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Prospects and Potentials for Sweet Lupine Production in West Shewa, Oromia Region, Ethiopia: Study on Spacing and Phosphate Fertilizer Rate

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Abstract: Sweet lupine is one of the legume plants which is a good protein source and potential alternative legume crop in acid-prone areas where faba bean and field pea could not perform well yet there are no agronomic research recommendations made so far. Hence, an experiment was conducted to determine the appropriate seed and fertilizer rate and provide information for users. Factorial combinations of inter-row spacing (30, 40 and 50 cm), intra-row spacing (7, 10 and 13 cm) and phosphate fertilizer (23, 46 and 69 kg P_2O_5/ha) were laid out in a randomized complete block design with three replications. Most of the interactions and the main effect of P_2O_5 fertilizer were non-significant for most of the studied parameters. The main effects of year and intra-row spacing showed a significant effect on most parameters measured while the main effect of inter-row spacing showed a significant ($P<0.05$) effect only on days to flowering, number of pods per plant and, grain yield. Plant height and number of seeds per pod positively correlated with grain yield. In general, fertilizer rate of 23 kg P_2O_5/ha together with 7 cm intra-row spacing and 30 cm inter-row spacing found optimum for sweet lupine production on nitosols of West Shewa.

Key words: Acid Soil · Intra-Row · Inter-Row · Phosphorus · Seed Rate · Sweet Lupine

INTRODUCTION

Lupines are among the oldest crops known in agriculture and their cultivation began over 2000 years ago in countries around the Mediterranean Sea [1]. According to Putnam *et al*. [2], there are over 300 species of the genus *Lupinus* (L.), but many have high levels of alkaloids (bitter-tasting compounds) that make the seed unpalatable and sometimes toxic. But plant breeders in the 1920s in Germany produced the first selections of alkaloid-free or "sweet" lupine, which can be directly consumed by humans or livestock. The lupine plant, like other grain legumes (beans, peas, lentils, etc.) fixes atmospheric nitrogen and produces seeds high in protein; 32-38% [2, 3]. Various scholars reported the nitrogen fixation and accumulation rates between 20 and 400 kg N/ha/year which demonstrate the effectiveness of nitrogen fixation in lupine [3-5]. Lupine plant residues provide the next culture with 32-96 kg N/ha [6].

The white lupine in Ethiopia is locally known as '*Gibto*' is an ancient traditional multipurpose crop that grows in the north-western part of Ethiopia in mixed crop-livestock farming systems of the area [4, 7]. However, its use as livestock feed and human food is limited due to its relatively high alkaloid (1.43%) content [7, 8]. Lupine production by smallholder farmers in the area is targeted for its grain and soil fertility maintenance values. Its grain is used as a snack and for the preparation of the local alcoholic drink, '*Areke*' [4]. On the other hand, sweet lupine is a new introduction to Ethiopia for which little information is available regarding its production practices and other utilization aspects [9]. However, currently, it is gaining more attention by smallholder farmers due to its value as human food that can be used for the preparation of a traditional stew called '*Shiro wot*' [7, 10].

Narrow-leafed lupine (*L. angustifolius*) varieties are most suited to acid soils with a pH of 4.5 - 7, formed with sand (or sand over clay) and well-structured loam soils [11]. In Ethiopia, the soil types in most traditional lupine growing areas are Nitosol and Acrisol with soil pH ranging between 4 and 5 [12]. However, the variety under this study; '*Welela*' (*L. angustifolius*) showed superior performance on very strongly acidic soils between pH

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3.93 - 5.1 and exchangeable acidity 0.93 - 5.63, respectively, Fekadu [10]. Hence, introducing hardy crops like 'Sweet lupine' into soil acidity-prone areas where other legume crops cannot be grown is considered an important approach to combat the protein-malnutrition and for enhancing soil fertility restoration [13]. Also, Fekadu [10] stated that this variety is under production in some areas where highland pulse crops are out of production due to soil acidity problems, though the effect of seed and fertilizer rate is not determined yet.

Therefore, currently, the producers use seed and fertilizer rates recommended for faba bean which is in line with the suggestions of Putnam *et al*. [2] that propose the use of recommendations similar to field bean or soybean. Hence, in Ethiopia, a seed rate of 80 kg/ha for a broadcast planting or in the case of row planting, 30 cm between rows and 7 cm between plants is being used together with initial fertilizer application equivalent to 100 kg DAP/ha [14, 15]. However, as stated in Yeheyis *et al*. [7], Mülayim *et al*. [16] and O'Connell *et al*. [17], different researchers reported different results on seed and fertilizer rates at different areas depending on the variety/cultivar, weather conditions during growing season and site yield potentials. Accordingly, a seed rate ranging from 75 kg/ha to 202 kg/ha or population densities ranging from 20 to 75 plants per square meter have been recommended around the globe [2, 5, 11, 16-20]. Specific to Ethiopia and in particular to the study area, no recommendations have been made despite the importance of this crop to acid-prone areas where it could be a potential alternative legume crop in west Shewa where farmers abandoned the cultivation of faba bean and field pea due to acidity and various disease problems. Hence, this experiment was conducted to determine the appropriate seed and fertilizer rate to provide information for users.

MATERIALS AND METHODS

Area Description: The experiment was conducted at Holeta, West Shewa, Ethiopia, under rain-fed conditions for two consecutive years from 2019 to 2020. The experimental site is located between 09°03' N latitude and 38°30' E longitude, 30 km west of Addis Ababa, at an altitude of about 2400 m above sea level. The long-term average annual rainfall is 1100 mm, about 85% of which is received from June to September with the remainder from January to May. The long-term average minimum and maximum air temperatures are 6.2°C and 22.1°C, respectively.

Soil Sampling and Analysis: One kg of composite soil sample was collected in a zigzag fashion from the whole plot to the depth of 0-30 cm at the time of sowing to determine soil reaction (pH), organic carbon, cation exchange capacity (CEC), total nitrogen, phosphorus and potassium. Soil reaction (pH) was measured in water with a solid to liquid ratio of 1:2.5 as described by Murphy [21]. Organic carbon was determined using Walkley and Black wet digestion method described by Tekalign [22]. The total nitrogen was determined following the Kjeldahl method [23]. The Extractable phosphorus was determined by the Bray II method [24] and the available phosphorus was determined by the Olson method described by Cottenie [25]. The Extractable potassium was determined by the ammonium acetate extraction method described by Nathan *et al*. [26]. The cation exchange capacity (CEC) was determined by the ammonium acetate extraction method described by Metson [27].

Weather Data Collection: Daily rainfall, maximum and minimum temperature data were recorded at Holeta research center. Secondary data were also collected from Holeta meteorology station to see the long-term averages for comparison.

Treatments, Experimental Design and Management: The treatments included 3 x 3 x 3 complete factorial combinations of inter-row spacing (30, 40 and 50 cm), intra-row spacing (7, 10 and 13 cm) and phosphate fertilizer in the form of P_2O_5 (23, 46 and 69 kg P_2O_5/ha) laid out in a randomized complete block design with three replications. Nitrogen (N) fertilizer at the rate of 19 kg N/ha was applied uniformly to all treatments/plots. 38 kg P_2O_5/ha and 19 kg N/ha were obtained from 100 kg NPS fertilizer and the remaining amount of P_2O_5 for the second level (8 kg P_2O_5/ha) and the third level (31 kg P_2O_5/ha) was added from TSP. The remaining amount of N for the first level (7.5 kg N/ha) was added from Urea. All the fertilizer was applied at the time of planting. The gross plot size of 4.0 m × 2.4 m (9.6 m^2) was used for all treatments while the net plot size was made by excluding one outer row from each side. Thus, the net plot size for the respective inter-row spacing of 30, 40 and 50 cm was 4m*1.8m (7.2 m^2), 4m*1.6m (6.4 m^2) and 4m*1.5m (6 m^2), respectively. The number of rows per plot for the 30, 40 and 50 cm inter-row spacing were 8, 6 and 5 rows, respectively and the number of plants per row for the 7, 10 and 13 cm intra-row spacing was 57, 40 and 31 germinated plants, respectively. The sweet lupine (*Lupinus angustijolius*), variety '*Welela*' was used for this experiment. The germination percentage and 100 seeds weight was determined before planting to convert into a seed rate. The seed rate was calculated using the equation stated by Matthews [28] as:

$$\text{Seed rate (kg/ha)} = \frac{\text{Target plant density (m}^{-2}\text{) X 100 seed weight (g) X 10}}{\text{Germination percentage (\%) X Establishment percentage}}$$

Consequently, to convert plant density into a seed rate, 100 seeds weight (for our purpose 13.75 g), germination rates (95%) and 15 % field loss (0.85 establishment rate) were used as estimation inputs. Two times hand weeding was undertaken.

Crop Data Collection, Measurement and Analysis: Plant parameters collected were days to flowering, days to physiological maturity, plant height, the number of pods per plant and number of seeds per pod, 100 seeds weight and grain yield. Data on plant height, number of pods per plant and number of seeds per pod were measured from 10 randomly selected plants from central rows of each plot. Days to flowering were recorded when 50% of the plants in a plot produced their first flower while days to physiological maturity were recorded when 90% of the plants in a plot reached physiological maturity. Grain yield was measured from central rows of each plot while 100 seeds weight was measured in grams for randomly counted 100 seed samples from each net plot.

Statistical Analysis: Data collected were subjected to the analysis of variance (ANOVA) following the statistical procedure stated by Gomez and Gomez [29] for three factors factorial experiments by using the General Analysis of Variance Procedure of GenStat for Windows Version 16 [30]. The mean comparison was performed using Least Significant Difference (LSD) at a 5% level of significance upon obtaining significant F-values of the factors and interaction [29].

RESULTS AND DISCUSSION

Soil Physico-Chemical Properties of the Experimental Site: As presented in Table 1, the pH of experimental fields in both years lies in the range of 4.42 to 5.48 and was found to be strongly acidic to very strongly acidic as rated by Murphy [21]. According to Fekadu [10], the variety under this study ('*Welela*' - *L. angustifolius*) showed superior performance even below the above range (pH 3.93 - 5.1). Hence, the present soil test results indicate the suitability of the soil of the study sites for sweet lupine production. The organic carbon of the experimental fields in both years lies in the range of 1.67 to 2.011% which is classified as medium [22]. The total nitrogen percentage was in the range of 0.16 to 0.19%. According to Berhanu [23], the total nitrogen content of the experimental fields in both years lies in the moderate range. The extractable soil phosphorous in the first year (2019) was 19.993 ppm which is classified as medium (Jones and Benton, 2003) while the available soil phosphorus in the second year (2020) was 5.26 ppm which is classified as low [25]. The Extractable soil potassium in the first year (2019) was 2.522 [cmol(+)/ kg soil] which is rated as very high [26]. The cation exchange capacity (CEC) in the first year (2019) was 20.04 cmol (+)/kg and classified as moderate [27]. In general, CEC is used as a measure of soil fertility and nutrient retention capacity. Accordingly, soils high in CEC contents are considered agriculturally fertile.

Weather Conditions During the Crop Growth Period: According to the unpublished data of Holeta met station, the total rainfall for the period of July to December 2020 was higher (856.6 mm) than the year 2019 (741.7 mm) and that of the year 2000-2018 (596.3 mm) for the same period. The major portion of the total annual rainfall received was between July and September in all years while the highest was received in August. Generally, the total rainfall received for July to September indicated an increasing pattern in 2019 and 2020 as compared to the average of nineteen years (2000 - 2018), except September 2019 (Table 2). There was an increasing trend in maximum temperature from August to November in 2020 than in 2019 and nineteen years average. The minimum temperature showed a decreasing trend in 2020 while it was inconsistent in 2019 and nineteen years (2000 - 2018) average (Table 2). In general, maximum and minimum temperature, as well as total rainfall was more consistent in 2020 than in the year 2019 and the 19 years average where fluctuations were observed.

A combined analysis of variance over years (2019 and 2020) was performed for grain yield and some agronomic parameters were considered. According to the results, most of the interactions including three-way interaction of P_2O_5*Intra-row*inter-row spacing were non-significant for most parameters considered (Table 3). However, the two-way interactions of Yr*Intra-row and Yr*inter-row spacing on number of pods per plant, P_2O_5*intra-row spacing on plant height, number of pods per plant and grain yield as well as the three-way interaction of Year*Intra-row*inter-row spacing on grain yield, P_2O_5*Intra-row*inter-row spacing on number of pods per plant were found significant.

Table 1: Soil physico-chemical properties of the experimental sites

Parameter	Value 2019	Value 2020	Rating/soil reaction class 2019	Rating/soil reaction class 2020
pH	5.48	4.42	Strongly acidic	Very strongly acidic
Organic carbon (%)	2.011	1.67	Medium/moderate	Medium/moderate
Total nitrogen (%)	0.19	0.16	Medium	Medium
Extractable phosphorus (ppm)	19.993 (Extractable)	5.26 (available)	Medium	Low
Extractable potassium [cmol(+)/ kg soil]	2.522	nd	Very high	nd
CEC [cmol(+)/ kg soil]	20.04	nd	Moderate	nd

CEC = cat-ion exchange capacity, nd = not determined

Table 2: Nineteen years (2000 - 2018) average, the year 2019 and 2020 monthly rainfall, maximum and minimum temperatures of sweet lupine growing period at Holeta

Year	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2000-2018 Min Temp°C	9.2	8.8	7.7	5.0	5.8	2.6
2019 Min Temp°C	10.4	10.0	6.5	3.8	6.0	3.8
2020 Min Temp°C	9.5	9.5	8.5	3.5	2.5	2.0
2000-2018 Max Temp°C	20.9	20.6	21.0	22.7	22.9	23.0
2019 Max Temp°C	20.8	19.6	20.5	23.9	22.1	23.1
2020 Max Temp°C	20.5	21.5	21.6	23.5	24.0	23.0
2000-2018 RFmm	217.7	216.1	126.6	18.0	11.2	6.7
2019 RFmm	249.0	356.1	97.0	7.8	28.2	3.6
2020 RFmm	263.4	334.2	216.2	31.6	8.0	3.2

Source: Holeta meteorology station (unpublished data)

Table 3: Mean squares of ANOVA for grain yield, some phenological- and growth parameters of sweet lupine as affected by phosphate, intra-row and inter-row spacing at Holeta, combined over years (2019-2020)

Source of variation	DTF	DTM	Plh	NPPP	NSPP	HSW	GY
Year (Yr)	494.377**	392**	10952**	19822.6**	37.231**	47.423**	0.434ns
Rep (Yr)	7.1543	28.34	1103.82	1426.1	5.736	3.964	3.849
P_2O_5	0.043ns	0.784ns	38.75ns	81.8ns	0.121ns	0.493ns	0.189ns
Intra-row (Intra)	22.840**	19.117*	1071.04**	2520.2**	0.065ns	14.478**	7.047**
Inter-row (Inter)	6.691**	1.284ns	73.52ns	2525.3**	0.091ns	2.436ns	1.282*
Yr*P_2O_5	0.080ns	1.722ns	228.46ns	291ns	0.003ns	0.47ns	0.355ns
Yr*Intra	0.691ns	7.574ns	6.91ns	908.1**	0.082ns	0.161ns	0.704ns
Yr*Inter	2.469*	1.407ns	45.91ns	438.8*	0.172ns	0.128ns	0.037ns
P_2O_5*Intra	0.191ns	7.238ns	267.95*	319.8*	0.060ns	1.001ns	1.208*
P_2O_5*Inter	0.154ns	5.015ns	20.27ns	194.5ns	0.037ns	0.272ns	0.346ns
Intra*Inter	0.506ns	3.293ns	118.95ns	38.9ns	0.092ns	0.916ns	0.749ns
Yr*P_2O_5*Intra	0.617ns	5.435ns	82.81ns	219.7ns	0.061ns	0.229ns	0.226ns
Yr*P_2O_5*Inter	0.284ns	7.102ns	23.09ns	259.9ns	0.027ns	0.333ns	0.570ns
Yr*Intra*Inter	0.506ns	5.120ns	51.26ns	82.6ns	0.093ns	0.736ns	1.315*
P_2O_5*Intra*Inter	0.636ns	4.233ns	90.73ns	386.3**	0.043ns	0.307ns	0.393ns
Yr*P_2O_5*Intra*Inter	0.793ns	2.079ns	40.18ns	171.4ns	0.068ns	0.386ns	0.341ns
Residual	0.5883	4.623	78.91	118.1	0.164	1.004	0.3972

DTF=Days to 50% heading, DTM= Days to 90% physiological maturity, Plh= Plant height, NPPP= Number of pods per plant, NSPP= Number of seeds per pod, HSW= Hundred seeds weight, GY= Grain yield

The main effect of the year showed a significant effect on all parameters measured, except grain yield that is probably related to the inconsistency of rainfall amount and distribution and fluctuation of maximum temperature in both years which was more pronounced in the year 2019 than the year 2020 and the long-term average (Table 2). Accordingly, significantly longer days to flower (67.6 days), taller plants (85.4 cm high), a higher number of pods per plant (60.9) and the heaviest 100 seeds weight (14.87 g) were recorded in the second year while significantly longer days to mature (154 days) and higher number of seeds per pod (4.8) was recorded in the first year. Lopez-Belido *et al*. [31] reported the presence of considerable and unpredictable year-on-year variation in seed yield of faba bean, despite adequate control of pests and diseases. According to these authors, yield shows a greater response to yearly environmental conditions such as rainfall and maximum daily temperatures.

On the other hand, grain yield and all the studied agronomic characters didn't respond to the applied phosphate fertilizer (Table 3) probably due to the availability of a sufficient amount of soil phosphorus (Table 1). Earlier research results on lupine also indicated that from five years experiments no yield differences have been observed due to the application of P [2]. Similarly, Sulas *et al*. [32] reported the best performance of white lupine at the location where the soil had the lowest amount of available phosphorus. Moreover, Lambers *et al*. [33] noted that through a deep taproot system and the secretion of organic acids from the root, the lupine crop can increase the availability of phosphorus. According to the above authors, the traits associated with nutrient acquisition make lupines ideally suited for either impoverished soils or soils with large amounts of phosphorus that is poorly available for most plants, e.g., acidic or alkaline soils. In spite of this, the interaction effect of P_2O_5 with intra-row spacing was significant (P<0.05) on plant height, number of pods per plant and grain yield (Table 3). From the results, the tallest plants (84.3 cm) and highest grain yield (3.99 t/ha) were obtained at the combination of 46 kg P_2O_5/ha with 7 cm intra-row spacing though not significantly different from the combination of 23 kg P_2O_5/ha with the intra-row spacing of 7 cm (Table 5). The present result is in line with the recommendations of Yenesew Abebe *et al*. [14] and Africa RISING [15] in which they suggested the use of intra-row spacing of 7 cm and the application of P_2O_5 at the rate of 46 kg/ha. On the other hand, the highest number of pods per plant (63.82) was obtained at the combination of 69 kg P_2O_5/ha with the intra-row spacing of 13 cm (Table 5).

The main effect of intra-row spacing showed a significant (P<0.05) effect on all parameters considered, except the number of seeds per pod (Table 3). Accordingly, days to flowering, days to physiological maturity, the number of pods per plant and hundred seeds weight linearly increased as intra-row spacing increased from 7 cm to 13 cm (Table 4). On the other hand, the plant height and grain yield linearly decreased with increasing intra-row spacing from 7 cm to 13cm (Table 4). This result is in agreement with the suggestions of Withers [34], Yenesew *et al*. [14] and AR [15] where they suggested the use of narrower intra-row spacing of 7 cm. The main effect of inter-row spacing showed a significant (P<0.05) effect only on days to flowering, the number of pods per plant and grain yield (Table 3). Accordingly, as inter-row spacing increased from 30 cm to 50 cm, there was a linear and significant (P<0.05) increase in days to flowering and the number of pods per plant while grain yield linearly and significantly (P<0.05) decreased as inter-row spacing increased from 30 to 50 cm (Table 4). In similar experiments, yield increases between 37-110% have been achieved for sweet lupine in Minnesota and Wisconsin trials by narrowing row spacing from 76 cm to 15 cm [2]. In another similar experiment, the grain yield of lupine (the average result of the varieties of *L. albus* and *L. angustifolius*) decreased by 29% as row spacing increased from 25 cm to 75 cm [35].

In general, though the interaction effect of intra-row and inter-row spacing was found non-significant (Table 3), the earliest days to 50% flowering (65.2 and 65.5 days) and the earliest days to 90% physiological maturity (151.9 and 152.5 days) were obtained at the narrower spacing of 7 cm intra-row- and 30 cm inter-row spacing, respectively (Table 4) probably due to increased competition between plants for growth factors like moisture and essential nutrients which enhanced early flowering and maturity at closer spacing. As reported by Birhanu *et al*. [36], the mean days to 50% flowering and 90% physiological maturity of chickpea was hastened by the use of narrower intra-row- and inter-row spacing justifying that the hastened time of flowering and maturity in intra-row- and inter-row spacing might be due to competition for nutrients, moisture and space. On the other hand, Fikadu *et al*. [9] reported a non-significant difference between 30x7 cm, 30x15 cm, 40x15 cm and 40x20 cm tied row spacing combinations on the effect of days to flowering and maturity of sweet lupine varieties. On contrary, other authors like Farag [37] for broad bean under irrigated condition, Holshouser and Joshua [38] for soybean, Almaz *et al*. [39] for faba bean under vertisols condition and Melaku [40] for chickpea reported that days to 50% flowering and 90% physiological maturity were significantly decreased as the inter-row- and/or intra-row spacing increased which might be the indication of the influence of plant population on days to flower initiation and physiological maturity varies from crop to crop as well as the prevailing environmental conditions under which the crops are grown. The tallest plants (82 and 78.3 cm high) were obtained at the narrower spacing of 7 cm intra-row- and 30 cm inter-row spacing, respectively (Table 4) probably due to competition for solar radiation. In a similar experiment, Fikadu *et al*. [9] reported taller plants from narrower row spacing of 30 cm × 7 cm indicating that under narrow spacing between plants, the interplant competition will be too high that may force the individual plant to grow taller. Wassermann [41] also reported the tallest plants of *Lupinus albus* at the narrower inter-row spacing of 25 cm than 50 and 75 cm explaining that competition among the plants due to crowding either by increased seeding rate or by narrower row spacing resulted in significantly taller plants. Similarly, in chickpea, the longest plant height was obtained at closer spacing than wider once probably due

Table 4: Main effect of phosphorus, intra- and inter row spacing on grain yield and some agronomic parameters of sweet lupine at Holeta, combined over years (2019-2020)

Treatments	DTF	DTM	Plh (cm)	NPPP	NSPP	100 SWg	GY (t/ha)
Year							
1	64.1	154	68.9	38.8	4.8	13.78	3.56
2	67.6	151	85.4	60.9	3.8	14.87	3.46
LSD (5%)	0.2389	0.7	2.77	3.386	*0.13*	0.157	*ns*
P_2O_5 (kg/ha)							
23	65.9	152.6	76.2	48.7	4.3	14.43	3.53
46	65.8	152.7	77.5	49.7	4.4	14.25	3.56
69	65.9	152.4	77.8	51.1	4.3	14.29	3.45
LSD (5%)	ns	ns	ns	ns	ns	ns	ns
Intra-row spacing (cm)							
7	65.2	151.9	82.0	45.0	4.4	13.86	3.90
10	65.9	152.6	76.4	46.9	4.3	14.24	3.45
13	66.5	153.1	73.2	57.7	4.3	14.88	3.19
LSD (5%)	0.2926	0.800	3.390	4.146	ns	0.193	0.24
Inter-row Spacing (cm)							
30	65.5	152.5	78.3	43.6	4.3	14.11	3.69
40	65.8	152.4	77.2	48.7	4.4	14.33	3.45
50	66.2	152.7	76.0	57.2	4.3	14.54	3.40
LSD (5%)	0.2926	ns	ns	4.146	ns	ns	0.24
Mean	65.8	152.6	77.2	49.8	4.3	14.33	3.51
CV (5%)	1.2	1.4	11.5	21.8	9.4	7.00	17.90

DTF=Days to 50% flowering, DTM= Days to 90% physiological maturity, Plh= Plant height, NPPP= Number of pods per plant, NSPP= Number of seeds per pod, HSW= Hundred seeds weight, GY= Grain yield

Table 5: Two-way interaction effects of potash with intra-row spacing on plant height, number of pods per plant and grain yield of sweet lupine at Holeta, combined over years (2019-2020)

	Plant height (cm)			Number of pods per plant			Grain yield (t/ha)		
	Intra-row (cm)			Intra-row (cm)			Intra-row		
P_2O_5 (kg/ha)	7	10	13	7	10	13	7	10	13
23	80.1^{abc}	72.1^{de}	76.4^{bcd}	44.63^{d}	45.04^{cd}	56.29^{b}	3.96^{a}	3.18^{cd}	3.45^{bc}
46	84.3^{a}	78.9^{abc}	69.2^{e}	46.98^{cd}	$49.4b^{cd}$	52.83^{bc}	3.99^{a}	3.71^{ab}	2.98^{d}
69	81.6^{ab}	78.0^{ad}	73.9^{cde}	43.36^{d}	46.16^{cd}	63.82^{a}	3.76^{ab}	3.45^{bc}	3.13^{cd}

Table 6: Correlation coefficients between sweet lupine studied characters

	DTF	DTM	Plh	NPPP	NSPP	100SW	GY
DTF	-						
DTM	-0.3815**	-					
Plh	0.3667**	-0.598**	-				
NPPP	0.6879**	-0.274**	0.3113**	-			
NSPP	-0.7441**	0.4114**	-0.3383**	-0.6391**	-		
100SW	0.5675**	0.0047ns	-0.0878ns	0.3442**	-0.4179**	-	
GY	-0.2695**	-0.031ns	0.4579**	-0.1216ns	0.1215ns	-0.471**	-

DTF=Days to 50% heading, DTM= Days to 90% physiological maturity, Plh= Plant height, NPPP= Number of pods per plant, NSPP= Number of seeds per pod, HSW= Hundred seeds weight, GY= Grain yield

to the highest plant population under closer spacing that might have to afford several competitions among the crop for growth resources, especially the nutrient, moisture and light [36].

On the other hand, the higher number of pods per plant (57.7 and 57.2) was recorded at the wider spacing of 13 cm intra-row- and 50 cm inter-row spacing, respectively (Table 4) probably due to lower competition effect for resources at wider row spacing. Fikadu *et al*. [9] also obtained a higher number of pods per plant from wider spacing (40 cm × 20 cm) compared to the narrower spacing (30 cm × 7 cm) indicating that sweet lupines were affected by the number of branches. The heaviest 100 seeds weight (14.88 g and 14.54 g) were also recorded at the wider spacing of 13 cm intra-row- and 50 cm inter-row spacing, respectively (Table 4) probably due to lower competition effect for resources at wider spacing. Wassermann [41] also reported the heaviest 100 seed weight for *Lupinus albus* at wider row spacing. In contrast, Fikadu *et al*. [9] reported a non-significant difference between the narrower and wider inter-row- and intra-row spacing combinations (in which the main effect factors are not separately justified). The higher grain yield (3.90 and 3.69 t/ha) was obtained at the narrower spacing of 7 cm intra-row- and 30 cm inter-row spacing, respectively (Table 4) probably related to the higher number of plants per square meter in the narrower spacing. Wassermann [41] also reported higher grain yield for *Lupinus albus* at narrower inter-row spacing justifying that a more equidistant spacing, therefore, favored seed yield. In contrast, Fikadu *et al*. [9] reported a non-significant difference between the narrower and wider inter-row- and intra-row spacing combinations (in which the main effect of the factors is not separately justified). According to Mondal *et al*. [42], although the number of pods per plant was the lowest in closer spacing but seed yield per square meter was the highest due to increased plant accommodation in closer spacing than that of wider spacing.

In our study, only plant height and number of seeds per pod positively correlated with grain yield reflecting the importance of plant height and number of seeds per pod in the determination of grain yield in the study area. On the other hand, a negative and significant ($p<0.001$) correlation was observed between grain yield and days to flowering and hundred seeds weight (Table 6). Similarly, days to physiological maturity and number of pods per plant showed a negative non-significant correlation with grain yield (Table 6). In agreement with this results, Fikadu *et al*. [9] reported the presence of a positive and significant correlation between grain yield with plant height, number of seeds per pod and hundred seeds weight while a positive non-significant correlation with the number of pods per plant indicating that selection for plant height, number of seeds per pod and hundred-seeds weight would help increase the seed yield in sweet lupine plants. In contrast, Goulden [18] reported that the number of pods per plant being the factor most directly influencing seed yield per plant.

Depending on the above results, the lowest fertilizer rate of 23 kg P_2O_5/ha together with 7 cm intra-row- and 30 cm inter-row spacing (equivalent to 48 plants per square meter or a seed rate of 81 kg/ha using 95% germination rate and 85% establishment as an input for a seed rate calculation) found to be optimum for the study area. The present result is in line with the suggestions of Yenesew Abebe *et al*. [14] and Africa RISING [15], except for fertilizer rate, in which they suggested the use of intra-row spacing of 7 cm and the inter-row spacing of 30 cm or a seed rate of 80 kg/ha for a broadcast planting together with the application of P_2O_5 at the rate of 46 kg/ha. However, further study using zero fertilizer rate and narrower intra-row- and inter-row spacing need to be considered as P_2O_5 showed no response and the narrower spacing produced significantly higher grain yield as it might become higher if further narrower rows would have been used. As discussed by Putnam *et al*. [2], yield increases between 37-110% have been achieved for sweet lupine by narrowing row spacing from 76 cm to 15 cm.

CONCLUSIONS

In the present study, most of the studied characters were significantly affected by both the main effects of spacing than phosphate fertilizer and the interaction effects. Based on ANOVA results, the lowest fertilizer rate of 23 kg P_2O_5/ha together with 7 cm intra-row spacing and 30cm inter-row spacing (equivalent to 48 plants per square meter or a seed rate of 81 kg/ha) was found to be optimum for sweet lupine production in west Shewa *nitosols* and similar agro-ecologies. In addition to this, further study needs to consider using zero fertilizer rates and narrower intra-row- and inter-row spacing as P_2O_5 showed no response and the tested narrower spacing produced significantly higher grain yield.

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