, seed yield/plant and stand percentage for fertizer rates (data not shown). Likewise, weeds control practices and fertilizer rates interacted significantly ($P \leq 0.05$) for all traits except wilt disease, seed yield/plant and seed yield/plot. Similarly, Getachew *et al*, (2006) reported siginificant ($P \leq 0.05$) effects of P fertilzer and weeding frequency on nine traits measured except on 1000-seed weight for P fertilizer, and on 1000-seed weight and crop stand for weeding frequency.

Interaction of weeding frequency and fertilizer rate was significant ($P \leq 0.05$) for seed yield (kg/ha) for individual years but non-significant ($P \leq 0.05$) for combined locations over years (Table 4). In general, the 2009/10 cropping season was bad year in tems of crops productivity compared to 2010/11 cropping season mainly due to heavy and prolonged rainfall that in turn resulted in poor seed bed preparation, poor weed control, low photosynthesis efficiency, flowers abortion and low seed set. Yet, interaction of weeding frequencies and fertilizer rates effect showed consistent results over years. The present results showed that W4F5 treatment produced consistently highest yield for individual years as well as for combined years over locations (Table 4). In other words, W4F5 treatment produced 333 kg/ha, 554 kg/ha and 444 kg/ha seed yield advantage over the control (W1F1) in 2009/10, 2010/11 and in combined years over locations. That is, W4F5 treatment produced 51%, 64% and 58% seed yield advantage over the control in the first, the second and in combined years over locations, respectively. Moreover, the present results revealed that W3F5 treatment produced 43%, 29% and 35% seed yield advantage over the control in the first year, the second year and in combined years over locations, respectively.

Table 3. Major weed flora, their classification and density at Kulumsa, Bekoji and Kofele in 2009/10 and 2010/11

Location	Scientific name	Classification	Weeds density (%)	Scientific name	Classification	Weeds density (%)
Kulumsa	*Convolvulus arvensis*	Dicot	64.7	*Setaria faberii*	Monocot	54.0
	Amaranthus graecizans	"	5.2	*Phalaris paradoxa*	"	29.0
	Corrigiola capensis	"	4.0	*Digitaria abyssinica*	"	12.0
	Taraxacum spp.	"	2.4	*Andropogen spp.*	"	3.0
	Anagallis spp.	"	2.0	*Snowdenia polystachya*	"	1.0
	Polygonum spp.	"	1.6			
	Galinsoga parviflora	"	1.4			
Bekoji	*Corrigiola capensis*	Dicot	26.0	*Phalaris paradoxa*	Monocot	70.0
	Taraxacum spp.	"	14.0	*Eragrostis spp.*	"	10.0
	Daucus carrota	"	14.0	*Juncus compresus*	"	8.0
	Rumex spp.	"	11.0	*Bromus pectinatus*	"	5.0
	Polygonum spp.	"	10.0	*Panicum spp.*	"	4.0
	Plantago lanceolata	"	10.0	*Digitaria abyssinica*	"	1.4
	Anagallis spp.	"	5.0	*Avena fatua*	"	1.0
	Ganaphalium spp.	"	5.0			
	Trifolium spp.	"	5.0			
Kofele	*Galinsoga parviflora*	Dicot	38.0	*Eragrostis spp.*	Monocot	59.4
	Plantago lanceolata	"	27.0	*Phalaris paradoxa*	"	19.0
	Polygonum spp.	"	17.0	*Panicum maxicum*	"	17.0
	Ganaphalium spp.	"	5.3	*Digitaria abyssinica*	"	2.0
	Corrigiola capensis	"	4.1	*Cyperus esculantus* L.	"	1.5
	Trifolium spp.	"	3.4			
	Taraxacum spp.	"	1.5			

Table 4. Effect of weeding frequencies and fertilizer rates on seed yield of linseed ('*Tolle*' variety) in 2009/10 and 2010/11 at Asasa, Bekoji, Kulumsa and Kofele

Treatment	Seed yield (kg/ha)		
	2009/10	2010/11	Mean
W1F1	653	869	761
W1F2	727	867	797
W1F3	704	835	769
W1F4	679	805	742
W1F5	676	766	721
W1F6	712	774	743
W1F7	625	827	726
W1F8	610	818	714
W2F1	708	1194	951
W2F2	796	1245	1020
W2F3	920	1225	1072
W2F4	832	1233	1033
W2F5	876	1115	996
W2F6	806	1217	1011
W2F7	844	1317	1080
W2F8	843	1252	1048
W3F1	905	1244	1075
W3F2	791	1172	981
W3F3	863	1207	1035
W3F4	890	1169	1030
W3F5	936	1120	1028
W3F6	982	1202	1092
W3F7	801	1185	993
W3F8	862	1210	1036
W4F1	841	1324	1082
W4F2	796	1282	1039
W4F3	867	1355	1111
W4F4	949	1354	1151
W4F5	986	1423	1205
W4F6	945	1447	1196
W4F7	963	1377	1170
W4F8	913	1466	1189
Mean	822	1153	987
LSD (5%)	191.5	166.3	NS
CV%	28.97	17.94	22.59

Where, W1=No weeding, W2=Once weeding at 30 to 35 days after sowing, W3=Once weeding at 55 to 60 days after sowing, W4=Twice weeding at W2 and W3, F1=No fertilizer, F2=11.5/11.5 kg/ha N and P_2O_5, F3=11.5/23 kg/ha N and P_2O_5, F4=23/11.5 kg/ha N and P_2O_5, F5=23/23 kg/ha N and P_2O_5, F6=23/34.5 kg/ha N and P_2O_5, F7=34.5/23 kg/ha N and P_2O_5, F8=34.5/34.5 kg/ha N and P_2O_5; NS=non significant at 0.05 probability level.

Similarly, W2F5 produced 34%, 28% and 31% seed yield advantage over the control in the first, the second and in combined years over locations, respectively (Table 4). Furthermore, W4F6 produced seed yield advantage of 45%, 67% and 57% over the control in the first year, the second year and in combined years over locations, respectively. However, W1F5 treatment produced 13% and 6% seed yield reduction over the control in the second and combined years, respectively. Similar trends were observed when W4F6 treatment was used. This showed that adding fertilizer without weeds control practices resulted in double losses, once in terms of seed yield reduction and the other was in terms of cost of fertilizer or loss of money to purchase fertilizer. This result also showed that weeds became more competent and vigorous, if fertilizer was added without weeding the crop and would result in more yield loss.

Based on results of combined locations over years, interaction of weeding frequencies and fertilizer rates showed significant differences ($P \leq 0.05$) for yield components like plant height, number of tillers/plant and number of pods/plant (Table 5). However, significant difference was not observed for seed yield/plant. This study revealed that W4F5 treatment showed 9%, 38% and 43% increment in number of tillers/plant, number of pods/plant and seed yield/plant, respectively as compared to the control (W1F1). Similarly, W3F5 treatment resulted in 52% and 71% increment in number of pods/plant and seed yield/plant, respectively compared to the control (Table 5).

Besides, number of tillers/plant, number of pods/plant and seed yield/plant were increased by 18%, 33% and 43%, respectively when treatment W2F5 was used compared to the control. Moreover, W2F5, W3F5 and W4F5 treatments resulted in 31%, 35% and 58% seed yield advantage, respectively over the control. Furthermore, W4F6 treatment resulted in 18%, 48% and 43% increment in number of tillers/plant, number of pods/plant and seed yield/plant, respectively as compared to the control. Thus, the present results showed that treatments W4F5 to W4F6 were better agronomic practices for linseed production in South-Eastern highlands of Ethiopia.

Table 5. Combined effect of weeding frequency and fertilizer rates on yield and yield components of linseed in 2009/10 and 2010/11 at Asasa, Bekoji, Kulumsa and Kofele

Treatments	Days to		Disease score (0-5)			PH	T/pl	P/pl	Y/pl	Stand	Yld
	Flower	Maturity	PM	PA	Wilt	(cm)				%	
W1F1	84	151	1.2	0.3	0.3	82	2.2	21	0.7	81	761
W1F2	83	151	1.1	0.3	0.3	86	2.2	23	0.8	76	797
W1F3	83	151	1.2	0.3	0.2	85	2.3	23	0.8	82	769
W1F4	83	150	1.1	0.3	0.2	84	2.1	20	0.7	82	742
W1F5	83	151	1.2	0.3	0.2	84	2.2	23	0.8	77	721
W1F6	83	152	1.2	0.4	0.2	88	2.1	22	0.8	77	743
W1F7	83	151	1.2	0.4	0.3	87	2.5	22	0.7	80	726
W1F8	83	150	1.1	0.2	0.2	89	2.5	24	0.9	74	714
W2F1	84	151	1.5	0.4	0.3	78	2.4	23	0.8	83	951
W2F2	84	151	1.4	0.4	0.5	77	2.5	27	0.9	81	1020
W2F3	84	151	1.5	0.4	0.5	81	2.6	30	1.0	81	1072
W2F4	83	151	1.5	0.5	0.4	80	2.5	31	1.0	84	1033
W2F5	83	152	1.4	0.4	0.3	82	2.6	28	1.0	83	996
W2F6	83	151	1.5	0.5	0.3	84	2.7	31	1.1	82	1011
W2F7	83	150	1.5	0.4	0.4	81	2.8	33	1.2	82	1080
W2F8	83	151	1.4	0.5	0.4	83	2.6	28	1.0	80	1048
W3F1	84	153	1.6	0.4	0.4	78	2.4	29	1.1	76	1075
W3F2	83	153	1.5	0.3	0.3	80	2.3	28	1.0	78	981
W3F3	84	153	1.5	0.4	0.3	80	2.4	29	1.0	77	1035
W3F4	83	152	1.5	0.5	0.3	82	2.3	26	1.0	79	1030
W3F5	83	153	1.5	0.5	0.3	83	2.4	32	1.2	77	1028
W3F6	83	152	1.5	0.5	0.2	83	2.4	31	1.1	77	1092
W3F7	83	152	1.5	0.4	0.2	80	2.4	28	1.0	77	993
W3F8	83	153	1.5	0.4	0.3	82	2.4	30	1.1	78	1036
W4F1	84	152	1.6	0.5	0.4	78	2.3	28	1.0	79	1082
W4F2	83	152	1.5	0.5	0.4	79	2.5	30	1.0	80	1039
W4F3	84	152	1.6	0.5	0.4	79	2.7	34	1.2	79	1111
W4F4	83	152	1.5	0.5	0.4	80	2.6	35	1.2	81	1151
W4F5	83	152	1.6	0.6	0.4	81	2.4	29	1.0	82	1205
W4F6	84	152	1.6	0.6	0.3	83	2.6	31	1.0	79	1196

W4F7	84	152	1.6	0.6	0.3	81	2.6	34	1.1	80	1170
W4F8	84	152	1.6	0.6	0.3	83	2.7	32	1.1	81	1189
Mean	**83**	**152**	**1.4**	**0.4**	**0.3**	**82**	**2.4**	**28.0**	**1.0**	**79**	**987**
LSD (5%)	0.57	1.19	0.13	0.17	NS	3.4	0.27	4.6	NS	5.2	NS
CV%	1.21	1.38	16.49	28.31	33.57	7.33	19.41	29.2	25.6	11.6	22.59

Where, W1=No weeding, W2=Once weeding at 30 to 35 days after sowing, W3=Once weeding at 55 to 60 days after sowing, W4=Twice weeding at W2 and W3; F1=No fertilizer, F2=11.5/11.5 kg/ha N and P_2O_5, F3=11.5/23 kg/ha N and P_2O_5, F4=23/11.5 kg/ha N and P_2O_5, F5=23/23 kg/ha N and P_2O_5, F6=23/34.5 kg/ha N and P_2O_5, F7=34.5/23 kg/ha N and P_2O_5, F8=34.5/34.5 kg/ha N and P_2O_5; PM=Powdery mildew; PA=Pasmo; PH=Plant height; T/pl=Number of tillers/plant; P/pl=Number of pods/plant; Y/pl=Seed yield/plant; Yld=Seed yield (kg/ha);NS=non significant at 0.05 probability level.

Effect of weeding frequencies

Results showed that twice hand weeding significantly (P≤0.05) increased seed yield/plant and final seed yield as compared to unweeded check. When we compare 2009/10 and 2010/11 cropping seasons, the 2010/11 was by far better in terms of productivity than the 2009/10 due to bad weather condition of the 2009/10 cropping season which was mainly manifested by heavy and prolonged rainfall that in turn affected land preparation, enhanced flowers defoliation, reduced efficiency of photosynthesis and created suitable condition for diseases severity and incidence. Eventually, the 2009/10 cropping season is being remembered by bread wheat yellow rust disease epidemic whereby highly popular varieties like '*Kubsa*' and '*Galama*' were badly affected from highland to mid-land and from their seedling stage throughout gain filling period throughout the country and linseed was not special.

Table 6. Effect of weeding freqencies on seed yield/plant and seed yield/plot of linseed in 2009/10 and 2010/11 at Asasa, Bekoji, Kulumsa and Kofele

Weeding frequency	Y/pl	Yld
W1	0.8	747
W2	1.0	1026
W3	1.1	1034
W4	1.1	1143
Mean	**1.0**	**988**

Where, Y/pl=Seed yield/plant; Yld=Seed yield/plot (kg/ha)

Combined results of the two cropping seasons have shown that twice hand weeding resulted in 45% and 38% increment in number of pods/plant and seed yield/plant as compared unweeded check. Besides, twice hand weeding brought 13% increase in number of tillers/plant in comparison to the control. In line to the present findings El Naim *et al* (2010) reported that weeds significantly reduced the vegetative growth attributes measured. Similarly, number of pods/plant, seed yield and 1000-seed weight were significantly (P≤0.05) influenced by time and weeding frequencies (Meseret *et al*, 2008). Likewise, twice hand weeding produced 396 kg/ha seed yield advantage over the control. In other words, 53% seed yield increment of linseed was achieved by employing W4 treatment as compared to unweeded check. Supporting evidences were reported in different crops by El Naim *et al* (2010) and Tolera and Daba (2004). Similar to the present results weeding twice had the highest number of pods/plant, 100-seed weight, seed yield/plant and final seed yield (El Naim *et al*, 2010). On the other hand, twice hand weeding negatively affected plant height. In other words, twice hand weeding decreased plant height by 8% as compared to unweeded check. This might be due to the fact that the crop used its energy for tillering, branching and pods setting rather than for height increment, which finally have more positive effect on the final product, seed yield. This result did not agree with reports of Alemayehu *et al* (2008) and El Naim *et al* (2010), as they found that increasing weeding times significantly increased plant height.

Effect of N and P fertilizer rates

Significant differences (P≤0.05) were not observed for seed yield/plant for individual as well as combined years (Table 7). These results agreed with Khajani *et al* (2012); they found that increased N and P fertilizer rates significantly increased pods and branches number. In general, present results showed that responses of linseed to fertilizer rates was very low compared to its responses to weeding frequencies. These results were in good agreement with the reports of Getinet and Nigussie (1997). In other words, as fertilizer rates vary from F1 to F8 difference observed was low on yield as well as yield components. Yet, the highest rate gave the highest plant height, the highest number of tillers/plant and number of pods/plant. Similar to the present findings, plant height exhibited positive response to applications of high rates of N fertilizer (Genene *et al*, 2006).

Table 7. Effect of N and P fertilizer rates on seed yield/plant and seed yield/plot of linseed in 2009/10 and 2010/11 at Asasa, Bekoji, Kulumsa and Kofele

Fertilizer rate	Y/pl	Yld
F1	0.89	967
F2	0.93	959
F3	1.00	997
F4	0.95	989
F5	0.99	987
F6	1.00	1011
F7	1.01	992
F8	1.02	997
LSD (0.05)	NS	NS
Mean	**0.97**	**987**

Where, F1=No fertilizer, F2=11.5/11.5 kg/ha N and P_2O_5, F3=11.5/23 kg/ha N and P_2O_5, F4=23/11.5 kg/ha N and P_2O_5, F5=23/23 kg/ha N and P_2O_5, F6=23/34.5 kg/ha N and P_2O_5, F7=34.5/23 kg/ha N and P_2O_5, F8=34.5/34.5 kg/ha, N and P_2O_5; NS=non significant at 0.05 probability level; Y/pl=Seed yield/plant; Yld=Seed yield/plot (kg/ha).

The authors also reported that only stand count and 1000-seed weight increased with increased P rates, while most of other agronomic parameters showed incosistent trends. Moreover, Genene *et al* (2006) reported the absence of discernible effects of applications of N and P fertilizers on number of pods/plant, which did not agree with the present investigation. According to these authors, both the main and interaction effects of N and P rates were inconsistent on several yield components. Yet, 11.5 and 34.5 kg N/P_2O_5 per ha was determined as optimum fertilizer application for linseed production under Bale conditions (Genene, *et al* 2006).

Data of combined locations and years showed 4% and 9% increment in plant height and number of tillers/plant as fertilizer rate was increased from F1 to F5 and F8, respectively. Simlarly, number of pods/plant and seed yield/plant were increased by 10% and 15% as fertilizer rates increased from F1 to F5 and F8, respectively. However, only 2% and 5% seed yield advantage was obtained when F5 and F6 treatments were used as compared to the control (Table 7).

Partial and marginal budget analysis of treatments

For a treatment to be considered as a worthwhile option to farmers, the marginal rate of return (MRR) needs to be at least between 50% and100% (CIMMYT, 1988). However, for the present study, 100% MRR was considered as a reasonable minimum acceptable rate since farmers in the study areas usually neither practice weeding nor apply fertilizer for linseed production (Abebe *et al*, 2011). The partial budget analysis in the present study indicated that high MRR (210% to 222%) was obtained by applying 23/34.5 kg/ha N/P_2O_5 (F6) with twice hand weeding (W4) and 23/23 kg/ha N/P_2O_5 (F5) with twice hand weeding, respectively (Tables 9 and 11). This means that the income obtained by applying F5/F6 with W4 for linseed was more than 2.22/2.10 times a unit total NP fertilizer and twice weeding cost. This analysis was done by considering only grain yield of linseed. If we add the value of the chaff, the straw, meal, pests cycle break, the return will obviously become more than the already estimated income. This is in line with the findings of Kedir *et al* (2005), where by seeding rate of 25 to 30 kg/ha combined with twice hand weeding gave optimum seed yield and recommended for linseed production under Bale conditions.

Table 8. Partial and marginal budget analysis for treatments for combined years

Treatment	W1F1	W1F5	W2F5	W3F5	W4F5
Average yield (qt/ha)	7.61	7.21	9.96	10.28	12.05
Correction factor (deduct 10%)	0.761	0.721	0.996	1.028	1.205
Adjusted yield (qt/ha)	6.849	6.489	8.964	9.252	10.845
Gross field benefits (birr/ha)	12328.2	11680.2	16135.2	16653.6	19521
Cost of labour for hand weeding	0	0	800	800	1600
Cost of fertilizer	0	1090	1090	1090	1090
Cost of labor to apply fertilizer	0	100	100	100	100
Total cost that vary	0	1190	1990	1990	2790
Net benefits (birr/ha)	**12328.2**	**10490.2**	**14145.2**	**14663.6**	**16731**
Gain in net benefits	0	-1838	1817	2335.4	4402.8
Net benefit/cost that vary			0.913065	1.173568	**1.578065**

Table 9. Partial and marginal budget analysis for 2010/11

Treatment	W1F1	W1F5	W2F5	W3F5	W4F5
Average yield	8.69	7.66	11.15	11.2	14.23
Correction factor (10%)	0.869	0.766	1.115	1.12	1.423
Adjusted yield	7.821	6.894	10.035	10.08	12.807

Gross field benefits (birr/ha)	14077.8	12409.2	18063	18144	23052.6
Cost of labour for hand weeding	0	0	800	800	1600
Cost of fertilizer	0	1090	1090	1090	1090
Cost of labor to apply fertilizer	0	100	100	100	100
Total cost that vary	0	1190	1990	1990	2790
Net benefits (birr/ha)	**14077.8**	**11219.2**	**16073**	**16154**	**20262.6**
Gain in net benefits	0	-2858.6	1995.2	2076.2	6184.8
Net benefit/cost that vary			1.002613	1.043317	**2.216774**

Table 10. Partial and marginal budget analysis for combined years

Treatment	W1F1	W1F6	W2F6	W3F6	W4F6
Average yield	7.61	7.43	10.11	10.92	11.96
Correction factor (10%)	0.761	0.743	1.011	1.092	1.196
Adjusted yield	6.849	6.687	9.099	9.828	10.764
Gross field benefits (birr/ha)	12328.2	12036.6	16378.2	17690.4	19375.2
Cost of labour for hand weeding	0	0	800	800	1600
Cost of fertilizer	0	1323	1323	1323	1323
Cost of labor to apply fertilizer	0	100	100	100	100
Total cost that vary	0	1423	2223	2223	3023
Net benefits (birr/ha)	**12328.2**	**10613.6**	**14155.2**	**15467.4**	**16352.2**
Gain in net benefits	0	-1714.6	1827	3139.2	4024
Net benefit/cost that vary			0.821862	**1.412146**	**1.331128**

Table 11. Partial and marginal budget analysis for 2010/11

Treatment	W1F1	W1F6	W2F6	W3F6	W4F6
Average yield	8.69	7.74	12.17	12.02	14.47
Correction factor (10%)	0.869	0.774	1.217	1.202	1.447
Adjusted yield	7.821	6.966	10.953	10.818	13.023
Gross field benefits (birr/ha)	14077.8	12538.8	19715.4	19472.4	23441.4
Cost of labour for hand weeding	0	0	800	800	1600
Cost of fertilizer	0	1323	1323	1323	1323
Cost of labor to apply fertilizer	0	100	100	100	100
Total cost that vary	0	1423	2223	2223	3023
Net benefits (birr/ha)	**14077.8**	**11115.8**	**17492.4**	**17249.4**	**20418.4**
Gain in net benefits	0	-2962	3414.6	3171.6	6340.6
Net benefit/cost that vary			1.536032	1.426721	**2.097453**

Where, price of DAP per 100kg=1400 birr; price of Urea per 100kg=1300 birr; price of linseed grain per 100kg=1800birr; price of labor=50birr/day; labor of hand weeding=16days/ha=800birr; labor of twice hand weeding=1600birr; and labor to apply fertilizer for a ha=100 birr.

Soil analysis

Soil analysis of the experimental sites indicated that the soils were sup-optimal for the production of linseed since the pH, total N and available P were below the optimum range, there by affecting the response of seed yield to applied P (Getachew and Sommer, 2000; KARC, 2013). Soil anaysis results revealed that available soil P was low for Kofele, Bekoji and Kulumsa, but medium for Asasa (KARC, 2013). Besides, total soil N was medium for Asasa and Kulumsa, but fair for Bekoji and high for Kofele (Tables 1 & 2) which suggested that soils of Kofele and Bekoji require high Phosphorus but low Nitrogen. On the other hand, soils of Asasa and Kulumsa require high Nitrogen but low Phosphorus. In addition, Kofele and Bekoji soils were strongly acidic, but that of Kulumsa and Asasa were moderately acidic. In several cases soils with pH lower than 5.5 are not suitable for linseed production unless they are reclamed with lime (Getinet and Nigussie, 1997; Adugna, 2007). In such soils the proportion of P fertilizer that could immediately be available to the crop becomes inadequate and residues of the fertilizer may be released very slowly (Sikora *et al*, 1991). Varieties may differ in their ability to grow in soils of low P status, Getinet and Nigussie (1997) reported that linseed grows best in soils with pH 5.5 to 6.6 and marginally grown in soils with pH 4.9 to 5.5 and in soils with pH 6.6 to 7.6.

CONCLUSION AND RECOMMENDATIONS

The results of the present study showed that twice hand weeding produced 53% seed yield advantage over unweeded check. Likewise, twice hand weeding resulted in 13%, 45% and 38% increment in number of tillers/plant, number of pods/plant and seed yield/plant, respectively as compared unweeded check. W4F5 and W4F6 treatments produced more than 50% seed yield advantage over the control. Furthermore, the partial budget analysis in the present study indicated that the highest marginal rate of return (210% to 222%) was obtained by applying 23/34.5 kg/ha N/P_2O_5 (F6) with twice hand weeding (W4) and 23/23 kg/ha N/P_2O_5 (F5) with twice hand weeding, respectively. In other words, application of 75 kg/ha DAP and 21 kg/ha Urea along with twice hand weeding, and application of 50 kg/ha DAP and 30 kg/ha Urea together with twice hand weeding gave optimum seed yield and yield components of linseed and hence farmers have to follow these agronomic recommendations for linseed production in South-Eastern highlands of Ethiopia. Further investigation has to be carried out on farmers fields in order to confirm the present results.

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