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Research Article

Effects of variety and seeding rate on performance of sweet lupin (*Lupinus angustifolius*) at Holetta, in the Central Highlands of Ethiopia

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Abstract

The study was executed to evaluate the agro-morphological and nutritional performance of four narrow-leafed blue sweet lupin varieties (Australian lupin, Probor, Sanabor, and Vitabor) sown with five seeding rates (60, 70, 80, 90, and 100 kg/ha) during the main cropping seasons of 2014 and 2015 at Holetta in the central highlands of Ethiopia. Randomized complete block design replicated three times in factorial arrangements was used for experimenting. The lupin varieties were sown in rows with an inter-row spacing of 30 cm. At sowing, diammonium phosphate fertilizer at the rate of 100 kg/ha was uniformly applied for all treatments in both years. Data were collected on plant height, dry matter yield, number of pods per plant, number of seeds per pod, seed yield, and nutritive value. All measured data were subjected to analysis of variance using procedures of SAS general linear model. The result revealed that plant height, number of pods per plant, and number of seeds per pod of lupin varieties were significantly ($P<0.001$) affected by experimental years. The varietal difference was the major cause of variation ($P<0.05$) for dry matter yield, the number of pods per plant, and seed yield. The Sanabor, Probor and Vitabor varieties had 38, 23, and 20% dry matter yield advantage over the introduced Australian lupin variety, respectively. The Sanabor variety which produced the highest seed yield had 25, 17, and 14% seed yield advantages over Vitabor, Australian lupin, and Probor variety, respectively. The seed yield performance of lupin varieties was positively correlated with the number of pods per plant while it was negatively correlated with the number of seeds per pod. The dry matter yield and number of seeds per pod were also significantly ($P<0.05$) affected by seeding rates of lupin varieties. The dry matter yield of lupin varieties increased with increasing seeding rates indicating the tested lupin varieties had a low tillering performance. The number of seeds per pod of lupin varieties decreased with increasing seeding rates. On the other hand, the nutritive values did not differ significantly ($P>0.05$) among the tested lupin varieties.

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However, Vitabor variety gave better CP and IVDMD followed by Australian lupin while Probor variety gave the lowest CP and IVDMD. Vitabor variety which exhibited better ash, CP, and IVDMD contents produced the lowest NDF, ADF, and ADL contents when compared with other varieties. Generally, Sanabor and Probor varieties had better forage dry matter yield and seed yield but Vitabor and Australian lupin had relatively better nutritive values. For forage production, lupin varieties should be sown with the highest seeding rate (100 kg/ha) while the lowest seeding rate (60 kg/ha) is recommended for seed production. However, this research should be done across locations and over years to prove the above-recommended seeding rates for forage and seed productions in the study area and similar agro-ecologies.

Keywords: Dry matter yield; Herbage quality; Plant height; Pod number; Seed yield; Seeding rate

1. Introduction

Livestock resources have significant economic and social importance at household levels and make significant contributions to the national economy and foreign currency earnings of the country through the export of live animals, meat as well as hides, skins, and leather products (Adugna et al., 2012). However, feed shortage in terms of quantity and quality is a critical problem for the production and productivity of livestock in the country (Fekede et al., 2015). The potential livestock feed resources in Ethiopia are grazing natural pasture, crop residue, cultivated forage crops, agro-industrial byproducts, and non-conventional feed resources (Alemayehu et al., 2017). However, the livestock feeding in Ethiopia mainly depends on natural pasture and crop residue, both of which have low nutritional quality (Adugna et al., 2012; Getu, 2019). However, the utilization of forage crops is increasing due to the reduction of pasture lands in the mixed crop-livestock farming system (Minta et al., 2012). Among the cultivated forage crops, sweet lupin is one of the most important dual-purpose annual legume crops to reduce the feed shortage problem in different parts of the country (Likawent, 2012).

Lupin cultivation most likely began in Egypt or the Mediterranean region before 2,000 years (Putnam et al., 1989). Lupin seeds grown in Ethiopia and locally known as ‘Gibto’ are used to prepare local alcoholic drink ‘Areqe’ and other food products especially in the northwestern part of the country (Tizazu & Shimelis, 2010). When it is used as human food mostly used as a snack and as a local sauce called ‘Shiro’ in Ethiopia (Likawent et al., 2010). There are about over 300 species of the genus Lupinus, but many have high levels of alkaloids (bitter-tasting compounds) that make the forage and seed unpalatable and sometimes toxic. High-level alkaloids in animal diets have been known to depress feed intake and growth (Zulak et al., 2006). The alkaloid level of lupin (0.5–4%) varies among cultivars, soil type, and growing season (Gladstones, 1970). The mean alkaloid content of marketable sweet lupin seed is on average 130-150 mg kg^{-1} (De Carvalho, 2005). However, it has been possible to grow sweet genetic varieties with low alkaloid contents ranging from 0.008% to 0.012% (Tsaliki et al., 1999). Within the species, there are sweet and bitter varieties (McDonald et al., 2002). Historically, most alkaloid of lupin is water-soluble, can be decreased to 0.04% from the seed by soaking into running water for a longer time. But the alkaloid-free or "sweet" lupin which can be directly consumed by humans or livestock was developed by plant breeders in Germany in the 1920s (Putnam et al., 1989; Faluyi et al., 2000).

The most commonly found and commercially important species of this genus are the four sweet and large-seeded annuals namely; narrow-leafed blue lupin (*Lupinus angustifolius*), white lupin (*Lupinus albus*), yellow lupin (*Lupinus luteus*), and pearl lupin (*Lupinus mutabilis*) cultivated for human food, green manure, and ruminant feed in the world (Kurlovich, 2006). The ability of the crop to be grown in acidic soils is one of the major important features of the crop in the traditional lupin growing areas of Ethiopia. Lupin is widely grown in the northwestern part of Ethiopia for soil fertility maintenance, forage, human consumption, and a supplement to low-quality roughages. The alkaloid content in bitter varieties limits its use (food and feed). In bitter varieties, alkaloid content ranges from 0.5 to 6% but in sweet lupin, it is less than 0.02%. The high protein content in lupin species makes them valuable feed resources for livestock production systems as they are cost-competitive with a wide range of other protein sources (Edwards & Bameveld, 1998). There are different varieties of sweet lupin in different parts of the world with low alkaloid content that could be introduced to our country. Lupin varieties have different responses when sown with different agronomic managements under various environmental conditions. Therefore, the study was initiated to evaluate the performance of sweet lupin (*Lupinus angustifolius*) varieties and to determine their optimum seeding rate for yield and nutritional quality in the central highlands of Ethiopia.

2. Materials and Methods

2.1 Description of the study area

The experiment was conducted at Holetta Agricultural Research Center during the main cropping seasons of 2014 and 2015 under rainfed conditions. The center is located at 9°00'N latitude, 38°30'E longitude at an altitude of 2400 m above sea level. It is 34 km west of Addis Ababa on the road to Ambo and is characterized by the long-term (30 years) average annual rainfall of 1055.0 mm, average relative humidity of 60.6%, and average maximum and minimum air temperature of 22.2°C and 6.1°C, respectively. The soil type of the area is predominantly red nitosol, which is characterized by an average organic matter content of 1.8%, total nitrogen 0.17%, pH 5.24, and available phosphorus 4.55ppm (Gemechu, 2007).

2.2 Experimental treatments and design

Four varieties of blue sweet lupin (Australian lupin, Probor, Sanabor, and Vitabor) with five different seeding rates (60, 70, 80, 90, and 100 kg/ha) were used as a treatment. The three varieties (Probor, Sanabor, and Vitabor) used in the experiment were obtained from Amhara Agricultural Research Institute and the remaining variety (Australia lupin) was introduced from Australia. The experiment was conducted in randomized complete block design in a factorial arrangement with three replications. The treatments were combined in factorial arrangements to produce 20 treatment combinations.

Seeds were sown in rows of 30 cm spacing on a plot size of 3 m x 4 m = 12m^2. A spacing of 1.5 m and 1.0 m were used between blocks and plots, respectively. At sowing, Diammonium phosphate (DAP) fertilizer at the rate of 100 kg/ha was uniformly applied for all treatments. Plots were hand-weeded twice per year to reduce the effect of weeds on crop performance. Moreover, appropriate agronomic management was uniformly applied at the right time to improve the yield per unit area.

2.3 Data collection and measurements

Sampling for plant height, dry matter yield, number of pods per plant, number of seeds per pod, seed yield was made from the interior rows. Plant height was measured using steel tape from the ground level to the tip of the plant at the forage harvesting stage. Five randomly selected plants were used to determine the plant height of each treatment. The plants were clipped at 5 cm above the ground from the two interior rows at the 50% flowering stage to determine the biomass yield. The weight of the total fresh biomass yield was recorded from each plot in the field and the estimated 500 g sample was taken from each plot to the laboratory. The sample taken from each plot was weighed to know the total sample fresh weight using sensitive table balance and oven-dried for 24 hours at a temperature of 105^{o}C for herbage dry matter yield determination.

Five plants were randomly taken and uprooted at the seed filling stage from each plot for the determination of the number of pods per plant. Five pods were then randomly taken to count the number of seeds per pod. The innermost two rows of each plot were maintained for seed yield determination. The plants were harvested at optimum seed harvesting time and seed yield was determined from two rows after threshing and winnowing. Seed samples were taken and oven-dried at 100°C for 48 hours to adjust the moisture content of 10%, a recommended percentage level for legumes (Biru, 1979). Seed yield (t/ha) was then calculated at 10% moisture content.

2.4 Herbage quality analysis

The plants were clipped at the recommended (50% flowering) harvesting stage of the lupin variety. The harvested forage samples were oven-dried at a temperature of 65°C for 72 hours to determine the chemical composition and *in-vitro* dry matter digestibility. The dried samples were then ground to pass a 1 mm sieve for laboratory analysis. The total ash content was determined by oven drying the samples at 105^{0}C overnight and by combusting the samples in a muffle furnace at 550°C for 6 hours (AOAC, 1990).

The nitrogen (N) content was determined following the micro-Kjeldahl digestion, distillation, and titration procedures (AOAC, 1995), and the crude protein (CP) content was estimated by multiplying the N content by 6.25. The NDF, ADF, and ADL contents were determined according to Van Soest & Robertson's (1985) procedure. The two-stage *in-vitro* fermentation technique of Tilley and Terry as modified by Van Soest & Robertson (1985) procedure was used to determine *in-vitro* dry matter digestibility (IVDMD).

2.5 Statistical analysis

The collected data were subjected to the analysis of variance procedures of the SAS general linear model statistical software package (SAS, 2002). Only traits that show a significant difference in ANOVA were promoted to mean comparisons using the least significance difference (LSD) at a 5% probability level. The data were analyzed using the following model (Eq. 1):

$$Y_{ijkl} = \mu + V_i + S_j + Y_k + (VS)_{ij} + (VY)_{ik} + (SY)_{jk} + (VSY)_{ijk} + (B)_l + e_{ijkl} \quad (1)$$

Where, Y_{ijkl} is the dependent variable; μ is overall mean; V_i is the effect of variety i; S_j is the effect of seeding rate j; Y_k is the effect of year k; $(VS)_{ij}$ is the interaction effect of variety i and seeding rate j; $(VY)_{ik}$ is the interaction effect of variety i and year k; $(SY)_{jk}$ is the interaction effect of seeding rate j and year k; $(VSY)_{ijk}$ is the interaction effect of variety i, seeding rate j and year k; B_l is the effect of the block I and e_{ijkl} is a random error.

3. Results and Discussion

3.1 Analysis of variance

The combined analysis of variance for measured agro-morphological traits of sweet lupin varieties sown with different seeding rates over years is indicated in Table 1. The result revealed that plant height, number of pods per plant, and number of seeds per pod of lupin varieties were significantly (P<0.001) affected by cropping years. The varietal difference was the major cause of variation (P<0.05) for dry matter yield, the number of pods per plant, and seed yield.

The dry matter yield and number of seeds per pod were also significantly (P<0.05) affected by seeding rates of lupin varieties. The plant height, dry matter yield, number of pods per plant, number of seeds per pod, and seed yield of lupin varieties were not significantly affected (P>0.05) by the interaction effects of variety by seeding rate, variety by the year, seeding rate by year, and variety by seeding rate by year. These non-significant interaction effects indicate the genotypes perform consistently over years for measured agro-morphological traits when sown with different seeding rates. The change in the relative behavior of the genotype in different environments is due to the differential response of genotypes to different growing conditions (Bernardo, 2002).

Table 1. Combined analysis of variance for measured agro-morphological traits of lupin varieties

Sources of variation	Parameters				
	PH	DMY	NPPP	NSPP	SY
Variety	NS	*	*	NS	*
Seeding rate	NS	*	NS	*	NS
Year	***	NS	***	***	NS
Variety * seeding rate	NS	NS	NS	NS	NS
Variety * Year	NS	NS	NS	NS	NS
Seeding rate * Year	NS	NS	NS	NS	NS
Variety *Seeding rate*Year	NS	NS	NS	NS	NS

NS= Non-significant; *** = P<0.001; * = P<0.05; PH = Plant height; DMY = Dry matter yield; NPPP = Number of pods per plant; NSPP = Number of seeds per pod; SY = Seed yield

3.2 Varietal differences in plant height and dry matter yield

In the combined analysis of variance, plant height was not significantly (P>0.05) affected by varieties of lupin at Holetta as shown in Figure 1. The result indicated that the mean plant height of lupin varieties ranged from 57.7–63.1 with a mean of 60.0 cm at the forage harvesting stage. The highest plant height was recorded for the Probor variety followed by Vitabor and Sanabor while the introduced Australian lupin variety produced the lowest plant height.

The variation in plant height among varieties was in agreement with Friehiwot et al. (2019), who reported that the plant height of Probor, Sanabor, and Vitabor varieties ranged from 53.8–67.6 with a mean of 60.5 cm. However, the mean plant height of Vitabor and Sanabor varieties was relatively higher (Riga et al., 2021) while the mean height of Vitabor, Sanabor, and Probor varieties was lower (Alemu et al., 2017; Alemu et al., 2019) when compared with the current study. On the other hand, the plant height of narrow-leafed lupin varieties had wide variations which varied from 20 to 100 cm (Edwards et al., 2011). The variation might be occurring due to environmental differences in experimental areas. The varietal differences and the response of the varieties to soil and weather conditions are the main factors for plant height variation in lupin varieties.

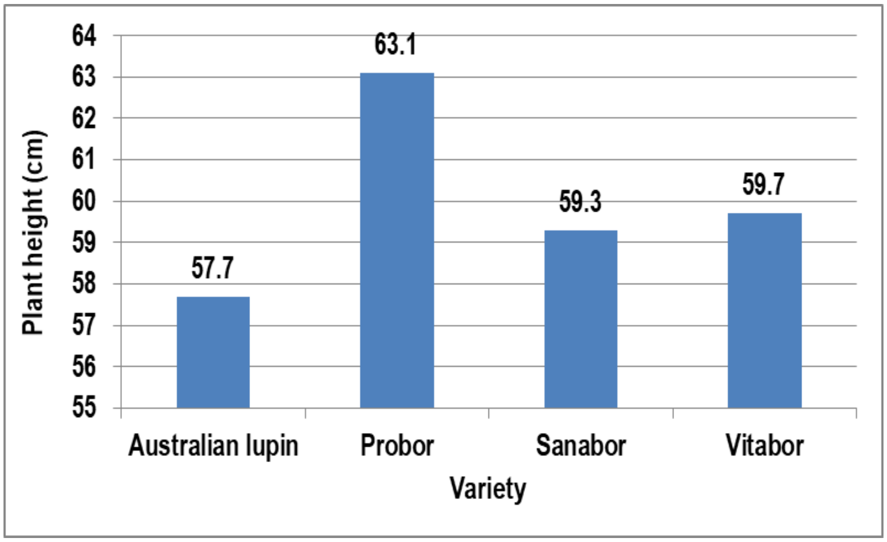

Figure 1. Mean plant height (cm) of lupin varieties at Holetta

In the combined analysis, lupin varieties responded differently (P<0.05) for dry matter yield at Holetta as indicated in Figure 2. The dry matter yield of lupin varieties ranged from 1.3–1.8 with a mean of 1.5 t/ha at the recommended forage harvesting stage. The highest dry matter yield was recorded from the Sanabor variety followed by Probor and Vitabor while the lowest dry matter yield was obtained from the Australian lupin variety. The Sanabor, Probor and Vitabor varieties had 38, 23, and 20% yield advantage over the introduced Australian lupin variety, respectively. Similarly, Sanabor variety had 14, and 11% yield advantages over Vitabor and Probor varieties, respectively. The three lupin varieties viz., Sanabor, Vitabor, and Probor produced the mean dry matter yield of 1.89 t/ha (Friehiwot et al., 2019) which was comparable with the mean dry matter yield of the respective varieties tested in this study.

Generally, annual blue lupin varieties produced lower dry matter yields because this species has a shorter plant height when compared with other forage legumes. Weerakoon & Somaratne (2013) indicated that varietal differences had a significant effect on forage dry matter yield. On the other hand, no difference in mean dry matter yield was observed for narrow-leafed lupin varieties (Alemu, 2016). The recorded mean dry matter yield (3.45 t/ha) for Vitabor and Sanabor was higher (Riga et al., 2021) than the current reported dry matter yield for the respective lupin varieties while the current reported forage dry matter yield was higher than those reported (1.4 t/ha) in narrow-leafed sweet lupine in Ethiopia (Likawent et al., 2010). Similarly, the mean dry matter yield (2.03 t/ha) of Vitabor, Sanabor, and Probor varieties was relatively higher (Alemu et al., 2019) than in the current study.

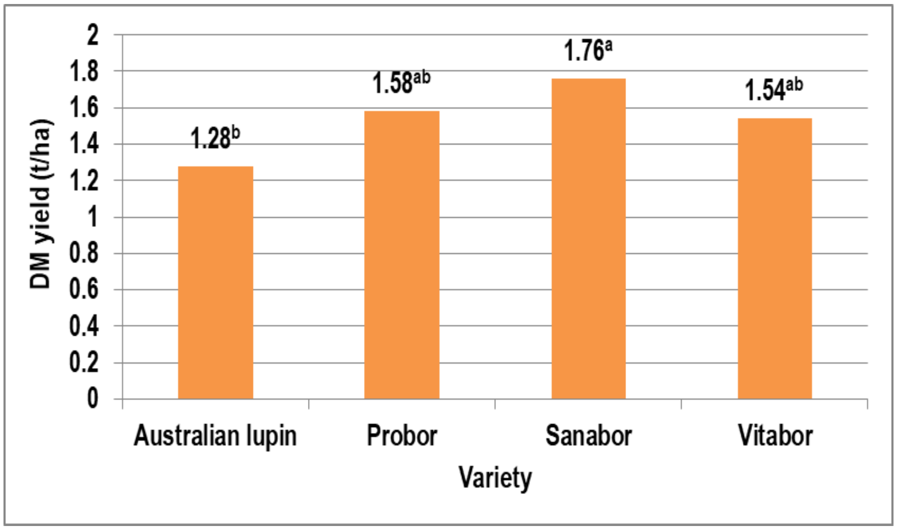

Figure 2. Mean dry matter yield (t/ha) of lupin varieties at Holetta

3.3 Varietal differences on seed yield and its yield components

The mean of podes per plant of lupin varieties tested at Holetta is indicated in Figure 3. The result indicated that the number of pods per plant varied significantly (P<0.05) among the tested lupin varieties at Holetta. The number of pods per plant of lupin varieties ranged from 27.3–32.7 with a mean of 29.4 at the seed maturity stage. The highest number of pods per plant was recorded for Sanabor followed by Vitabor (30.1) while Probor and Australian lupin produced the lowest number of pods per plant.

The number of pods per plant variation among the tested lupin varieties attributed to differences in the number of branches per plant. The mean of pods per plant of Sanabor, Vitabor, and Probor was 10.2 (Friehiwot et al., 2019) which was too low when compared with the respective lupin varieties tested in this study. On the other hand, the mean of pods per plant (53.9) of Vitabor and Sanabor varieties was relatively higher (Riga et al., 2021) than the respective lupin varieties tested in this study. However, Kurlovich et al. (2011) reported no significant difference in the number of pods per plant among narrow-leafed lupin varieties.

The mean of seeds per pod of lupin varieties tested at Holetta is indicated in Figure 4. The result revealed that the tested varieties did not differ significantly (P>0.05) for the number of seeds per pod at the seed maturity stage. The number of seeds per pod of lupin varieties ranged from 4.27– 4.43 with a mean of 4.38. The introduced Australian lupin variety produced the highest number of seeds per pod followed by Probor (4.42) and Vitabor (4.40) while Sanabor produced the lowest number of seeds per pod. Generally, the highest number of pods per plant producing variety produced the lowest number of seeds per pod and vice versa.

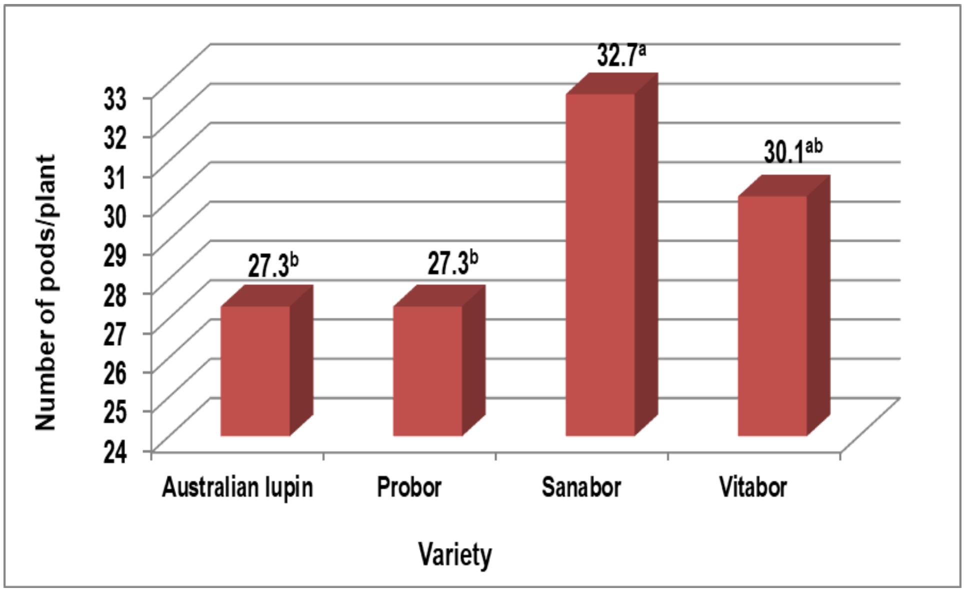

Figure 3. Mean number of pods per plant of lupin varieties at Holetta

The reported mean of seeds per pod (3.67) for Sanabor, Vitabor, and Probor varieties was lower (Friehiwot et al., 2019) than the respective lupin varieties tested in this study. Significant differences in the number of seeds per pod were exhibited among lupin varieties as shown by Yang et al. (2016). The number of seeds per pod of Vitabor and Sanabor varieties reported by Riga et al. (2021) was higher than the respective lupin varieties in the current study. Tizazu & Shimelis (2010) reported that the number of seeds per pod ranges between 4.33 and 4.67 which almost agreed with this study.

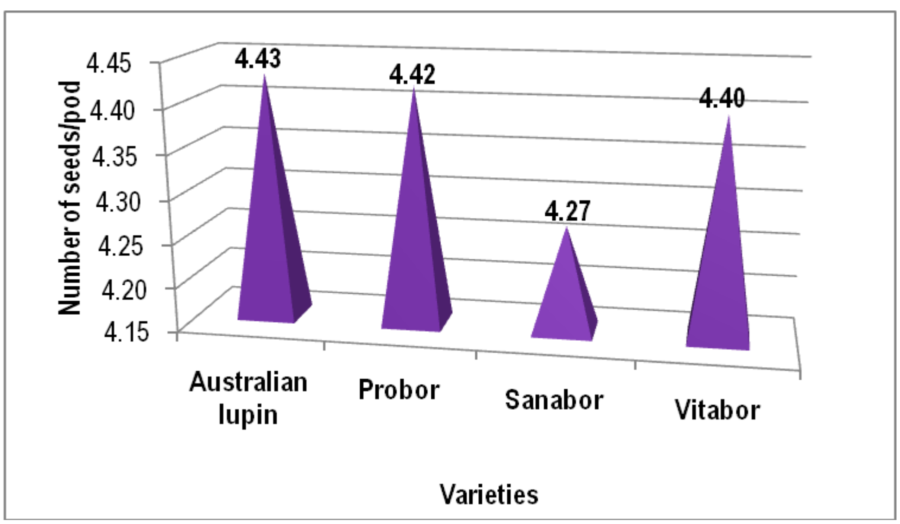

Figure 4. Mean of seeds per pod of lupin varieties at Holetta

The mean seed yield performance of lupin varieties tested at Holetta is indicated in Figure 5. The seed yield performance varied significantly (P<0.05) among the tested lupin varieties at the seed harvesting stage. The seed yield of lupin varieties ranged from 23.3–29.1 with a mean of 25.73 qt/ha. The highest seed yield was recorded for the Sanabor variety followed by Probor (25.6 qt/ha) and Australian lupin (24.9 qt/ha) while the lowest was produced from Vitabor variety. The variety which produced the highest number of pods per plant gave the highest seed yield.

The Sanabor variety which produced the highest seed yield had 25, 17, and 14% seed yield advantages over Vitabor, Australian lupin, and Probor variety, respectively. Similarly, Probor variety had 10 and 3% seed yield advantages over Vitabor and Australian lupin variety, respectively. The Australian lupin variety had a 7% yield advantage over the Vitabor variety. The reported mean seed yield (13.9 qt/ha) of Sanabor, Vitabor, and Probor varieties was too lower (Friehiwot et al., 2019) than the respective lupin varieties tested in this study. These differences could be due to variation in agro-ecologies among the study areas. Alemu (2016) also found that Sanabor gave higher grain yield than other tested narrow-leafed lupin varieties which was in agreement with the current study. The seed yield of narrow-leafed sweet lupin in this study was in line with the reports of Fraser et al. (2005) and Riga et al. (2021), but higher than the findings of Tizazu & Shimelis (2010). Generally, the seed yield performance of lupin varieties was positively correlated with the number of pods per plant while it was negatively correlated with the number of seeds per pod.

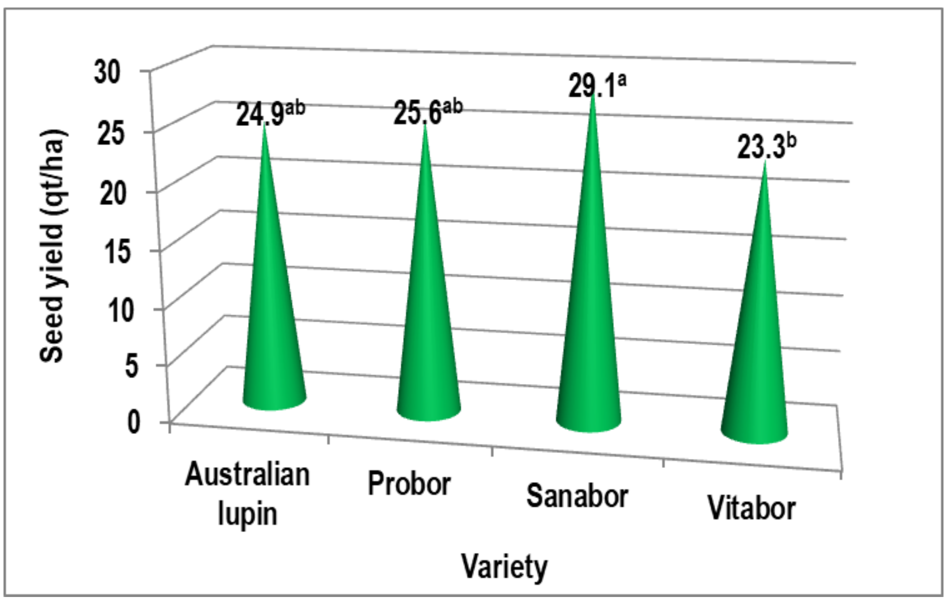

Figure 5. Mean seed yield qt/ha of lupin varieties at Holetta (1 qt = 100 kg)

3.4 The effect of seeding rate on plant height and dry matter yield

The effect of seeding rates on the mean plant height performance of lupin varieties tested at Holetta is indicated in Figure 6. The result showed that the plant height of lupin varieties did not vary significantly (P>0.05) for different seeding rates at the forage harvesting stage. The mean plant height of lupin varieties sown with different seeding rates ranged from 59.6–60.8 with a mean of 60.0 cm at the forage harvesting stage. The lupin varieties sown with a seeding rate of 80 kg/ha gave the highest plant height followed by varieties sown with seeding rates of 100 and 70 kg/ha while the lowest plant height was recorded for varieties sown with seeding rates of 60 and 90 kg/ha.

Generally, due to competition for limited growth resources, the plant height of lupin varieties was higher with increasing rates of seeding. The reason could be plants under narrow spacing between plants, and the interplant competition will be too high that the individual plant increases in height (Rasul et al., 2012). The largest increment in mean plant height was recorded in the forage harvesting stage due to massive root development and efficient nutrient uptake allowing the plant to continue the increase in height. Similar results had also been reported by another worker (Tizazu & Shimelis, 2010).

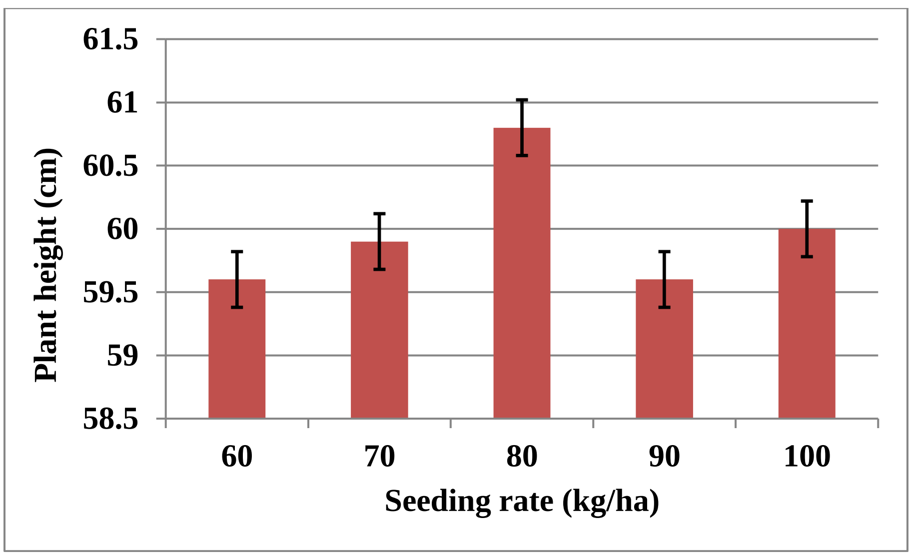

Figure 6. Mean plant height (cm) of lupin varieties as influenced by seeding rates at Holetta

The effect of seeding rates on dry matter yield performance of lupin varieties tested at Holetta is indicated in Figure 7. The lupin varieties sown with different seeding rates responded differently (P<0.05) for dry matter yield at the forage harvesting stage. The varieties sown with a seeding rate of 100 kg/ha produced the highest (1.77 t/ha) dry matter yield followed by the varieties sown with seeding rates of 90 kg/ha and 80 kg/ha while the lowest dry matter yield

(1.10 t/ha) was recorded for varieties sown with a seeding rate of 60 kg/ha. Generally, the dry matter yield of lupin varieties increased with increasing seeding rate indicating the varieties had a low tillering performance. So, the varieties should be sown with the highest seeding rate to get a better dry matter yield. The result of this study agreed with Pholsen & Sornsungnoen (2004), who reported that higher yield was attributed to high plant populations that allowed the fodder crop to thrive well in terms of nutrient uptake from soil and a solar interception in the early period of plant growth and development.

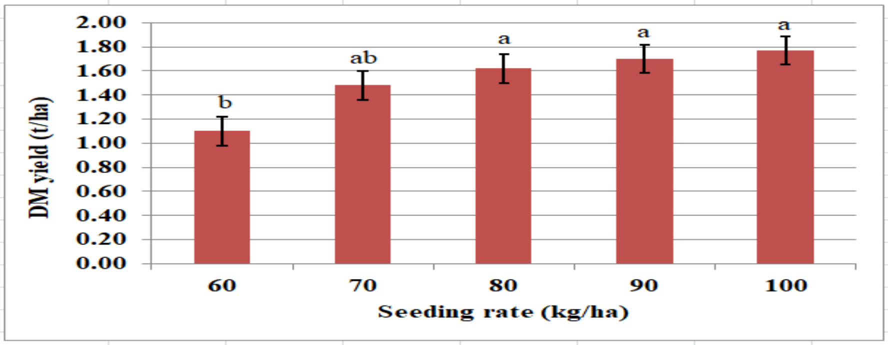

Figure 7. Mean DM yield (t/ha) of lupin varieties as influenced by seeding rates at Holetta

3.5 The effect of seeding rate on seed yield and its yield components

The effect of seeding rates on the number of pods per plant of lupin varieties tested at Holetta is indicated in Figure 8. The result showed that the number of pods per plant of lupin varieties sown with different seeding rates did not differ (P>0.05) at the seed harvesting stage. The number of pods per plant of lupin varieties sown with different seeding rates ranged from 26.7–31.2 with a mean of 29.3.

The highest number of pods per plant was recorded when the varieties were sown with a seeding rate of 90 kg/ha followed by 80 kg/ha while the varieties produced the lowest number of pods per plant when sown with a seeding rate of 100 kg/ha. The varieties sown with a seeding rate of 90 and 80 kg/ha had 17 and 12% increments in the number of pods per plant, respectively, over the varieties sown with a 100 kg/ha seeding rate. High plant populations tended to produce plants with fewer branches and a greater number of pods on the main stems. As a result, a greater proportion of the yield was derived from the pods on the main stem. On the other hand, a lower seeding rate gave a better number of pods per plant by increasing the number of branches per plant. Plants were sown at wider spacing resulted in a higher pod number per plant compared to narrower spacing (Riga et al., 2021). Generally, the results indicated that the number of pods per plant increased as the planting population decreased since sweet lupin varieties were affected by the number of branches.

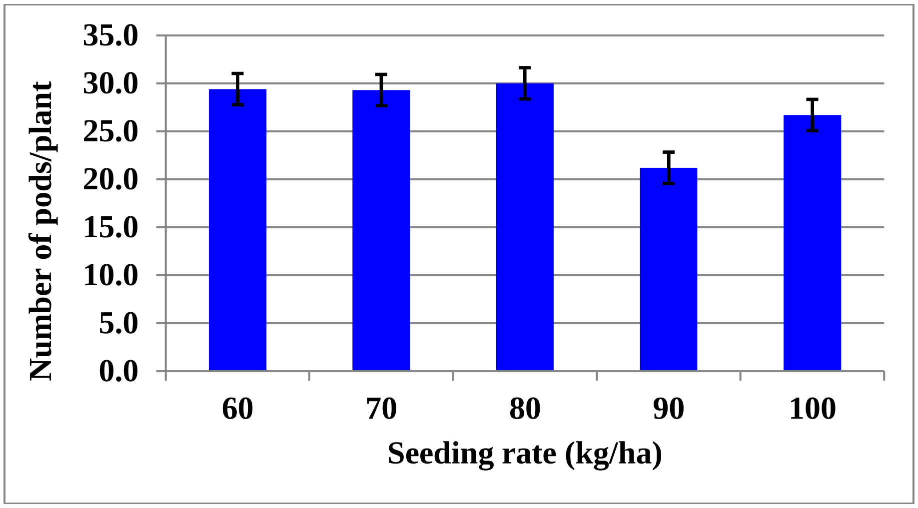

Figure 8. Mean number of pods per plant of lupin varieties as influenced by seeding rates at Holetta

The effect of seeding rates on the number of seeds per pod of lupin varieties tested at Holetta is indicated in Figure 9. The result revealed that the number of seeds per pod of lupin varieties sown with different seeding rates varied significantly ($P<0.05$) at the seed harvesting stage. The number of seeds per pod of lupin varieties sown with different seeding rates ranged from 4.09–4.64 with a mean of 4.38. But the potential number of seeds per pod of lupin varieties ranges from 3 to 6, depending on the location of the plant. As branch order increases up the plant, the number of seeds per pod decreases.

Different genotypes showed different performances in the number of seeds per pod which could be associated with the variations in agro-ecology and edaphic conditions. The highest number of seeds per pod was recorded when the varieties sown with a seeding rate of 70 kg/ha while the varieties sown with a seeding rate of 60 kg/ha produced the lowest number of seeds per pod. Seed set is determined mainly by temperature and moisture during flowering, both of which affect assimilate supply.

Generally, the number of seeds per pod of lupin varieties decreased with increasing seeding rates. The presence of critical competition among plants for limited growth resources is the major reason for decreased number of seeds per pod with increasing seeding rates of lupin varieties. Riga et al. (2021) reported that a higher number of populations per unit area increased the number of seeds per pod of lupin varieties by reducing the number of pods per plant which was not in line with this study.

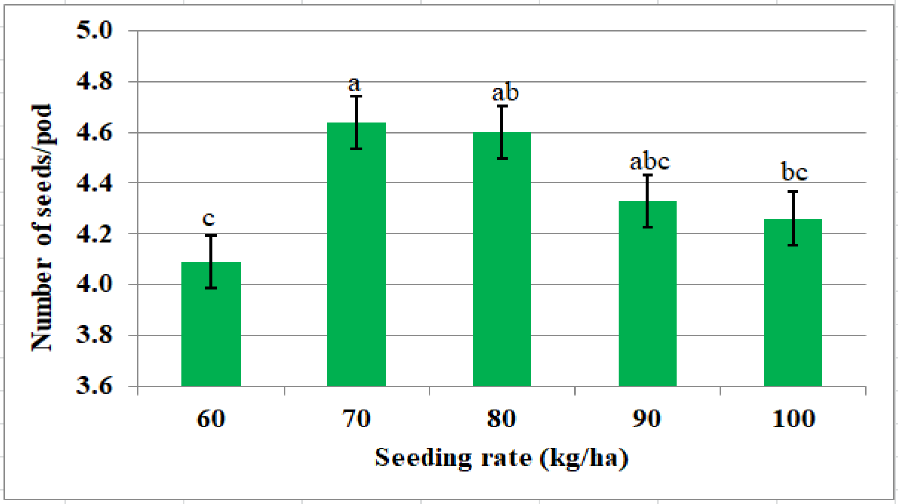

Figure 9. Mean of seeds per pod of lupin varieties as influenced by seeding rates at Holetta

The effect of seeding rates on the seed yield performance of lupin varieties tested at Holetta is indicated in Figure 10. The result showed that the varieties did not differ (P>0.05) in seed yield performance when sown at different seeding rates. The seed yield performance of lupin varieties sown with different seeding rates ranged from 22.8–27.3 with a mean of 25.8 qt/ha at the seed harvesting stage. The highest seed yield was recorded when the lupin varieties sown with a seeding rate of 90 kg/ha.

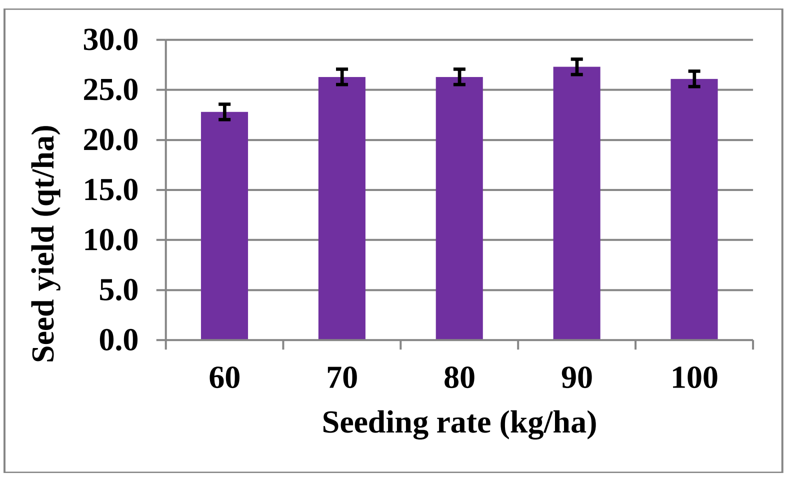

Figure 10. Mean seed yield qt/ha of lupin varieties as influenced by seeding rates at Holetta (1 qt = 100 kg)

On the other hand, the lupin varieties sown with the lowest and highest seeding rates generally produced the lowest seed yield. The seed yield of lupin varieties sown with a seeding rate of 90 kg/ha had a 20% yield advantage over the varieties sown with a seeding rate of 60 kg/ha. Seed yield from lupin varieties is determined by the number of pods per square meter (pod density), number of seeds per pod, and seed weight. The seed yield obtained from lupin varieties sown with less population density was higher than more population density (Riga et al., 2021).

Sowing with a higher seeding rate reduced the seed yield performance of lupin varieties because the competition for limited growth is higher when the varieties sown with a higher seeding rate.

3.6 Varietal differences of herbage nutritive value

The mean ash, crude protein (CP), and *in-vitro* dry matter digestibility (IVDMD) of lupin varieties tested at Holetta are indicated in Figure 11. The result indicated that the varieties did not vary (P>0.05) in ash, CP, and IVDMD at the forage harvesting stage. The ash content of lupin varieties was ranged from 14.0–14.8 with a mean of 14.3%. The highest ash content was recorded for the Sanabor variety while the Probor variety produced the lowest ash content. The highest CP content was recorded for Vitabor variety (21.6%) followed by Australian lupin (20.8%), and Sanabor (19.8%) while Probor variety produced the lowest (19.5%) content of CP. The IVDMD of lupin varieties ranged from 75.4–77.3 with a mean of 76.6%. The Vitabor variety gave the highest IVDMD followed by Australian lupin and Sanabor variety while Probor variety gave the lowest IVDMD.

Generally, Vitabor variety gave better CP and IVDMD followed by Australian lupin while Probor variety gave the lowest CP and IVDMD. The ash and CP contents of Vitabor and Sanabor varieties reported by Riga et al. (2021) were 14.5% and 22.1%, respectively, which were in agreement with the current study. The CP content in yellow lupin forage ranged from 18.4–21.5% (Bruno-Soares et al., 1999), and the CP content in blue lupin was 16.7% (Bruno-Soares & Mira vaz, 1999) which were lower than the CP content of this study. Similarly, the IVDMD content (67.5%) reported by Riga et al. (2021) was lower when compared with this study. Differences in variety, location, soil, and management conditions could cause variations in the nutritive values of lupin varieties.

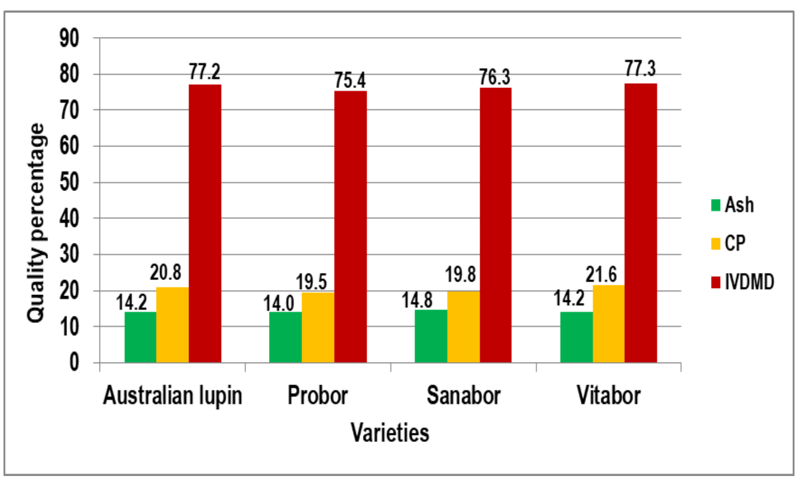

Figure 11. Mean ash, crude protein, and in-vitro dry matter digestibility of lupin varieties at Holetta

The mean neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) contents of lupin varieties tested at Holetta is indicated in Figure 12. The result showed that a non-significant difference (P>0.05) for NDF, ADF, and ADL contents was recorded among lupin varieties at the forage harvesting stage. The highest NDF was recorded for Probor (49.9%) followed by Sanabor (48.3%), Australian lupin (47.0%) while the lowest was recorded from Vitabor (46.8) variety. The Prober variety gave the highest ADF (36.2%) and ADL (35.6%) contents followed by Sanabor while Vitabor gave the lowest contents of ADF (33.8%) and ADL (8.7%).

Generally, Vitabor variety which exhibited better ash, CP, and IVDMD contents produced the lowest NDF, ADF, and ADL contents when compared with other varieties. The NDF and ADF contents of lupin varieties in this study were comparable with the study done by Riga et al. (2021) and Bruno-Soares et al. (1999). However, the ADL reported by Riga et al. (2021) was lower when compared with the current study. Feed value is the potential of a feed to supply the nutrients required by an animal both in terms of quantity and quality to support a desired type of production. The feed value of a given feed is influenced by feed factors such as chemical composition, digestibility, physical structure and intake level of the feed, and animal factors such as the physiological status of the animal (Mlay et al., 2006). Lupin forage has the potential to be used as a protein supplement in livestock feed. Dairy cows supplemented with 4–8 kg of lupin forage dry matter per day after grazing Kikuyu grass pasture produced a higher milk yield of up to 3.8 L/day/cow, especially at early lactation, as compared to the control group (Hughes et al., 1988).

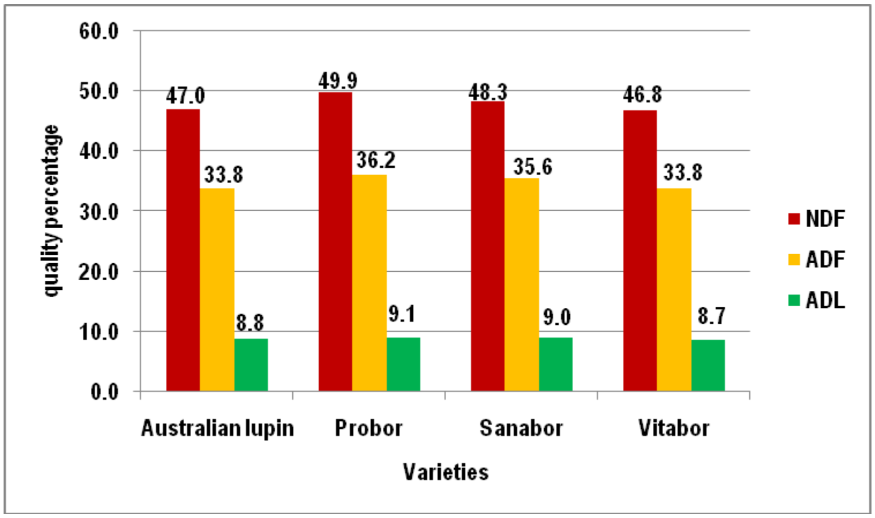

Figure 12. Mean Neutral detergent fiber (NDF), Acid detergent fiber (ADF), and acid detergent lignin (ADL) of lupin varieties at Holetta

4. Conclusion

The tested lupin varieties had different plant height, forage dry matter yield, number of pods per plant, number of seeds per pod, seed yield, and nutritive values and the varieties responded differently for measured traits when sown with different seeding rates. Among the tested lupin varieties, Sanabor and Probor varieties had better forage dry matter yield and seed yield but Vitabor and Australian lupin had relatively better nutritive values. The forage dry matter yield of lupin varieties increased significantly with increasing seeding rates. But, the seed yield performance of the varieties did not vary significantly with increasing seeding rates. Generally, for better forage dry matter yield and seed yield, the varieties should be sown with seeding rates of 100 and 60 kg/ha, respectively. However, this research should be done across locations and over years to prove the above-recommended seeding rates for forage and seed productions in the study area and similar agro-ecologies.

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