Forage Res., **51**(1) : pp. 35-46 (2025) **http://forageresearch.in**

EFFECT OF LIME APPLICATION RATES ON GROWTH CHARACTERISTICS AND DRY MATTER YIELD OF COWPEA (*VIGNA UNGUICULATA*) VARIETIES ON ACIDIC SOIL AT ALGE SACHI WOREDA, SOUTH WESTERN ETHIOPIA

TEMAM UMAR[1]*, SOLOMON DEMEKE[2] AND ZEMENE WORKU[3]

[1]South Western Agricultural Research Institute (SWARI), Tarcha Agricultural Research Center, Ethiopia
[2]Department of Animal Science, Jimma University College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia
[3]Department of Animal Science, Jimma University College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia
**(e-mail: tamamumar2019 @gmail.com)*

(Received: 14 May 2025; Accepted: 10 June 2025)

SUMMARY

This study was carried out at Alge Sachi Woreda to evaluate the effect of lime application rates on growth characteristics and dry matter yield of cowpea varieties on acidic soil. The experiment was laid out in a 3x5 factorial arrangement of randomized complete block design replicated three times with the involvement of three cowpea varieties (Bole, Bekur, and Sewunet) and five rates of lime (0, 0.3, 0.6, 0.9, and 1.2 tons/hectare). All collected data were subjected to two-way analysis of variance using the general linear model of SAS software version 9.3. Significant treatment means were separated using the least significant difference at a 5 % significant level. The results obtained indicated that the interaction effect of varieties and lime application rates significantly ($p<0.05$) resulted in the highest mean dry matter yield of cowpea forage at the Sewunet variety assigned to the plot dressed with 0.6, 0.9, and 1.2 tons/hectare, and the Bole variety assigned to the plot dressed with 0.9 and 1.2 tons/hectare of lime application rates. The results of partial budget analysis showed that 8.26 t/ha of adjusted forage dry matter yield obtained at the Sewunet variety assigned to the plots dressed with a 0.6 ton/hectare lime application rate was economically feasible and brought 2.63 Ethiopian birr extra income. Therefore, the Sewunet variety assigned to the plot dressed with 0.6 ton/hectare of lime application rate was economically feasible and recommended for farmers' use in the study area and in other areas with similar agro-ecologies and soil types.

Key words: Acidic soil, Cowpea varieties, Lime, Rate

Despite Ethiopia being believed to have the largest livestock population in Africa, the contribution of the country's livestock sub-sector to human nutrition, the national economy, and export earnings is disproportionately low because of feed scarcity and poor nutritional quality, among other things (FAO, 2018). Thus, the production of enough quantity of good-quality forages to supplement crop residues and roughage is one way of overcoming the existing nutritional bottlenecks in the country. Because of their higher protein content, greater digestibility, and decreased structural fiber content, enhanced forages are considered an attractive approach for animal feeding (Alemayehu *et al.,* 2012).

Cowpea is one of the high-quality forage legumes used as livestock feed in numerous countries. Digestibility and yield of some cowpea varieties were shown to be similar to that of alfalfa (FAO, 2012). It is also used for human consumption as "Shiro wet," bread (Kita), and cooked grains (Nifro) in Ethiopia, mostly in the Amhara region (Alemu et al., 2016). The other benefit of cultivating cowpea is attributed to its biological nitrogen fixation capacities, which offer an economically attractive and ecologically sound means of improving plant yield and lessen farmers' reliance on commercial fertilizers (Ibrahim, 2018). Cowpea boosts the yield of cereal crops that are grown in rotation or as intercrops with it (OECD, Organization for Economic Co-operation and Development, 2016). Thus, being a genetic resource for future crop improvement, contributing to resilience, and improving agricultural sustainability under climate change conditions, it can be part of a sustainable food system (Mekonnen *et al.*, 2022).

However, soil acidity is one of the most limiting factors for leguminous plants, including cowpea (Zwieten et al., 2015). It reduces nutrient availability to plants, negatively affects plant growth (Nisa et al., 2012), and reduces the nitrogen-fixing capacity of legumes (Amba *et al.*, 2011).

An important point to highlight is that liming enhances nitrogen and phosphorus availability to plants, including cowpea, on acidic soils (Bello *et al.*, 2017). Liming improves growth performance, dry matter yield (Kang, 1988), and nutritional quality of cowpea on acidic soils (Edwards, 1981). However, the inclusion of high-yielding legumes on highly acidic soils depends upon the identification and selection of varieties that possess satisfactory yield potential under such conditions. Thus, identifying varieties of those responses to minimal input of lime and exhibiting high degrees of tolerance to soil acidity are the two broad strategies that could be considered (Edwards, 1981). Nevertheless, production of forage legumes, including cowpea, has been pushed on marginal lands without taking into account the constraints of soil acidity in Ethiopia and Alge Sachi Woreda in particular. This being the case, the objective of this study was to determine the effect of lime application rates on growth characteristics and dry matter yield of cowpea varieties on acidic soil at Alge Sachi Woreda, South Western Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

The experiment was carried out during the 2021 cropping season (April to August) at the Adare Kebele Farmers' Training Center (FTC) of Alge Sachi Woreda, which is located in the Ilubabor Zone of Oromia Regional State. The Woreda is located at 660 km southwest of Addis Ababa between 08° 48, 08° 68 latitudes and 035° 64, 035° 72E longitudes with an elevation of 1543m above sea level. The area has a warm, humid climate with the mean annual minimum and maximum temperatures of 14.5 and 30°C, respectively. The area receives an average annual rainfall of 1000-1200 mm. It has a mono-modal rainfall pattern with erratic rainfall ranges from April to June, and the majority of rainfalls occur from July to September. The area is characterized by coffee-based farming systems and crop-livestock mixed farming systems. The dominant soil type in the area is Nitisols, which ranges from very strongly to strongly acidic in nature and sandy loam in texture (ASWAO, 2021).

Experimental material

Three cowpea varieties i.e., Bole (85D-3517-2), Sewunet (IT-93KD596), and Bekur (8386894) were used for the experiment due to their adaptability

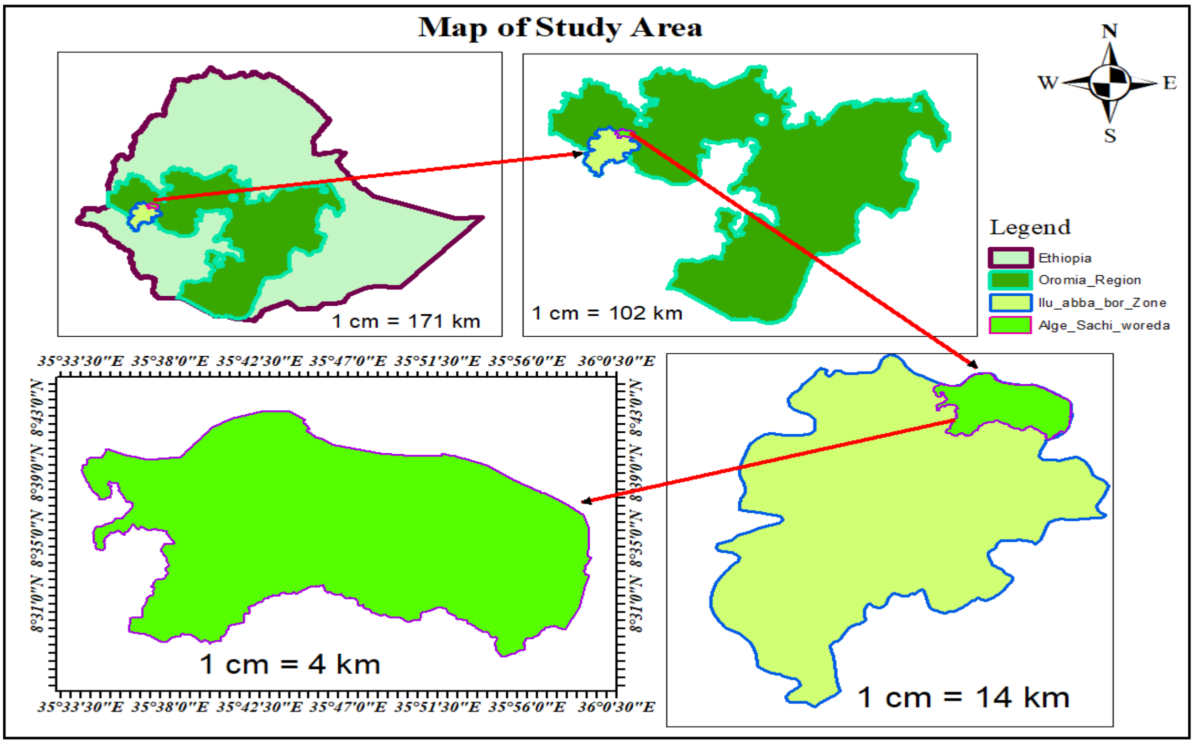

Fig. 1. Map of study area.

to the warm-humid agro-ecology of western Oromia. Agricultural liming material ($CaCO_3$) with a pH value of 10.0, calcium content of 22.22%, and magnesium content of 0.29 % was obtained from Guder lime factory of Oromia Regional State.

Treatments and experimental design

The experiment was laid out in a 3x5 factorial arrangement of randomized complete block design replicated three times. The experiment had totally fifteen treatments with the involvement of three cowpea varieties and five different rates of lime i.e. 0, 0.3, 0.6, 0.9 and 1.2ton/ha based on the lime recommended for the experimental soil (1.2ton/ha) by Bedele Agricultural Research Center (2021). Total area of experimental plot was 528m^2 (12 m X 44 m), which was divided into three blocks or replications based on soil fertility status each with an area of 132m^2 (3 X 44m). Each block was further divided into fifteen sub- plots with an area of 6m^2 (2mx3m). The distance between plots and blocks was 1m and 1.5 m respectively as suggested by Akililu and Alemayehu (2007). The distance between rows and plant within rows was 40cm and 20cm respectively as described by Solomon and Kibrom (2014). All treatments were randomly assigned to each plot of experimental blocks.

Experimental procedures

A farm suspected of soil acidity was selected purposely based on the previous history and the current fertility status. After the initial soil sample was subjected to laboratory chemical analysis, the land was plowed three times and leveled before sowing. Five different rates of lime were applied to each plot of experimental blocks four weeks before sowing based on treatment allocation as recommended by Hirpha *et al.* (2013). Two seeds of each of the three cowpea varieties were sown together according to treatment allocation, with extra seedlings thinned 14 days after germination as practiced by Muoneke *et al.* (2008). Diammonium phosphate (DAP) fertilizer at 100 kg/ha was uniformly applied to each experimental plot at the time of sowing as recommended by Ayana et al. (2015). Weeding was done two times manually, starting two weeks later after sowing. Close observation and follow-up were done throughout the study period.

Data collection

Growth parameters

Five plants were randomly selected from the three middle rows of each experimental plot to avoid edges or border effects. The average result of five plants in each plot was used to determine growth parameters of cowpea, like number of leaves per plant, branches per plant, plant height, and number of nodules per plant at 50% flowering as recommended by Tessema (2018). Plant height was measured by tape meter as used by Akililu and Alemayehu (2007).

TABLE 1
Experimental Treatments

No	Varieties	Lime rates	Treatment combination	Descriptions	Replications
1	V1	L0	V1*L0	Bole variety with 0 ton/ha^{-1} of lime	3
2		L1	V1*L1	Bole variety with 0.3 ton/ha^{-1} of lime	3
3		L2	V1*L2	Bole variety with 0 .6 ton/ha^{-1} of lime	3
4		L3	V1*L3	Bole variety with 0.9 ton/ha^{-1} of lime	3
5		L4	V1*L4	Bole variety with 1.2 ton/ha^{-1} of lime	3
6	V2	L0	V2*L0	Bekur variety with 0 ton/ha^{-1} of lime	3
7		L1	V2*L1	Bekur variety with 0.3 ton/ha^{-1} of lime	3
8		L2	V2*L2	Bekur variety with 0.6 ton/ha^{-1} of lime	3
9		L3	V2*L3	Bekur variety with 0.9 ton/ha^{-1} of lime	3
10		L4	V2*L4	Bekur variety with 1.2 ton/ha^{-1} of lime	3
11	V3	L0	V3*L0	Sewunet variety with 0 ton/ha^{-1} of lime	3
12		L1	V3*L1	Sewunet variety with 0.3 ton/ha^{-1} of lime	3
13		L2	V3*L2	Sewunet variety with 0.6 ton/ha^{-1} of lime	3
14		L3	V3*L3	Sewunet variety with 0.9 ton/ha^{-1} of lime	3
15		L4	V3*L4	Sewunet variety with 1.2 ton/ha^{-1} of lime	3
Total			15		45

Forage biomass yield

The entire three middle rows of herbage from each experimental plot were harvested at 50% flowering to determine forage biomass yield according to the recommended practice of Solomon and Kibrom (2014). Forage harvesting was conducted by using a sickle, leaving a stubble height of 10 cm above the ground as practiced by Leta *et al.* (2013). The harvested green forage per plot was weighed by hanging scale and converted to ton/ha. After freshly harvested forage biomass yield was chopped into smaller pieces using a sickle, a sub-sample of 300 g was taken from each plot and transported to the JUCAVM Animal Nutrition Laboratory. The samples of forage taken from each experimental treatment were dried in an oven at 65°C for 72 hours to determine partial dry weight, from which total dry matter yield was estimated as the following.

DM yield (ton/ha) = (10 x TFW x SSDW) / (HA x SSFW) (Mutegi *et al.*, 2008). Where, 10 = constant for conversion of yields in kg/m^2 to ton/ ha, TFW = total fresh weight from harvesting area (kg), SSDW = sub-sample dry weight (g), HA = harvest area (m^2) and SSFW = sub-sample fresh weight (g)

Laboratory chemical composition analysis

Soil sampling and analysis

Initial soil samples were collected from nine points in a zigzag pattern at the depth of 20cm before the start of the experiment, and one composite soil sample was subjected to laboratory chemical analysis as described by Ryan (2017). Post-harvest soil samples were taken from each plot of experimental blocks following the same procedure, and fifteen composite soil samples were subjected to laboratory chemical analysis. The composite soil samples were dried in open air, ground, and sieved to pass through a 2 mm sieve for analysis of soil pH, phosphorus, total nitrogen, organic carbon, and exchangeable acidity at Bedele Agricultural Research Center. Soil pH was determined in a 1:2.5 soil-to-water ratio using a glass electrode attached to a digital pH meter as described by Anderson and Ingram (1993). Total nitrogen was determined following the Kjeldahl procedure described by Bremner and Mulvaney (1982). Available phosphorus was determined following Olsen II methods of Olsen *et al.* (1954). Organic carbon was determined by the wet digestion method of Walkley and Black (1934). Exchangeable acidity was determined by saturating the soil samples with 1M KCl solution and titrating with 0.02M HCl as described by Rowell (1994).

Partial budget analysis

Dry matter yield obtained from each experimental treatment was adjusted by 10% to show the difference between experimental and farmers' yield as suggested by CIMMYT (1988). The costs of performing different operations such as ploughing, spreading lime, weeding, and harvesting were estimated by using a local wage rate of 75 ETB/person/day. The price of lime was 6.3 ETB/Kg, whereas the price of cowpea forage dry matter was estimated at 4.00 ETB/ Kg at Alge and around Alge town. Farm gross and net benefits were calculated based on the estimated prices of cowpea forage, lime, and costs of performing different operations. Gross farm benefit (GFB) was determined by multiplying each adjusted dry matter yield of cowpea forage with the estimated price. Net farm benefit (NFB) was calculated by subtracting total variable costs from gross farm benefit without including costs of DAP and seed; those were constant for all treatments (NFB=GFB-TVC). Besides, treatments with higher TVC but a net benefit that is less than or equal to the preceding treatments (with lower TVC but higher net benefits) were identified as dominated treatments and marked as "D. Thus, the marginal rate of return (MRR) was determined only for non-dominated treatments as the ratio of change in net benefit to change in total variable cost (MRR = Δ NB/ ΔTVC) as described by CIMMYT (1988).

Data analysis

All collected data were subjected to a two-way analysis of variance (ANOVA) procedure by using the General Linear Model (GLM) of SAS software version 9.3. Significant treatment means were separated using the least significant difference (LSD) at a 5 % significant level or 95 % confidence interval. The statistical model used for data analysis was Yijk = μ + Bi + X j + Y k + (XY) jk + Eijkl. Where : Yijkl = the measurable variable; μ = overall mean; Bi = the ith block effect (i = 1, 2, 3); X j = the jth variety effect (j = 1, 2, 3); Y k = the k-th lime application rates effect (k = 0, 1, 2, 3, 4); (XY) jk = the jk-th interaction effect (jk = 1, 2, ..., 15); and Eijkl = random error term.

RESULTS AND DISCUSSION

Chemical properties of experimental soil

The results of the soil chemical properties analysis before and after the trial are presented in Table 2. The results of pre-trial soil analysis showed that the soil had a pH value of 4.3, exchangeable acidity of 0.828, total nitrogen content of 0.114%, phosphorus content of 5.48%, and carbon content of 1.085%. According to soil pH classification made by Eyasu *et al.* (2016), the soil of the experimental site before the trial was rated as extremely acidic. Based on classification made by EthioSIS (2014), exchangeable acidity of pre-trial soil was low. Based on the rating done by Havlin *et al.* (1999), the total nitrogen content of pre-trial soil was low. According to soil phosphorus content classification made by Black (2013), the available phosphorus content of pre-trial soil was rated as very low. Besides, based on the classification made by Tekalign (1991), the organic carbon content of pre-trial soil was categorized as low.

The results of post-harvest soil analysis revealed that the plots planted to each of the three cowpea varieties at the liming rates of 0.6 to 1.2 tons/ha significantly increased the mean soil pH as compared to the control treatment (Table 2). Moreover, liming at the rates of 0.9 and 1.2 tons/ha significantly increased the mean soil pH by 34.41% and 43.87%, respectively, as compared to the control treatment. According to Udoh *et al.* (2005), medium to neutral soil pH is recommended for cowpea growth and yield in the tropics because rhizobia that fix nitrogen do best in this soil pH range. Thus, the mean soil pH obtained (pH=5.23) in the current study was within the ranges of soil pH recommended for cowpea growth and yield. On the other hand, the mean exchangeable acidity of the experimental soil was negatively and significantly ($p<0.05$) affected by lime application rates. Liming at the rates of 0.6 to 1.2 tons/ha significantly decreased the mean exchangeable acidity of the experimental plots planted to each of the three cowpea varieties as compared to the control treatment. Moreover, significantly, the lowest mean exchangeable acidity of soil was determined for the plots dressed with 0.9 and 1.2 tons/ha of lime. The mean available phosphorus, total nitrogen, and organic carbon content of post-harvest soil were significantly ($p<0.05$) affected by lime application rates (Table 2).

Lime application at the rates of 0.6 to 1.2 tons/ha significantly increased the mean available phosphorus, total nitrogen, and organic carbon content of the plots planted to each of the three cowpea varieties as compared to the control. Furthermore, liming at the rates of 0.9 and 1.2 tons/ha significantly increased the mean available phosphorus and organic carbon content of the plots planted to each of the three cowpea varieties by 49.37%, 56%, 44%, and 50%, respectively, as compared to the control treatment. Liming at the rates of 0.6 to 1.2 tons/ha significantly increased the mean total nitrogen content of experimental plots planted to each of the three cowpea

TABLE 2
Chemical properties of experimental soil

	Parameters				
Pre -trial	pH (H20)	EA (meq/100gm soil)	P (mg/kg soil)	TN%	OC%
	4.3	0.828	5.48	0.114	1.085
Effect of lime application rates on post- harvest soil					
Lime rate	pH(H2O)	EA(meq/100gm soil)	P(mg/kg soil)	TN%	OC%
L0	4.33^{c}	0.78^{a}	5.53^{c}	0.116^{c}	1.148^{c}
L1(0.3ton/ha)	4.46^{c}	0.57^{a}	5.86^{c}	0.12^{bc}	1.26^{bc}
L2(0.6ton/ha)	5.34^{b}	0.29^{b}	7.76^{b}	0.185^{ab}	1.42^{b}
L3(0.9 ton/ha)	5.82^{ab}	0.073^{bc}	8.26^{ab}	0.191^{a}	1.65^{a}
L4(1.2ton/ha)	6.23^{a}	0.018^{c}	8.64^{a}	0.195^{a}	1.72^{a}
Mean	5.23	0.34	7.21	0.16	1.43
LSD 0.05	**	**	**	**	**
% CV	8.27	24.43	5	15.8	7.2

Means with the different superscript letters in the same column are significantly different ($P<0.05$). L0= 0, L1=0.3ton/ha of lime, L2=0.6ton/ha of lime, L3=0.9ton/ha of lime, L4= 1.2 ton/ha of lime, EA=exchangeable acidity, meq/100gm soil = milliequivalet per 100 gram of soil, TN=total nitrogen, OC= organic carbon=phosphorus, CV=coefficient of variation, ton/ha= ton per hectare, LSD=least significant difference and ** significant at $P < 0.05$.

varieties by 59.48%, 64.5%, and 68%, respectively, as compared to the control treatment. The raise of soil pH, phosphorus, total nitrogen, and organic carbon and the decline of exchangeable acidity in the current study might be attributed to the decrease in soil acidity following lime application rates. The current result is in agreement with that of Geremew et al. (2020), who reported that lime application to acidic soil significantly increased soil pH and phosphorus content and reduced exchangeable acidity. Similarly, Jafer and Gabresillase (2007) noted that the exchangeable acidity of soil significantly decreased with the increased rates of lime application. The current result is also in line with that of Rukia *et al.* (2020), who reported that total nitrogen and organic carbon content significantly increased with the increased rates of lime application on acidic soil.

Growth characteristics

Number of leaves per plant

The current study showed that the number of leaves per plant was significantly ($p<0.05$) affected by lime application rates, cowpea varieties, and their interaction (Table 3). Lime application at the rates of 0.3 to 1.2 tons/ha significantly increased the mean number of leaves per plant in three different cowpea varieties grown on acidic soil as compared to the control treatment. Moreover, lime application at the rates of 0.9 and 1.2 tons/ha significantly resulted in the highest mean number of leaves per plant. This might be due to the decrease in soil acidity following lime application rates, which in turn increases nutrient availability and enhances vegetative growth of plants (Amarasiri and Olsen, 1993). The current result is in agreement with those of Muoneke et al. (2008) and Dugalic *et al.* (2012), who reported that the mean number of leaves per plant significantly increased with the increased rates of lime application in cowpea and alfalfa grown on acidic soil, respectively. Similarly, Ibrahim (2018) found that lime application significantly increased the mean number of leaves per plant in soybean plants grown on acidic soil.

Sewunet variety was recorded with the highest mean number of leaves per plant, whereas the Bekur variety was recorded with the lowest mean number of leaves per plant. This might be due to the differential response of different cowpea varieties to lime application rates. The current result is in line with that of Muoneke *et al.* (2008), who found that cowpea genotypes grown on acid soil significantly differed in the mean number of leaves per plant. The interaction effect of varieties and lime application rates significantly resulted in the highest number of leaves per plant at treatment combinations of Sewunet variety with 0.6 to 1.2 tons/ha and Bole variety with 0.9 to 1.2 tons/ha of lime application rates. Conversely, Sewunet and Bole varieties were recorded with the significantly lowest mean number of leaves per plant on lime untreated plots. The current result is in agreement with that of Muoneke *et al.* (2008), who found that the mean number of leaves per plant was significantly affected by the interaction effect of cowpea varieties and lime application rates on acidic soil.

Number of branches per plant

The number of branches per plant was significantly ($p<0.05$) affected either by main effects or their interaction (Table 3). Lime application at the rates of 0.6 to 1.2 tons/ha significantly increased the mean number of branches per plant in three different cowpea varieties grown on acidic soil as compared to the control treatment. However, the highest mean number of branches per plant was recorded at the liming rates of 0.9 and 1.2 tons/ha. The reason might be due to the increased availability of nutrients to plants following lime application rates. The current result is in line with that of Kang (1988), who reported that liming at the rates of 0.25 to 1 ton/ha significantly increased the mean number of branches per plant in different cowpea varieties grown on acidic soil.

Similarly, Muoneke *et al.* (2008) found that lime application at the rates of 0.5 to 2 tons/ha significantly increased the mean number of branches per plant in different cowpea varieties grown on acidic soil.

Sewunet and Bole varieties were recorded with a significantly higher mean number of branches per plant. The Bekur variety was recorded with the lowest mean number of branches per plant. This might be due to the varietal differences. The current result is in agreement with that of Hirpha *et al.* (2013), who reported that there were significant differences among common bean genotypes grown on acidic soil in the mean number of branches per plant. The interaction effect of varieties and lime application rates significantly resulted in the highest mean number of leaves per plant at treatment combinations of Sewunet variety with 0.6 to 1.2 tons/ha and Bole variety with 0.9 to 1.2 tons/ha of lime application rates. In contrast, all control treatments resulted in the lowest mean number of branches per plant. The current result is in line with that of Muoneke *et al.* (2008), who reported that the number of branches per plant was significantly affected by the interaction effect of varieties and lime application rates on acidic soil.

Plant height

The current study also revealed that plant height was significantly ($p<0.05$) affected by lime application rates, cowpea varieties, and their interaction (Table 3). Lime application at the rates of 0.3 to 1.2 tons/ha significantly increased the mean plant across three different cowpea varieties grown on acidic soil as compared to the control treatment. The highest mean plant height was recorded at the liming rates of 0.9 and 1.2 tons/ha. This might be attributed to the increase in availability of nutrients to plants following lime application rates. This result is in line with that of Kang (1988), who found that lime application at the rates of 0.25 to 1 ton/ha significantly increased the mean plant height in cowpea grown on acidic soil. The current result is also in agreement with those of Dugalic *et al.* (2012) and Hirpha *et al.* (2013), who reported that the mean plant height significantly increased with the increased rates of lime application on acidic soil in alfalfa and common bean genotypes, respectively.

The Sewunet variety was recorded with the highest mean plant height, whereas the Bekur variety was recorded with the lowest mean plant height, which might be due to the varietal differences. The current result is in line with that of Hirpha *et al.* (2013), who noted that different common bean genotypes significantly differed in the mean plant height on acidic soil. The interaction effect of varieties and liming rates significantly resulted in the highest mean plant height on acidic soil at treatment combinations of Sewunet variety with 0.6 to 1.2 tons/ha of lime application rates. On the other hand, the Bole variety was recorded to have the significantly lowest mean plant height on lime untreated acid soil.

Number of nodules per plant

Analysis of variance revealed that the number of nodules per plant was significantly ($p<0.05$) affected either by main effects or their interaction (Table 3). Lime application at the rates of 0.6 to 1.2 tons/ha significantly increased the mean number of nodules per plant in three different cowpea varieties grown on acidic soil as compared to the control treatment. Furthermore, liming at the rates of 0.9 and 1.2 tons/ha significantly resulted in the highest mean number of nodules per plant. This might be due to the reduction in soil acidity following lime application rates, which in turn enhances nodule formation by legumes rhizobia symbiosis (Sanginga and Woomer, 2010).

The current result is in line with those of Muoneke *et al.* (2008) and Ibrahim (2018), who found that the mean number of nodules per plant significantly increased with the increased rates of lime application on acidic soil in cowpea and soybean plants, respectively. Contrary to the current result, Kang (1988) reported that the mean number of nodules per plant significantly decreased with the increased rates of lime application in cowpea grown on acidic soil. This might be due to the differential responses of different cowpea varieties to lime application rates.

Sewunet variety was recorded with the highest mean number of nodules per plant, followed by Bole variety, whereas Bekur variety was recorded with the lowest mean number of nodules per plant. The current result is in line with that of Muoneke *et al.* (2008), who reported that cowpea varieties significantly differed in the mean number of nodules per plant on acidic soil. Besides, the interaction effect of varieties and liming rates significantly resulted in the highest mean number of nodules per plant on acidic soil at treatment combinations of Sewunet variety with 0.6 to 1.2 tons/ha and Bole variety with 0.9 tons/ha of lime application rates. Bole variety was recorded as having the significantly lowest mean number of nodules per plant on lime-untreated plots. The current result is in line with those of Muoneke *et al.* (2008) and Edwards (1981), who reported the interaction effect of varieties and lime application rates significantly increased the mean number of nodules per plant in different cowpea varieties grown on acidic soil.

Days to 50% flowering

The current study showed that days to 50 % flowering was significantly ($p<0.05$) affected by lime application rates, cowpea varieties, and their interaction (Table 3). Lime application at the rates of 0.6 to 1.2 ton/ha significantly hastened the mean days to 50% flowering in different cowpea varieties grown on acidic soil as compared to the control treatment. Moreover, lime application at the rates of 0.9 and 1.2 tons/ha significantly resulted in the shortest mean days to 50%

flowering. The reduced mean days to 50% flowering might be attributed to the increased availability of phosphorus minerals following lime application rates, which in turn stimulate nutrient cycling and flowering hormones in plants (Hina *et al*., 2018). The current result is in line with that of Muoneke *et al.* (2008), who found that lime application at the rates of 0.5 to 2 tons/ha significantly decreased the mean days to 50% flowering in different cowpea genotypes grown on acidic soil. Hirpha *et al.* (2013) also pointed out that lime application significantly hastened the mean days to 50% flowering of different common bean genotypes grown on acidic soil. The longest mean days to 50% flowering was attained by the Sewunet variety, whereas the shortest mean days to 50% flowering was attained by the Bole and Bekur varieties; that might be due to the varietal differences. The current result is in agreement with those of Muoneke *et al.* (2008) and Hirpha *et al.* (2013), who reported the significant differences in the mean days to 50% flowering among cowpea and common bean genotypes grown on acidic soil, respectively.

The interaction effect of varieties and lime application rates significantly resulted in the lowest mean days to 50% flowering on acidic soil at treatment combinations of Bole variety with 0.6 to 1.2 tons/ha and Bekur variety with 0.9 to 1.2 tons/ha of lime application rates. In contrast, Bekur and Sewunet varieties resulted in a significantly longer mean time to 50% flowering on lime untreated acid soil. This might be due to the varietal effect of cowpea forage. This result is in agreement with that of Hirpha *et al.*

TABLE 3

Main and interaction effects of varieties and lime application rates on growth and biomass yield of cowpea forage on acidic soil

Treatments	Parameters						
	NNPP	NLPP	PH	NBPP	DF	FBY (t/ha)	DMY (t/ha)
Lime rates							
L0	14.07^{c}	64.60^{d}	50.5^{d}	3.56^{c}	65.36^{a}	25.97^{d}	4.01^{d}
L1(0.3 ton/ha)	16.99^{c}	70.27^{c}	59.08^{c}	4.28^{c}	62.99^{ab}	28.83^{c}	5.5^{c}
L2(0.6 ton/ha)	27.16^{b}	80.66^{b}	68.8^{b}	6.24^{b}	59.79^{bc}	40.85^{b}	7.2^{b}
L3(0.9 ton/ha)	30.09^{ab}	83.92^{ab}	72.9^{ab}	7.29^{a}	57.47^{cd}	42.96^{ab}	7.86^{ab}
L4(1.2 ton/ha)	31.91^{a}	86.75^{a}	78.26^{a}	7.4^{a}	55.54^{d}	44.53^{a}	7.98^{a}
LSD 0.05	**	**	**	**	**	**	**
Varieties							
V1(Bole)	23.83^{b}	76.98^{b}	64.2^{b}	5.87^{a}	55.66^{b}	36.64^{b}	6.7^{b}
V2(Bekur)	20.47^{c}	72.01^{c}	58.55^{c}	5.04^{b}	58.65^{b}	31.65^{c}	5.18^{c}
V3(Sewunet)	27.84^{a}	82.72^{a}	75.05^{a}	6.35^{a}	66.38^{a}	40.47^{a}	7.6^{a}
LSD0.05	**	**	**	**	**	**	**
Interaction effect							
Bole*0 ton/ha of lime	9.86^{h}	57.48^{h}	42.5^{g}	3.07^{f}	61.96^{bcd}	22.45^{g}	3.65^{i}
Bole*0.3 ton/ha of lime	15.85^{fgh}	68.77^{efg}	57.46^{ef}	4.47^{de}	58.26^{cde}	28.43^{def}	5.24^{efgh}
Bole*0.6 ton/ha of lime	28.51^{cd}	84.53^{bc}	69.7^{d}	6.53^{bc}	55.44^{def}	39.34^{b}	7.33^{cd}
Bole*0.9 ton/ha of lime	33.48^{abc}	87.38^{abc}	76.45^{bcd}	7.73^{ab}	52.05^{ef}	46.52^{a}	8.87^{ab}
Bole*1.2 ton/ha of lime	31.43^{bcd}	86.40^{abc}	74.83^{bcd}	7.53^{ab}	50.59^{f}	45.25^{a}	8.6^{ab}
Bekur*0 ton/ha of lime	17.89^{fg}	68.63^{efg}	55.47^{ef}	4.23^{ef}	64.17^{abc}	27.63^{f}	4.26^{ghi}
Bekur*0.3 ton/ha of lime	17.28^{fg}	65.99^{g}	53.2^{f}	4.43^{de}	62.97^{abc}	27.25^{f}	4.5^{fgh}
Bekur*0.6 ton/ha of lime	19.85^{efg}	70.63^{efg}	56.13^{f}	4.63^{de}	58.04^{cde}	31.98^{cde}	5.42^{efg}
Bekur*0.9 ton/ha of lime	21.60^{ef}	74.63^{def}	58.25^{ef}	5.77^{cd}	55.37^{def}	34.90^{bc}	5.54^{ef}
Bekur*1.2 ton/ha of lime	25.71^{de}	80.19^{cd}	70.7^{cd}	6.83^{bc}	52.68^{ef}	38.49^{b}	5.8^{ef}
Sewunet*0 ton/ha of lime	14.46^{gh}	66.33^{fgh}	53.54^{f}	3.37^{ef}	69.96^{a}	26.83^{fg}	4.14^{hi}
Sewunet*0.3 ton/ha of lime	17.82^{fg}	76.03^{de}	67.58^{de}	4.63^{de}	67.75^{ab}	32.81^{cd}	6.13^{de}
Sewunet*0.6 ton/ha of lime	33.11^{abc}	86.82^{abc}	80.60^{abc}	7.57^{ab}	65.88^{ab}	45.35^{a}	9.18^{ab}
Sewunet*0.9 ton/ha of lime	35.19^{ab}	89.76^{ab}	84.24^{ab}	8.37^{a}	65.11^{abc}	47.47^{a}	9.43^{ab}
Sewunet*1.2 ton/ha of lime	38.58^{a}	94.66^{a}	89.29^{a}	7.83^{ab}	62.43^{bc}	49.87^{a}	9.73^{a}
Over all Mean	24.04	77.24	65.93	5.75	60.23	36.24	6.5
LSD 0.05	**	**	**	**	**	**	**
CV%	16.26	6.52	9.16	13.67	7.06	7.86	11.4

Means with the different superscript letters in the same column are significantly different ($P<0.05$). NNPP=number of nodule per plant, NLPP=number of leave per plant, PH=plant height, NBPP= number of branch per plant, DF= days flowering, FBY= fresh biomass yield, DMY=dry matter yield, CV=coefficient of variation, LSD=least significant difference and ** significant at $P < 0.05$.

(2013), who reported that the mean days to 50% flowering, was significantly affected by the interaction effect of lime application and common bean genotypes on acidic soil.

Forage biomass yield

Fresh biomass yield

Analysis of variance showed that fresh forage biomass yield was significantly ($p<0.05$) affected either by main effects or their interaction (Table 3). Liming at the rates of 0.3 to 1.2 tons/ha significantly increased the mean fresh forage biomass yield in three different cowpea varieties grown on acidic soil as compared to the control treatment. Moreover, liming at the rates of 0.9 and 1.2 tons/ha significantly resulted in the highest mean forage fresh biomass. The increase in the mean fresh forage biomass yield might be due to the improved growth performance of different cowpea varieties grown on acidic soil following lime application rates.

The Sewunet variety was recorded to have the highest mean fresh forage biomass yield, whereas the Bekur variety was recorded to have the lowest mean fresh biomass yield. The current result is in agreement with that of Dugalic *et al*. (2012), who found that alfalfa fresh fodder yield significantly increased with increased rates of lime application on acidic soil; nevertheless, alfalfa genotypes significantly differed. The interaction effect of varieties and liming rates significantly resulted in the highest mean fresh biomass yield on acidic soil at treatment combinations of Sewunet variety with 0.6 to 1.2 tons/ha and Bole variety with 0.9 to 1.2 tons/ha of lime application rates. Bole and Sewunet varieties were recorded to have the lowest mean fresh forage biomass yield on lime-untreated plots.

Dry matter yield

According to the current study, dry matter yield was significantly ($p<0.05$) affected by lime application rates, cowpea varieties, and their interaction (Table 3). Lime application at the rates of 0.3 to 1.2 tons/ha significantly increased the mean dry matter yield in different cowpea varieties grown on acidic soil as compared to the control treatment. Moreover, liming at the rates of 0.9 and 1.2 tons/ha significantly resulted in the highest mean dry matter yield in different cowpea varieties. This might be attributed to the improved growth performance of cowpea varieties following lime application rates. This result is in agreement with that of Kang (1988), who noted that liming at the rates of 0.25 to 1.00 ton/ha significantly increased the mean dry matter yield in different cowpea varieties grown on acidic soil.

The current result is also in line with that of Dugalic *et al*. (2012), who found that lime application at the rate of 6 tons/ha significantly increased the mean alfalfa forage dry matter yield from 2 to 18 tons/ha on acidic soil. The current study tends to indicate that the tested cowpea varieties significantly differed in the mean dry matter yield. The Sewunet variety was recorded with the highest mean dry matter yield, followed by the Bole variety, whereas the Bekur variety was recorded with the lowest mean dry matter yield. This might be due to the differential responses of cowpea varieties to lime application rates. The current result is in line with that of Grewal and Williams (2003), who reported that alfalfa genotypes significantly differed in the mean dry matter yield in response to different rates of lime application on acidic soil. The interaction effect of varieties and liming rates significantly resulted in the highest mean dry matter yield on acidic soil at treatment combinations of the Sewunet variety with 0.6 to 1.2 tons/ha and the Bole variety with 0.9 to 1.2 tons/ha of the lime application rates. Conversely, all control treatments resulted in the lowest mean dry matter yield. This result is in line with that of Kang (1988), who reported that the interaction effect of varieties and lime application rates significantly affected the growth performance and dry matter yield of cowpea on acidic soil.

Partial budget analysis

The results of partial budget analysis showed that the highest gross farm benefit of 35,040 ETB/ha was obtained from yield recorded at treatment combination of Sewunet variety with 1.2 ton/ha of lime application rate (T_{15}), followed by the gross farm benefit of 33,920 ETB/ha obtained at treatment combination of Sewunet variety with 0.9 ton/ha of lime application rate (T_{14}). Conversely, the lowest gross farm benefit of 13,120 ETB/ha was obtained from Bole variety on lime untreated acid soil (T_1). However, rather than only looking at the highest gross farm benefits, it is important to compare treatments in view of economic profitability to remove undesirable treatments. Thus, the net benefit and marginal rate of return were done to get the treatment worthwhile to farmers.

The highest net farm benefit of 28,060ETB/ha with the highest marginal rate of return (263.86%) was obtained at treatment combination of Sewunet variety with 0.6 ton/ha of lime application rate (T13). This implies that from every Ethiopian birr invested in cowpea forage production by using the Sewunet variety assigned to the plots dressed with a 0.6 ton/ha lime application rate (T13), farmers can expect to recover the expenses and earn an additional profit of 2.63 ETB. In contrast, the lowest net farm benefit of 11,000 ETB/ha was recorded at the Bekur variety assigned to the plots dressed with a 1.2 ton/ha lime application rate (T10). In line with the current finding, CIMMTY (1988) reported that treatment with the highest net benefit per hectare and marginal rate of return greater than the minimum acceptable rate of return (50-100%) could be a tentative recommendation. Therefore, the treatment combination of the Sewunet variety with a 0.6 ton/ha lime application rate (T13) had an economic advantage over the use of other alternative treatment combinations on acidic soil.

CONCLUSION AND RECOMMENDATION

From the results of the current study, it is concluded that growth characteristics and dry matter yield of cowpea forage was significantly affected by varieties, lime application rates, and their interaction. The results of partial budget analysis also showed that 8.26 t/ha of adjusted forage dry matter yield obtained at the Sewunet variety assigned to the plots dressed with 0.6 t/ha of lime application rate was economically feasible and brought 2.63 Ethiopian birr extra income invested in cowpea forage production. Therefore, based on the results of the current study, the following recommendations were drawn.

- Sewunet variety at 0.6 ton/ha of lime application rate (50% of the lime requirement of soil) can be best recommended for farmers' uses in the study area and in other areas with similar agro-ecologies and soil types.
- Further research over years and locations is vital to give valid recommendations.
- It is also advisable to test the effect of cowpea forage produced by different combinations of varieties and lime application rates on animal performance.

ACKNOWLEDGMENTS

I would like to express my gratitude to the Oromia Livestock and Health Office for providing me with the opportunity to pursue my M. Sc. degree. Moreover, I would like to express my heartfelt

TABLE 4
Effect of varieties and lime application rates on economic feasibility of cowpea forage production on acidic soil

Treatments	AVDMY (t/ha)	ADMY (t/ha)	GB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)	Dominance	MRR %
L0V1	3.65	3.28	13120	-	13120	-	-
L1V1	5.24	4.72	18880	2490	16390	D	-
L2V1	7.33	6.59	26360	4980	21380	D	-
L3 V1	8.87	7.98	31920	7470	24450	D	-
L4V1	8.4	7.56	30240	9960	20280	D	-
L0V2	4.26	3.83	15320	-	15320	-	-
L1V2	4.5	4.05	16200	2490	13710	D	-
L2V2	5.42	4.88	19520	4980	14540	D	-
L3V2	5.54	4.98	19920	7470	12450	D	-
L4V2	5.82	5.24	20960	9960	11000	D	-
L0V3	4.14	3.73	14920	-	14920	-	-
L1V3	6.13	5.5	22000	2490	19510	ND	184.33
L2V3	9.18	8.26	33040	4980	28060	ND	263.86
L3V3	9.43	8.48	33920	7470	26450	D	-
L4V3	9.73	8.76	35040	9960	25080	D	-

L0= 0, L1=0.3ton/ha of lime, L2=0.6ton/ha of lime, L3=0.9ton/ha of lime, L4= 1.2 ton/ha of lime ,V1=Bole variety, V2= Bekur variety ,V3= Sewunet variety , AVDMY= average dry matter yield, ADMY=adjusted dry matter yield, GB= gross benefit, TVC=total variable cost, NB= net benefit, MRR=marginal rate of return, ETB=Ethiopian Birr, t/ha= ton per hectare, D=dominance , ND=non-dominance, lime cost=6.3ETB/Kg, labor Cost = 75 ETB /Person /day , cowpea forage dry matter price = 4ETB/Kg.

gratitude to my major advisor, Prof. Solomon Demeke, for his efforts in guiding and molding this thesis. I am also greatly indebted to my co-advisor, Mr. Zemene Worku, for his valuable guidance, constructive comments, and voluntary assistance in the completion of this study. Moreover, I would like to thank Mr. Habtamu Teferi and Mr. Sefu Shifa for their support during site selection, field layout, and data collection. Finally, I would like to express my heartfelt gratitude to my wife Rahamate Yasin for her support and patience throughout my academic undertakings.

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