Research Article

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Dry matter Yield and Nodulation of Common Bean as Influenced by Phosphorus, Lime and Compost Application at Southern Ethiopia

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Abstract: Soil acidity is among the major limiting factors for common bean nodulation and productivity. Therefore, field experiments were conducted to investigate the effects of the application of phosphorus (P), lime, and compost on nodulation and dry-matter accumulation of common bean under field conditions at Areka during the long rainy season (*belg*) and short rainy season (*meher*). Three rates of compost (0, 5 and 10 t ha⁻¹), three rates of lime (0, 0.64 and 1.28 t ha⁻¹) and three rates of phosphorus (0, 23 and 46 kg P₂O₅ ha⁻¹) were laid out as a randomized complete block design in a factorial arrangement and replicated three times. All data on nodulation and aboveground dry-matter were collected. Results showed that the combined application of P at rates of 46 kg P₂O₅ ha⁻¹ and lime at rates of 1.28 t ha⁻¹ resulted in the maximum number of total and effective nodules during the long rainy season. Similarly, application of the highest rates of compost along with the highest rates of lime increased the aboveground dry biomass yield significantly over the control during both seasons. Finally, it can be concluded that the application of compost, lime and phosphorus can boost biomass accumulation and nodulation of common bean in acid soils.

Keywords: number of nodules, soil acidity, common bean, productivity

1 Introduction

Nitrogen (N) plays an important role in the growth and development of plants (Fageria 2014; Uchida, 2000). It is also responsible for many physiological and biochemical functions in plants (Fageria 2014). Despite these, tropical soils are frequently deficient in N (Hungria and Vargas 2000). It is also one of the deficient nutrients in the highland soils of Ethiopia (Beteru 1999). Biological N fixation can help to overcome the problem (Hungria and Vargas 2000).

Common bean (*Phaseolus vulgaris* L.) is a legume with a capacity of fixing atmospheric nitrogen (N) by forming a symbiotic relationship with specific soil bacteria, which can then be converted into a usable form for growth and development (Kabahuma 2013). Nevertheless, compared to other legumes, common bean is a weak fixer of atmospheric N₂ (Farid and Navadi, 2015; Kabahuma 2013). Besides, soil acidity is one of the major constraints to nodulation (Hungria and Vargas 2000).

Soil acidity is one of the major soil fertility problems in Ethiopia (Schlede 1989; Wassie and Shiferaw 2009). Mesfin (2007) also pointed out that in Ethiopia, common bean production is constrained by poor soil fertility management that results in soil acidity, which in turn could result in poor nodulation. Further, Lunze et al. (2002) reported that common bean production is constrained by the low availability of nutrients and soil acidity in central and eastern Africa. Soil pH in the range of 5.2– 6.8 was found to be optimum for bean growth (Wallace, 1980 cited by Fageria et al. 2009). According to Fageria and Filho (2008) the maximum yield of shoot dry weight and seed yield for common bean were attained at pH 6.4. Low soil pH adversely affects the symbiotic relationship between legumes and rhizobia (Corea and Barneix 1997), which may be due to the failure of rhizobia to survive in acidic soils at pH below 5.0 and failure of nodulation (Zahran 1999). The optimum pH range for rhizobial growth is between 6.0 and 7.0 below which very few rhizobia are capable of growing (Brockwell et al. 1991). Accordingly,

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under Ethiopian conditions, the application of lime also significantly improved nodulation in soybean (Derib 2014), which may be attributed to improvement in soil pH, thereby creating favorable conditions for soil microbes following the application of lime (Suryantini 2014).

Further, in acid soils, there is a low availability of essential nutrients such as P, nitrogen (N), magnesium (Mg), calcium (Ca) and molybdenum (Mo) (Crowford et al. 2008). Among these essential nutrients, Ca and P are limiting nutrients for biological N fixation in the acid soils (Waluyo et al. 2004). The same authors reported the importance of P in nodule initiation, development, and function of the nodules of soybean plants in the acid soils of their study area. There is also an immense amount of research findings on the positive effects of P application on nodulation or number of nodules (Nosheen and Shafique 2006; Amare et al. 2014).

Mugwe et al. (2007) also suggested the need for appropriate soil fertility regimes for improved crop productivity. So far remarkable results have been obtained on acid soils in Southern Ethiopia by the combined application of lime and inorganic fertilizers (Abay 2011; Wassie and Shiferaw, 2009). Gruhn et al. (1995) also pointed out that the application of inorganic fertilizers alone is inadequate to keep in balance soil nutrient loss by different means and do not maintain soil structure. For instance, Wassie and Shiferaw (2009) reported the significantly highest potato tuber yields in response to application of lime along with inorganic fertilizer on acid soils of the Chencha Southern Ethiopia area.

In view of these, the application of inorganic and organic nutrient sources along with lime is imperative for improving nodulation and maximizing productivity of common bean in Ethiopia in general and in the study area in particular. However, information has been lacking on the effects of the combined use of lime, organic inputs and mineral fertilizers on common bean productivity. Therefore, this study has set out to explore the effect of combined application of P, lime, and compost on dry matter accumulation and nodulation of common bean under field conditions on acid soils of Areka, Southern Ethiopia.

2 Materials and methods

2.1 Description of the Study Area

Field experiments were conducted at Areka Agricultural Research Centre (AARC), which is situated in the SNNPR at the geographical location of 7°3'25"N, 37°40'52"E" at an

altitude ranging from 1800 to 2230 meters above sea level (Abayneh et al. 2003). The Center has a bimodal rainfall pattern. The first and long rainy season (*belg*) is starting from April and extending to mid-July, while the short rain season (*meher*) begins in late July and extends to October. The soil of the experimental site is very deep and clayey in texture (Abayneh et al. 2003) with dominant soil type Haplic Alisols (FAO, classification) (FAO 2006).

2.2 Description of the Experimental Material

The common bean cultivar used for this experiment was Dinkinesh obtained from Melkasa Agricultural Research Center. Triple super phosphate (TSP) [$\text{Ca}(\text{H}_2\text{PO}_4)_2$] (21% P) and Urea [$\text{CO}(\text{NH}_2)_2$] (46% N) was used for this experiment as a source of P and N, respectively. Liming materials CaO and CaCO_3 with purity of 98 and 89%, respectively were used for the incubation experiment.

Well prepared and decomposed compost was used for this experiment.

2.3 Experimental Procedures

2.3.1 Determination of lime requirement

Lime (CaO) was applied at the rates of 0, 0.56, 1.12, 1.68, 2.24 and 3.36 g kg⁻¹ to soil samples each weighing 1 kg and were uniformly mixed, for the determination of lime requirement of soils of Areka. Then, the soil samples were added in triplicates into a pot containing 1 kg soil. Water was added into the samples approximately to field capacity. The soil in the pot was thoroughly mixed and incubated under room temperature for a period of two weeks. Then, the soils were ground; all plant debris and roots were removed. The soils in each pot were sieved in a 2 mm mesh size sieve and the pH in water for individual pots was determined. The relationships between the amounts of CaO applied and the pH values obtained were plotted and the level of CaO sufficient to raise the pH of the soil to desired pH was determined. The CaCO_3 equivalent of CaO was used for subsequent liming experiment.

2.3.2 Soil pH Curve

Soil pH equivalent to 6.5 was taken as the optimum pH for common bean and the lime rate needed to the optimum pH was determined by plotting the pH with the lime rate. Hence, based on the p^H curve, the CaO rate needed to raise

the soil pH to the desired pH level of 6.5 was found to be 2.76 g kg^{-1} (Figure 1). Accordingly, the CaCO_3 equivalent of CaO to obtain the optimum pH of 6.5 was 5.4 g CaCO_3 (lime) kg^{-1} soil assuming 89% purity of lime, assuming 20 cm plough depth and taking 1.18 g cm^{-3} soil bulk density was found to be equivalent to $1.28 \text{ tonne ha}^{-1}$.

Figure 1. Soil pH plotted against CaO level for Areka soil

2.4 Soil Sampling and Analysis

Soil sampling was done before planting. Samples were randomly collected using an Auger to the soil depth of 30 cm in a zig-zag pattern from the experimental field. The samples were mixed thoroughly in a bucket and composited. A one-kg composite sample was prepared, bagged and labeled and transported to Debre-Ziet Agricultural Research Center for analysis of selected soil physical and chemical properties. Available P was determined by the Bray I method using ammonium fluoride as an extractant and measuring

the concentration of the nutrient at 880 nm (Bray and Kurtz 1945). Soil organic carbon was determined by the Walkley-Black wet digestion method (Walkley and Black 1934). Total N was determined by the wet oxidation procedure of the Kjeldhal method (Bremner 1995). Soil pH was determined potentiometrically in a supernatant suspension of 1:2.5 soils: water ratio using a combined glass electrode pH meter (Chopra and Kanwar 1976). Exchangeable bases (Ca, Mg, K and Na) in the soil were estimated by the ammonium acetate (1M NH OAc at pH 7) extraction method as described by Rowell (1994).

Compost was also analyzed for determining total P, N, Ca, Mg and K after wet digestion of the samples following the same procedure for soil analysis.

2.5 Soil at the Study Area

Soil physico-chemical properties were determined before sowing during both seasons (Table 1). The pH of the soil is strongly acidic, whereas the organic matter and total nitrogen contents of the soil are high, the CEC of the soil is moderate; the base saturation percent is high. However, according to both authors, the available phosphorus content of the soil is low (Landon 1991). This indicates that the soil has limitations in soil pH and P availability for crop production. As a result, management options to improve soil pH and P availability are important for enhancing plant growth and production in the study area.

2.6 Treatments and Experimental Design

The treatments consisted of three P rates (0, 23 and $46 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$), three lime rates (0, 0.64 and $1.28 \text{ tonnes ha}^{-1}$) and three compost rates (0, 5, and $10 \text{ tonnes ha}^{-1}$).

Table 1. Physico-chemical properties of the soils of the study area before planting in the long and short rainy seasons. P^{H} : (1:25 H_2O)

Seasons of sampling	P^{H}	Total N (%)	OC (%)	Available P(mg kg^{-1})	Exchangeable Cations			CEC (Cmolc(+)/kg soil)
					K	Ca	Mg	
Belg	4.9	0.20	2.9	6.47	0.14	10.1	11.3	26.9
Meher	4.7	0.20	2.7	6.16	0.17	14.5	1.08	24.7

Table 2. Chemical properties of the compost used for the experiment in long and short rainy season

Seasons of sampling	P^{H}	N (%)	P (mg Kg^{-1})	K (%)	Ca (%)
Belg	6.2	1.7	0.435	0.1098	0.658
Meher	6.0	1.53	0.428	0.1118	0.679

The experiment was laid out as a randomized complete design in a $3 \times 3 \times 3$ factorial arrangement and replicated three times per treatment. Each treatment was assigned to each plot randomly. The experimental plot had a 2.8 m width and a 3 m length. There were 7 rows per plot at the spacing of 40 cm between plants. The middle rows were used for agronomic data collection. The outer two rows were left as border rows. Plants in two rows, one at one side and the other at the opposite side of the plots next to the boarder rows were used for destructive sampling. The experimental plots within the blocks were separated 1m apart and the blocks were separated by 2 m.

2.7 Experimental procedure

Land preparation of the experimental field was done properly both during the long and short rainy seasons. In each season, the experiment was done at different experimental fields. The experimental field was ploughed by a tractor three times prior to planting in both seasons. In the long rainy season, planting was done on April 17, 2013, while in the short rainy season, planting was done on August 12, 2013. Weeding was done as required. Similarly, other crop management practices such as pest and disease control were done for all experimental plots. Lime was applied in broadcast two months prior to planting of the crop. Compost was applied in broadcast one month prior to planting in rows. The P fertilizer was applied in band at planting based on the specific rates required. Nitrogen was applied at the rate of 18 kg N ha^{-1} in the form of urea, at the active stage of vegetative growth before flowering (MORAD 2008).

2.8 Data Collection and Measurement

Aboveground dry biomass yield per hectare were determined from harvested plants in the net plot area at harvest. Total number of nodules and effective nodules were collected from five randomly selected plants grown in rows left for destructive sampling during flowering stage. The total and effective nodules were studied after washing the root samples carefully in plastic containers to remove the soils attached to the roots. The separated root nodules were counted the total was recorded and then the nodules were dissected using forceps and knives to determine the effective based on the color of the dissected nodules. Hence, the nodules with pink colour were recorded as effective and those nodules with white color were recorded as non-effective.

2.9 Statistical Analysis

The data of the two seasons were tested for homogeneity of variance using F-test (Gomez and Gomez, 1984). The F-test indicated that the treatment means were significantly different and heterogeneous for the parameters between the two seasons. Accordingly, separate analysis was done. All data were subjected to analysis of variance using SAS version 8, Statistical software. Significant means were separated using LSD test.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results and discussion

3.1 Nodule Growth

3.1.1 Number of nodules

The application of compost, lime and P significantly ($P < 0.001$) increased the total and effective number of nodules in both seasons. An increasing trend in the number of nodules observed as a result of increasing the rate of compost from zero to 10 tonnes ha^{-1} . In the short rainy season, total and effective nodules increased by about 98 and 46% compared to the control as a result of the application of compost at rates of 10 tonnes ha^{-1} (Table 3). Hence, the increase in total and effective nodules might be attributed to improved availability of nutrients such as P and Ca following application of compost, which are important for nodulation (Kouas et al. 2005; Thung 1991). In line with this, Endalkachew et al. (2018) obtained a significantly high nodule number as a result of the application of 8 t ha^{-1} farmyard manure in the acid soil of Lay Gayint District, northwestern highlands of Ethiopia. Tigist (2017), who studied the response of soybean to lime and vermin-compost amelioration on acidic nitisols at Assosa, Northwestern Ethiopia also reported the highest nodules per plant as a result of application of vermicompost alone. Furthermore, Otieno et al. (2007) reported that the application of manure resulted in significant increase in number of nodules of some food grain legumes. In contrast, Sulieman and Hago (2009) reported non-significant effects of manure application on nodulation of common bean. Further, total and effective numbers of nodules were increased as a result of lime application in short rainy season (Table 4). In general, these nodule traits showed an increasing trend with increase in lime rate. However, the application of lime beyond 0.64 tonne ha^{-1} did not result in a significant increase in total and effective nodules.

During the short rainy season, the results revealed that P application significantly improved the number of total and effective nodules. As a result, increasing P rate from nil to 46 kg P_2O_5 ha⁻¹ resulted in a 38 and 44% increase in total and effective nodules, respectively compared to the control (Table 3). In agreement with the result, Amare *et al.* (2014) recorded the highest (31.85) significant values for number of nodules per plant of common bean as a result of the application of 20 kg P_2O_5 ha⁻¹ in Southern Ethiopia. Further, Donald, (2016) reported significant ($P = 0.007$) increase in nodule numbers in soybean varieties by 40-50% as a result of inorganic P fertilizer application in different districts of Malawi. Nosheen and Shafique (2006) also reported significant increase in nodulation of chickpea as a result of P application.

Deficiency of P adversely affects nodulation in legumes (Giller 2001). In other words, P plays important roles in nodule initiation, development and function (Waluya *et al.* 2004). Consequently, enhancement in soil P status of the soil due to soil applied P might have contributed to an increase in number of total and effective nodules as a result of P application. This implies sufficient P is required for nodulation in legumes (Kouas *et al.* 2005; Waluya *et al.* 2004). Kouas *et al.* (2005) also reported severe restriction of number of nodules under P deficient conditions. Contrary to this, Sulieman and Hago (2009) reported non-significant effects of P on nodulation of common bean.

Interaction between compost and lime also significantly ($P < 0.01$) increased total and effective number of nodules per plant in the long rainy season (Table 4). Accordingly,

Table 3. Effects of compost, lime and P on total number of nodules and effective nodules per plant of common bean during the short rainy seasons

Compost rate (tonnes ha ⁻¹)	Total number of nodules plant ⁻¹	Number of effective nodules plant ⁻¹
0	19.7 ^c	15.1 ^c
5	28.8 ^b	24.4 ^b
10	34.2 ^a	29.9 ^a
Lime rate (tonne ha ⁻¹)		
0	24.12 ^b	19.8 ^b
0.64	28.80 ^a	24.5 ^a
1.28	29.81 ^a	25.1 ^a
Phosphorus rate (P_2O_5 kg ha ⁻¹)		
0	22.0 ^b	17.8 ^b
23	30.4 ^a	25.6 ^a
46	30.3 ^a	26.0 ^a
CV (%) =	20.4	17.15
LSD (0.05) =	2.4567	2.5947

Means followed by the same letter within the same column are not significantly different at 5% probability level.

Table 4. Interaction effect of compost and lime on total and effective number of nodules per plant during long rainy

Compost rate (tonnes ha ⁻¹)	Lime rate (tonne ha ⁻¹)					
	Total number of nodules			Effective nodules		
	0	0.68	1.28	0	0.68	1.28
0	13.4 ^d	22.3 ^c	31.4 ^{ef}	9.8 ^d	19.6 ^{dc}	27.8 ^{bc}
5	27.6 ^{cb}	33.9 ^b	44.4 ^a	24.5 ^c	30.2 ^{bc}	41.2 ^{ba}
10	48.2 ^a	50.2 ^a	52.0 ^a	45.1 ^a	46.9 ^a	48.5 ^a
CV (%) =	15.37				17.15	
LSD(0.05)=	8.5				14.62	

Means followed by the same letter are not significantly different at 5% probability level

compared to the control, the application of 10 t ha⁻¹ compost along with 1.28 t ha⁻¹ lime resulted in approximately a three-fold increase in number of total and effective nodules per plant. In agreement with this, Tigist, (2017) reported a significant increase in the number of nodules per plant as a result of the combined application of lime and vermin-compost at Assosa, Northwestern Ethiopia. Similar to the effects of separate application of compost, lime and P, on number of total and effective nodules, application of compost along with lime improve the availability of important nutrients such as Ca and P, which are important for nodulation (Kouas et al. 2005; Thung, 1991; Waluya et al. 2004), thereby leading to an increase in the number of total and effective number of nodules.

In a similar pattern, the total and effective number of nodules per plant significantly ($P < 0.001$) influenced by combined application of lime along with P in the long rainy season (Table 5). The application of 1.28 tonne lime ha⁻¹ along with 46 kg P₂O₅ ha⁻¹ resulted in the highest total number of nodules per plant, which exceeded the control by nearly two-fold. Hence, the application of the same rate of lime and P increased the effective number of nodules per plant by 2.5 times compared with the control. Phosphorus and Ca play important role in nodulation (Thung 1991; Waluya et al. 2004). Hence, the application of lime and P might have contributed to improved availability of nutrients such as P and Ca, which in turn increased number of total and effective nodules. In line

with this, Ouertatani et al. (2011) reported significant increase in the number of nodules of faba bean due to combined application of lime and P. Further, Grewal (2010) reported 163% increase in nodulation of alfalfa as a result of applying P along with lime, compared with the application of lime alone.

The total number of nodules per plant significantly ($P < 0.001$) influenced by the combined application of compost along with P during the short rainy season (Table 6). The highest total number of nodules per plant was obtained when 10 tonnes ha⁻¹ compost was applied along with 46 kg P₂O₅ ha⁻¹, while the lowest total number of nodules recorded for the control. Hence, the application of 10 tonnes ha⁻¹ compost along with 46 kg P₂O₅ ha⁻¹ recorded 4.5 times higher total number of nodules compared with the control. Keeping the rate of compost at nil and increasing the P rate from nil to 46 kg P₂O₅ ha⁻¹ resulted in an approximately 44% increase in nodules number over the control. Phosphorus is important for nodulation (Giller 2001), which might be due to its role in energy transfer processes. Hence, the increase in the number of nodules per plant might be attributed to improved availability of nutrients due to release of nutrients from the applied compost and direct addition of P from the inorganic P. In line with this, Ogutu (2013) reported a higher nodule number for common bean than the untreated control as a result of combined application of 100 kg per ha NPK with chicken and farm yard manure each at 4 and 8 tonnes ha⁻¹.

Table 5. Interaction effect of lime and phosphorus on total number of nodules and number of effective nodules per plant during long rainy season

Lime rate (tonne ha ⁻¹)	Phosphorus rate (kg P ₂ O ₅ ha ⁻¹)					
	Total number of nodules			Number of effective nodules		
	0	23	46	0	23	46
0	20.0 ^f	31.1 ^{ed}	38.1 ^{cd}	15.89 ^d	28.3 ^{dc}	35.27 ^{bc}
0.64	20.0 ^f	39.0 ^{cd}	50.7 ^{cb}	15.8 ^d	35.6 ^{bc}	45.3 ^{ba}
1.28	23.5 ^{ef}	46.0 ^b	58.7 ^a	19.3 ^d	42.4 ^{bac}	55.8 ^a
CV (%) =	15.37				17.15	
LSD (0.05) =	8.3984				14.218	

Means followed by the same letter are not significantly different at 5% probability level

Table 6. Total number of nodules per plant of common bean grown under three compost and P regimens during long rainy season

Compost rate (tonne ha ⁻¹)	Phosphorus rate (kg P ₂ O ₅ ha ⁻¹)		
	0	23	46
0	16.2 ^f	23.3 ^{ed}	27.7 ^d
5	21.1 ^{ef}	40.6 ^c	44.2 ^{cd}
10	26.1 ^{ed}	51.6 ^b	72.8 ^a
CV (%) =	15.37	17.5	
LSD = 6.376			

Means followed by the same letter are not significantly different at 5% probability level

3.1.2 Above-ground dry matter yield

Above-ground dry matter yield is significantly influenced due to the two-way interaction effect of compost $\times$ lime in both seasons. Accordingly, the combined application of compost and lime appreciably improved aboveground dry biomass yield (Table 7). Hence, the highest aboveground dry biomass yield in both seasons was recorded for plots receiving 10 tonnes ha⁻¹ of compost along with 1.28 tonne ha⁻¹ lime, which exceeded the control by about 79 and 55% during the short and the long rainy seasons, respectively (Table 7). Better aboveground dry biomass yield production due to the combined application of compost and lime might be ascribed to an increase in leaf area (data not shown) that contributed to higher assimilation of carbon dioxide during photosynthesis, which in turn lead to better accumulation of photo-assimilates. Further, when the availability of certain essential nutrients such as P is improved, the allocation of assimilates to roots will decrease and vice-versa. As a result, improvement in major plant nutrients such as P, N, Ca and Mg due to the application of lime along with compost might have contributed to the increase in aboveground dry biomass yield in both seasons as pointed out by different authors (Fageria 2008; Abay 2011; Manoj-Kumar et al. 2012). The results are in agreement with the findings of Verde (2014), who reported significantly higher stover and total dry matter yield of soybean as a result of combined application of 2.5 tonnes ha⁻¹ manure along with 2 tonnes ha⁻¹ lime.

Similarly, Mekonnen et al. (2014) reported a 187% increase in straw yield of wheat due to the combined application of 5 tonnes manure and 2.2 tonnes ha⁻¹ lime over the control treatment on *Dystric Nitisols* of northwestern Ethiopia.

During the long rainy season, the combined application of lime and P significantly increased above-ground dry biomass yield (Table 8). Hence, the highest aboveground dry biomass yield ha⁻¹ was obtained following the application of 0.64 tonne ha⁻¹ lime along with 46 kg P₂O₅ ha⁻¹, which exceeded the control treatment by about 64%. Better aboveground dry biomass yield production might be attributed to the positive effects of the combined application of lime and P on the availability of nutrients in the soil mainly P, which have a critical role in many nucleotide-based metabolic processes (Sinclair and Vadez 1999) inducing cellulose and hemicelluloses synthesis and leaf area expansion (Fujita et al. 1999). As a result, higher photosynthetic efficiency resulted in better growth and biomass accumulation (Sinclair and Vadez 1999; Zafar et al. 2013). Corroborating the results, Fageria et al. (1995) reported significant interaction effects of lime and P for top weights of common bean, rice and corn.

4 Conclusion

The results of this study demonstrated that better nodulation and growth performance in common bean was found to be related to soil amendments through the

Table 7. Interaction effect of compost and lime on aboveground dry matter yield during short and long rainy season

Compost rate (tonnes ha ⁻¹)	<i>Meher</i> (short rainy season)			<i>Belg</i> (long rainy season)		
	Lime rate (tonne ha ⁻¹)			Lime rate (tonne ha ⁻¹)		
	0	0.64	1.28	0	0.64	1.28
0	3515.2 ^f	3756.7 ^{fe}	3864.2 ^{fed}	4846.3 ^e	5423.2 ^{ed}	5998.4 ^{cbd}
5	4396.9 ^{cbd}	4674.6 ^{cb}	4787.7 ^b	5497.5 ^{ed}	6114.3 ^{ed}	6452.8 ^b
10	4139.8 ^{ced}	4690.2 ^{cb}	6287.8 ^a	5599.8 ^{cd}	6234.8 ^{cb}	7503.1 ^a
CV (%) =	11.1			7.27		
LSD (0.05) =	568.45			692.61		

Means followed by the same letter within each season are not significantly different at 5% probability level.

Table 8. Interaction effect of lime and phosphorus on aboveground dry matter yield during long rainy season

Lime rate (tonne ha ⁻¹)	Phosphorus rate (kg P ₂ O ₅ ha ⁻¹)		
	0	23	46
0	4308.6 ^d	5690.7 ^{cb}	5944.2 ^{cb}
0.64	5473.0 ^c	6081.7 ^{cb}	6217.6 ^b
1.28	5861.2 ^{cb}	7017.8 ^a	7075.3 ^a
CV (%) =	7.27		
LSD (0.05) =	617.28		

Means followed by the same letter are not significantly different at 5% probability level.

application of compost, lime and P either separately or through the combined application of either of these. This also implies that the poor fertility status of the soils of the study area and the possibility of rectifying the problems through the application of organic and inorganic nutrient source as well as liming. However, since the data is only for one location, repeating the experiment across locations is imperative to validate the results.

Conflict of interest: Authors declare no conflict of interest.

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