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Effects of nitrogen, phosphorus and vermicompost fertilizers on productivity of groundnut (*Arachis hypogaea* L.) in Babile, Eastern Ethiopia

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Abstract: Though groundnut (*Arachis hypogaea* L.) is a main cash crop for smallholder farmers in several districts of eastern Ethiopia, its yield is very low. Farmers apply little or no fertilizers to grow the crop possibly because no generic or recommended fertilizers rates available for farmers. Therefore field experiments were conducted for two consecutive cropping seasons in Babile district, to prove the hypothesis that one of the major factors that severely reduce the yield of the crop was lack of nutrients in the soil with the objective of investigating the effects of applying mineral NP fertilizers and vermicompost on the productivity of improved groundnut variety 'BaHa-Gudo'. The experiment was 3×3×3 factorial with three replications laid down in a randomized complete block design comprising nitrogen (0, 23 and 46 kg N ha^{-1}), phosphorus (0, 46 and 92 kg P_2O_5 ha^{-1}) and vermicompost (0, 2.5 and 5 t vermicompost ha^{-1}). The data on crop growth, nodulation and yield were collected and subjected to analysis of SAS 9.2 software. Means separation were made using Duncans Multiple Range Test (DMRT) at 5% level of significance. The results revealed that growth, yield attributes, and yields were significantly ($P < 0.01$) affected by the main and interactions effect of the treatments. The pod yield obtained from combined application of 46:46 kg N: P_2O_5 ha^{-1} and 2.5 t vermicompost ha^{-1} exceeded the pod yield produced from nil application of fertilizers by about 100%. The economic analysis also indicated that the highest marginal rate of return (671%) and net benefit ($ 1,830) ha^{-1} were obtained from combined application of 46:46 kg N: P_2O_5 ha^{-1} and 2.5 t vermicompost ha^{-1}. From the results it could be concluded that applying the aforementioned doses of fertilizers combination would enable farmers increase productivity of groundnut so as to enhance farmers' income and livelihoods.

Key words: groundnut; mineral NP fertilizers; vermicompost; combined application.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a monoecious annual legume widely grown in tropical and sub-tropical regions for direct use as food, oil, high protein meal and animal feed (Pande et al., 2003; Taru et al., 2010). It is among important oil crops in Ethiopia, with Oromia region as the major producer in the country contributing 55% to the national groundnut production (CSA, 2017). Moreover, as a cash crop, groundnut is high value crop with relatively high return on a limited land area, and it is well adapted to hot semi-arid conditions (Wangai et al., 2001).

The lowland areas of Ethiopia have immense potential for groundnut production. The estimated production area and yield of groundnut in the country during 2016/2017 cropping season were 74,861.4 ha and 129,636.4 tonnes, respectively, and the largest production areas are in Oromia (41,055.3 ha), Benshangul-Gumuz (19,729.0 ha) and Amhara (7,104.4 ha) (CSA, 2017). However, the productivity of the crop in the country remained low. The mean dry pod yield of groundnut on farmers' field (1.73 t ha^{-1}) is lower than the mean potential dry pod yield of 1.80–2.50 t ha^{-1} recorded at research field under rain-fed (Teklemariam et al., 2012; Chala et al., 2014). In fact, there have been some efforts to improve the productivity of groundnut in Ethiopia. However, the effort was not boosted the crop productivity as expected (Sahelemedhin & Taye, 2000). The low groundnut yield is, therefore, related to poor agronomic practices (Page et al., 2002; Chala et al., 2014) particularly soil fertility management in addition to other biotic and abiotic production constraints.

Declined soil fertility due to continuous land cultivation with little fertilizers inputs is a major threat to crop production in Africa, including Ethiopia (Sanchez & Jama, 2002; Negassa et al., 2005; Tesfaye et al., 2011). Inadequate fertilizers supply accompanied with low rate of return of biomass to the soil in a cultivated land aggravated soil degradation leading to low productivity (Zelleke et al., 2010; Samuel, 2013). This is a major problem particularly in East Hararghe Zone, where crop residues are rigorously used for competing ends such as animal feed and fuel wood while fertilizers input is insufficient. Most Ethiopian soils are deficit in major nutrients, especially nitrogen (N) and phosphorus (P) (Maheswar & Sathiyavani, 2012) and N (Mohamed & Abdalla 2013; Samuel, 2013). Although groundnut can satisfy part of its N need through beneficial N_2 fixation; the crop showed response to external N fertilizer supply (Singh & Singh 2001; Kandil et al., 2007). Besides, in semi-arid regions, N_2 fixation by legumes is limited by moisture stress (Devi et al., 2013; Collino et al., 2015). Furthermore, N_2 fixation potential of groundnut is restricted by P as it is essentially required for growth of efficient root system and nodulation (Ndakidemi et al., 2006; Zafar et al., 2013; Abdulkadir et al., 2014). Thus, external source of N and P is essentially required for growth and yield of the crop.

Groundnut is best grown in semi-arid eco-systems where rainfall is low and erratic (Hamidou, 2012); soils are sandy and sandy loam which with poor fertility and low water holding capacity (Mohsen et al., 2015); low soil organic matter (Samuel, 2013) and thus poor fertilizer use efficiency. The nutrient and water holding capacity of such soils can be improved through adding organic materials (Mohsen et al., 2015). Thus combined use of mineral and organic fertilizers like manures, compost and vermicompost (VC) is becoming increasingly important (Saadatnia & Riahi, 2009; Chouichom & Yamao, 2011). Gursum and Babile districts of eastern Ethiopia are major areas of groundnut prodution (Chala et al., 2014). These districts are mainly semi-arid and commonly influenced by water stress araised from low, highly variable and erratic rainfall. Due to moisture scarcity, the soil organic matter turnover and fertilizer use efficiency is very low. Furthermore, the soil is sandy or sandy loam with low water holding capacity and deficient in organic carbon, total N and available P (Argaw et al., 2015). To cope up with the problems some farmers of the study area have been commonly using di-amonium phosphate (DAP) and urea [$CO(NH_2)_2$] in groundnut production (Chala et al., 2014).

However, despite, the generally low content of soil organic matter, no organic fertilizer is applied by farmers or no recommended rate of application for such fertilizers is available. Moreover, to exploit the yielding potential of recently released improved groundnut varieties a specific fertilizer recommendation need to be developed. Therefore, this study was conducted to elucidate the nodulation, growth and yield response of groundnut to the combined application of mineral NP fertilizers and vermicompost in Babile District of eastern Ethiopia.

MATERIALS AND METHODS

Description of the Experimental Site

Field experiments were conducted in East Hararghe Zone, Babile district. The district is known for a significant share of groundnut production in the East Hararghe Zone and the country. It is located at 9° 13' 13.5'' N latitude and 42° 19' 20.9'' E longitude and at an altitude of 1,647 meters above sea level. The experiment was undertaken during the main rainy season 2015 and 2016. The area has mean annual minimum and maximum temperatures of 16 °C and 31 °C, respectively and annual rainfall of the area varied within the range 500 to 700 mm with erratic nature (Samuel, 2013). The area has soil texture of sandy loam with low water holding capacity. The soil physical and chemical properties of the experimental site were described in Table 1. The experimental fields were planted sorghum in the previous years of cropping seasons.

Table 1. Soil physical and chemical properties of the experimental site

Physico-chemical properties	Value	Rating	References
pH (1:2.5 H_2O)	7.11	Neutral	Tekalign Tadese (1991)
Organic carbon (%)	0.68	Very low	Tekalign Tadese (1991)
Total N (%)	0.11	Low	Tekalign Tadese (1991)
Available P (mg/kg soil)	2.61	Very low	Olsen et al. (1954)
CEC (cmol (+)/kg soil)	24.55	Medium	Landon (1991)
Exchangeable Ca (cmol (+) kg^{-1} soil)	7.18	High	FAO (2006)
Exchangeable Mg (cmol (+) kg^{-1} soil)	3.63	High	FAO (2006)
Exchangeable Na (cmol (+) kg^{-1} soil)	0.17	Low	FAO (2006)
Exchangeable K (cmol (+) kg^{-1} soil)	1.04	High	FAO (2006)
Physical properties (texture)			
Clay (%)	20		
Silt (%)	15		
Sand (%)	65		
Textural class	Sandy loam		

H_2O: water; N: nitrogen; P: phosphorus; CEC: cation exchange capacity; Ca: calcium; Mg: magnesium; Na: sodium; K: potassium.

Experimental Procedures

Groundnut (*Arachis hypogaea* L.) variety, BaHa-Gudo (NC-AC-2748×Chico) was used as a test crop. Nitrogen in the form of urea (46% N), P in the form of tri superphosphate (TSP) (46% P_2O_5) and vermicompost (VC) were used as fertilizer. The VC was prepared at Haramaya University from animal manure and plant waste materials by using earthworm (*Eisenia fetida)* for decomposition. The analysis of the VC before application revealed slightly alkaline pH of 7.48, total organic carbon content of 29.25%, total N content of 1.59%, total P content of 986.74 part per million (ppm), and electric conductivity of 8.96 millisiemens per centimeter (mS cm^{-1}). The treatments consisted of three doses of nitrogen (0, 23, and 46 kg N ha^{-1}), three doses of phosphorus (0, 46, and 92 kg P_2O_5 ha^{-1}) and three doses of VC (0, 2.5, and 5 t VC ha^{-1}). Thus, there were 3×3×3 = 27 treatment combinations. The treatments were laid out in randomized complete block design (RCBD) in a factorial arrangement with three replications.

Two groundnut seeds per planting hole were planted at row spacing of 60 cm and plant spacing of 10 cm in both seasons on gross plot size of 7.2 m^2 (3.6 m×2 m). Each plot was consisted of 6 plant rows. Plots and blocks were separated by 0.50 m and 1.00 m spaced pathways for intercultural operations. Full doses of P fertilizer were applied in the form of TSP at planting time. Vermicompost was applied to the plots in band at time of planting. Nitrogen was applied in two splits, one at planting, and the second one at flower initiation stage in the form of urea. All other production and agronomic practices were kept uniform for all treatments in both seasons. From the four central rows of each plot one rondomly selcted row was used for destructive sampling while the rest three central rows per plot (i.e., net plot of 3.6 m^2 = 1.8 m×2 m size) were harvested for the crop yield data analysis.

Data collection and analysis

The crop canopy (a layer of branches and leaves at the top of the crop) spread, height was taken from randomly selected and pre tagged five plants per plot, measuring from the last leaf on one side to the last leaf on the other side across and along plant row using a measuring tape and the average taken as canopy spread. Height and number of branches of the pre tagged plants were taken at 75% maturity of the crop. Destructive sampling raw for nodule data was randomly selected from central rows of each plot. Five plants from sampling rows of each plot were gently uprooted at complete flowering stage and washed on a fine sieve with tap water to remove soil particles. The nodules were carefully removed from roots, the number of nodules on each plant was counted and the average nodules number $plant^{-1}$ was determined. Ten nodules were randomly taken from the total number nodules of each plant and effective nodules and non-effective nodules were identified by their pinkish or red color on cutting (Unkovich et al., 2008). The weight of dry pods from the respective net plot was recorded after plucking the pods, drying them, and adjusting their moisture contents to 13% (Konlan et al., 2013). The weight of pods harvested from each net plot area was then was converted to total pod yield (t ha^{-1}). The dried pods were hand-shelled, the seed weighed, and the differences between the pod and seed weights of the treatments were used to compute shelling percentage (%). Shelling percentage was determined as the weight of groundnut seed divided by the weight of pods as shown below:

$$Shelling\ (\%) = \frac{Weight\ of\ seeds}{Weight\ of\ pods} \times 100 \qquad (1)$$

Five plants were randomly selected and harvested with their pods from the sampling row of each plot to determine total dry biomasses yield at physiological maturity.

Then the aboveground part plus the pods were oven dried at 65 °C to a constant weight to determine the total dry biomass yield (t ha^{-1}). The harvest index was calculated in percentage as the ratio of the economic yield to the total dry biomass yield of the plant multiplied by 100.

All the collected data were subjected to analysis by SAS (statistical analysis system) version 9.2 (SAS Institute, 2004). Homogeneity test of error variances for the two years was performed using the F-test as described by Gomez & Gomez (1984). In all cases, the variations in the two years were not significantly different for all the parameters and the error variances were homogeneous. Thus, a combined analysis of variance (ANOVA) for the two years data was performed. Differences among treatment means were delineated using the Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Economic Analysis

Economic evaluation of the effect of N (urea), TSP (Tri-superphosphate) and VC were performed on the pod yield. Thus, the economic gains of the different treatments were calculated to estimate the net returns, considering the costs of fertilizers N, P, VC and labor related to them, and the income from the harvest following procedures of CIMMYT (1988).

RESULTS

Crop Growth and Nodulation

Canopy spread. The main effects of N, P, and VC significantly ($P < 0.001$) affected canopy spread. However, all of these factors did not interact to influence canopy spread. The canopy spread of groundnut improved by application of N or VC application over the control. The result also showed that medium level (46 kg P_2O_5 ha^{-1}) of P fertilizer resulted in maximum (43.3 cm per plant) crop canopy spread (Table 2).

Table 2. Main effects of nitrogen (N), phosphorus (P) and Vermicompost (VC) doses on canopy spread (CS) of groundnut at Babile (2- year's pooled data)

Treatment	Canopy spread (cm)
Nitrogen (kg N ha^{-1})	
0	40.4^{b}
23	41.8^{a}
46	42.0^{a}
F-test	***
Phosphorus (kg P_2O_5 ha^{-1})	
0	40.7^{b}
46	43.3^{a}
92	40.3^{b}
F-test	***
Vermicompost (t ha^{-1})	
0	39.2^{b}
2.5	42.2^{a}
5.0	42.9^{a}
F-test	***
CV (%)	5.15

Means followed by the same letter within a column are not significantly different at 5% level of probability according to Duncan's Multiple Range Test (DMRT) at 5% level of significance.

***: significant at $P < 0.001$; CV: coefficient of variation.

Plant height. The analysis of variance revealed that the main effect of N, P, and VC as well as the two-factors interactions effect except P×VC, significantly ($P < 0.001$) influenced plant height at harvest. Moreover, the interaction of N×P×VC significantly ($P < 0.001$) affected the height of groundnut. Plant height was significantly enhanced in response to increased doses of N and P across the increasing doses of vermicompost. The tallest (27.2 cm) height was obtained at combined application of 23:46 kg N: P_2O_5 ha^{-1}with 5 t VC ha^{-1} as well as at 46:46 kg N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1} (Table 3).

Number of branches per plant. The combined analysis of variance showed significant ($P < 0.001$) differences in the number of branches plant^{-1} due to the main effect of N, P and VC as well as all their interactions effect. Increasing the dose of P led to significantly ($P < 0.001$) increased plant height as well as number of branches plant^{-1} across the increasing doses of N and VC (Table 3). The highest (6.4) numbers of branches plant^{-1} were recorded at the combined application of 23:46 kg N: P_2O_5 ha^{-1} with 5 t VC ha^{-1} as well as at 46:46 kg N: P_2O_5 with 2.5 t VC ha^{-1}. Thus, the number of branches plant^{-1} produced at the aforementioned combined doses of fertilizers significantly exceeded the number of branches plant^{-1} obtained from non fertilized plots by about 25% (Table 3).

Table 3. Interaction effects of nitrogen (N), phosphorus (P) and vermicompost (VC) doses on number of branches and plant height of groundnut at Babile (2-year's pooled data)

Fertilizers (kg ha^{-1})		Vermicompost (t ha^{-1})					
		number of branches plant^{-1}			plant height (cm)		
N	P_2O_5	0	2.5	5.0	0	2.5	5.0
	0	5.1^{f}	5. 6^{cde}	5.9^{bc}	19.9^{l}	20.5^{jkl}	20.8^{i-l}
0	46	5.7^{b-e}	5.5^{cde}	5.6^{cde}	20.6^{jkl}	21.1^{i-l}	21.2^{h-l}
	92	5.8^{bcd}	5.7^{bcd}	5.7^{b-e}	19.8^{kl}	21.5^{f-j}	21.9^{d-j}
	0	5.5^{df}	5.7^{b-e}	6.0^{b}	20.9^{i-l}	21.7^{e-j}	23.3^{cde}
23	46	5.7^{b-e}	6.0^{b}	6.4^{a}	22.3^{c-i}	23.0^{c-f}	27.2^{a}
	92	5.7^{b-e}	5.7^{b-e}	5.6^{b-e}	20.7^{jkl}	23.3^{cde}	22.9^{c-g}
	0	5.7^{b-e}	5.9^{bc}	5.4^{ef}	21.3^{g-k}	23.2^{cde}	22.9^{c-g}
46	46	5.8^{bcd}	6.4^{a}	5.6^{cde}	22.4^{c-i}	26.8^{a}	25.4^{b}
	92	5.6^{cde}	5.8^{bcd}	5.8^{bcd}	22.7^{c-h}	23.5^{cd}	23.5^{c}
F-test		***			***		
CV (%)		5.39			6.27		

Means sharing the same letter are not significantly different according to DMRT at 5% level of significance. CV: coefficient of variation; ***: significantly at $P < 0.001$.

Nodulation. The combined analysis of variance of nodulation assessment at 50% flowering stage revealed that the main factors N, P and VC and their interactions significantly ($P < 0.001$) influenced both total and effective number of nodules plant^{-1}. The number of total and effective nodules obtained in response to the combined application of 23:46 kg N: P_2O_5 ha^{-1} without VC ha^{-1} exceeded the total and effective number of nodules plant^{-1} obtained control plots by about 47% and 50%, respectively (Table 4).

Yield

Dry pod yield. The three-factor interaction significantly ($P < 0.001$) influenced pod yield of groundnut. Increasing the doses of N across the increasing doses of P and VC increased pod yield of groundnut. The highest (3.05 t ha^{-1}) pod yield was obtained at combined application of 46:46 kg N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1} (Table 6). Thus, the results have demonstrated that the maximum pod yield was obtained at the highest dose of mineral N fertilizer, medium doses of mineral P and vermicompost fertilizers.

Dry biomass yield. The combined analysis of variance revealed that the main factors N, P and VC as well as their interactions significantly ($P < 0.001$) influenced dry biomass (DBM) yield of groundnut (Table 5). Similar to pod yield, all the fertilizer treatments gave significantly higher DBM yield over the control. The highest DBM (6.91 t ha^{-1}) was obtained in the plot received combination of 23:46 kg N: P_2O_5 ha^{-1} with 5.0 t VC ha^{-1} which was statistically at par with the biomass (6.82 t ha^{-1}) obtained at combined application of 46:0 kg N: P_2O_5 ha^{-1} with 5 t VC ha^{-1}. The lowest DBM yield (3.53 t ha^{-1}) was recorded in the control treatment (Table 5).

Table 4. Interaction effects of nitrogen (N), phosphorus (P) and vermicompost (VC) doses on number of total and effective nodules plant^{-1} of groundnut at Babile (2-year's pooled data)

Fertilizers		Vermicompost (t ha^{-1})					
N	P_2O_5	number of total nõudles plant^{-1}			number of effective nodules plant^{-1}		
(kg ha^{-1})	(kg ha^{-1})	0	2.5	5.0	0	2.5	5.0
0	0	113.7^{e-h}	124.1^{c-g}	118.2^{d-g}	100.4^{e-h}	106.8^{d-g}	103.1^{e-h}
	46	126.3^{c-f}	169.1^{a}	136.7^{bc}	112.9^{c-f}	150.6^{a}	118.8^{cd}
	92	120.3^{d-g}	127.5^{c-f}	123.4^{c-g}	108.2^{c-g}	113.4^{cde}	108.8^{c-g}
23	0	111.0^{gh}	$136. 3^{c}$	122.3^{c-g}	99.5^{f-i}	121.4^{bc}	108.5^{c-g}
	46	166.9^{a}	151.2^{b}	117.6^{d-g}	150.3^{a}	134.1^{b}	104.1^{e-h}
	92	126.9^{c-f}	128.6^{cd}	127.0^{c-f}	113.9^{cde}	111.4^{c-g}	111.8^{c-f}
46	0	95.5^{i}	110.9^{gh}	128.2^{cde}	84.1^{j}	98.3^{ghi}	112.9^{c-f}
	46	101.4^{hi}	99.6^{hi}	100.4^{hi}	91.2^{hij}	86.2^{ij}	86.2^{ij}
	92	120.9^{d-g}	113.6^{fgh}	120.4^{d-g}	106.2^{d-g}	101.0^{e-h}	106.3^{d-g}
F-test		***			***		
CV (%)		10.34			10.76		

Means sharing the same letter are not significantly different according to DMRT at 5% level of significance. CV: coefficient of variation; ***: significant at $P < 0.001$.

Table 5. Interaction effects of nitrogen (N), phosphorus (P) and vermicompost (VC) doses on dry pod yield and dry biomass yield of groundnut at Babile (2-year's data pooled)

Fertilizers		Vermicompost (t ha^{-1})					
N	P_2O_5	dry pod yield (t ha^{-1})			dry biomass yield (t ha^{-1})		
(kg ha^{-1})	(kg ha^{-1})	0	2.5	5.0	0	2.5	5.0
	0	1.50^{n}	2.09^{kl}	2.29^{hij}	3.53^{g}	5.76^{b-e}	$5. 48^{b-e}$
0	46	2.06^{l}	2.36^{e-i}	2.34^{f-i}	4.66^{f}	5.62^{b-e}	5.65^{b-e}
	92	2.12^{jkl}	2.40^{e-h}	2.51^{ef}	5.58^{b-e}	5.41^{b-e}	5.80^{b-e}
	0	1.81^{m}	2.30^{g-i}	2.38^{e-h}	5.59^{b-e}	5.23^{def}	5.93^{bc}
23	46	2.34^{f-i}	2.81^{bc}	2.98^{ab}	5.66^{b-e}	5.94^{bc}	6.91^{a}
	92	2.41^{e-h}	2.44^{e-h}	2.45^{e-h}	5.74^{b-e}	5.69^{b-e}	5.56^{b-e}
46	0	2.05^{l}	2.18^{i-k}	2.26^{h-k}	5.19^{ef}	5.33^{c-f}	6.82^{a}
	46	2.55^{de}	3.05^{a}	2.72^{cd}	5.87^{b-e}	5.93^{bd}	6.05^{b}
	92	2.41^{e-h}	2.49^{efg}	2.52^{ef}	5.60^{b-e}	5.90^{bcd}	5.73^{b-e}
F-test		***			***		
CV (%)		7.13			10.45		

Means sharing the same letter are not significantly different according to DMRT at 5% level of significance. ***: significant at $P < 0.001$.

Pod harvest index. The main effects of P and N as well as the interaction effects of VC with either N or P were significant ($P < 0.01$) on pod harvest index. The highest pod harvest index (51.9%) was obtained from combined application of 46:46 kg N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1}, which was statistically identical with plots that received combination of 23:46 kg N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1} (Table 6). On the other hand the lowest pod harvest index (32.4%) was obtained from sole application of 23kg N ha^{-1}, which was statistically at par with plots that received 46kg N ha^{-1} and 2.5 t VC ha^{-1} without P_2O_5 (Table 6).

Economic Analysis

The economic analysis revealed that the highest net benefit of \$ 1,830 ha^{-1} with MRR of 671% was obtained from combined application of 46:46 kg mineral N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1}, followed by net benefit of \$ 1,683 with MRR of 55% and \$ 1,620 with MRR of 565%, \$ 1,496 with 322% and \$ 1,213 with MRR of 391% which were recorded for 23:46 kg N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1}, 46:46 kg N: P_2O_5 ha^{-1} with no VC, and 23:46 kg N: P_2O_5 ha^{-1} with no VC and 23:00 kg N: P_2O_5 ha^{-1} with no VC respectively (Table 7). Since the minimum MRR assumed in this study was 100%, the treatment with application of 23:46 kg mineral N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1} was not considered rewarding treatments as it gave MRR of 55% (Table 7).

Table 6. Interaction effects of nitrogen (N), phosphorus (P) and vermicompost (VC) doses on pod harvest indices of groundnut at Babile (2-year's data pooled)

Fertilizers		Vermicomost (t ha^{-1})		
N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	0	2.5	5
0	0	42.7^{cde}	36.3^{fgh}	41.8^{c-f}
	46	44.5^{bcd}	42.2^{cde}	41.6^{c-f}
	92	38.3^{efg}	45.2^{bc}	43.4^{b-e}
23	0	32.4^{h}	44.9^{bcd}	40.2^{c-f}
	46	41.9^{cde}	48.9^{ab}	43.3^{cde}
	92	42.2^{cde}	42.9^{cde}	44.3^{bcd}
46	0	39.6^{def}	41.5^{c-f}	33.2^{gh}
	46	45.0^{bcd}	51.9^{a}	45.2^{bc}
	92	43.1^{cde}	42.2^{cde}	44.5^{bcd}
F-test		**		
CV (%)		11.47		

Means sharing the same letter are not significantly different according to DMRT at 5% level of significance.

**: significant at $P < 0.01$; CV: Coefficient of variation.

Table 7. Results of the economic analysis for combined application of nitrogen (N), phosphorus (P) and vermicompost (VC) in groundnu t at Babile (2-year's data pooled)

N (kg ha^{-1})	P (P_2O_5) kg ha^{-1}	VC (t ha^{-1})	Ad PY (t ha^{-1})	TVC (\$ ha^{-1})	GFB (\$ ha^{-1})	NB (\$ ha^{-1})	MRR (%)
0	0	0	1.50	_	1042	1042	-
23	0	0	1.81	44	1257	1213	391
23	46	0	2.34	132	1628	1496	322
46	46	0	2.55	154	1774	1620	565
23	46	2.5	2.81	267	1950	1683	55
46	46	2.5	3.05	289	2119	1830	671

AdPY: Adjusted pod yield; TVC: Total variable cost; GFB: Gross field benefit; NB: Net benefit; MRR: Marginal rate of return.

DISCUSSION

Crop growth and nodulation

Crop growth. In this study mineral N, P and VC application significantly ($P < 0.001$) increased canopy spread (Table 2) while their combined application significantly increased plant height and number of branches $plant^{-1}$ (Table 3). Similar results have been reported by Bala et al. (2011), Mathivanan et al. (2013) and

Mukhtar et al. (2014) that application of N in soybean, manures and VC in groundnut, respectively, significantly increased canopy spreads. Similarly, Abbasi et al. (2008) and Ahiabor et al. (2014) reported improved canopy spread due to P application in soybean. The synergistic effects of combined application of mineral NP fertilizers and VC on plant height and number of branches plant^{-1} in the current experiments have been also reported by Malligawad (2010) and Singh et al. (2017). Similarly, Rajkhowa et al. (2002); Channaveerswami (2005); and Yagoub et al. (2012) reported better growth response of green gram, groundnut and soyabean, respectively, to combinations of organic and inorganic fertilizers. Bhosale et al. (2017) reported higher number of branches plant^{-1} of groundnut over the control due to combined application of different proportion mineral NP fertilizers and VC. Furthermore, Singh et al. (2011) & Armin et al. (2016) also reported that combined application of inorganic fertilizers which led to the highest number of branches plant^{-1} of French bean and mungbean, respectively.

Nodulation. The highest numbers of both total and effective nodules were obtained at the combined application of 23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} without VC ha^{-1} (Table 4). However, higher doses of inorganic N fertilizer and VC application suppressed the number of nodules. In support with the present result, Basu et al. (2007) reported that application of 20:40:30 kg NPK ha^{-1} along with 2.5 t FYM ha^{-1} significantly increased the nodule formation as compared to mineral NPK alone while, at high dose, NPK (40:80:60 kg ha^{-1}) decreased the nodule formation and nitrogen accumulation in nodules over low level of NPK (20:40:30 kg ha^{-1}) in groundnut. Similarly, Ouslim et al. (2015) & Islam et al. (2016) reported reduced nodulation at adequate or high N application in different legumes. The result conclusively indicated that nodule formation could be reduced by high doses of mineral N, while small starter doses of applied N may stimulate nodule formation (Biswas et al., 2003; Abayomi et al., 2008). Amba et al. (2013), Weisany et al. (2013) & Taruvinga (2014) reported increased nodulation in groundnut with application of P. Contrarily, Latif et al. (2014) reported that P did not directly involved in the process of nodulation and N_2 fixation of groundnut suggesting that the role of P varies with crop, growing conditions and time of measurement.

Yield. The dry pod yield (3.05 t ha^{-1}) obtained in this study was higher by about 43% compared to pod yield of groundnut obtained in farmers' fields (1.74 t ha^{-1}, regional average yield, reported by CSA, 2017). The maximum yields obtained in these experiments either at 46:46 kg N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1} or at 23:46 kg N: P_2O_5 ha^{-1}, with 5.0 t VC ha^{-1} (Table 5). As depicted in Table 3 the aforementioned doses of fertilizers resulted in high plant height and number of branches plant^{-1} of groundnut. Therfore, the amximum yield recorded might be due to additive effects of combined use of inorganic NP fertilizers and VC on nutrient supply that promote growth in plant height and number of branches leading to high pod yield. The number of branches was more important in determining the node number which in turn determines pod number and yield. In addition to the additive effect on nutrient supply, VC adds soil organic matter; hence improve soil physical conditions to conserve moisture and resulting in better growth, pod formation and greater yields (Oke, 2015; Sengupta et al., 2016). Murthy et al., 2009 and Sengupta et al. (2016) reported improved growth and yield components leading higher pod yield of 3.32 ha^{-1} from application of recommended dose of NPK ha^{-1} with vermicompost at 2.5 t ha^{-1} along with gypsum and 3.21 ha^{-1} application of recomended dose of NPK ha^{-1} with manure, respectively.

Dry biomass. As depicted in Table 5 statistically similar DBM yields obtained at 23:46 kg N: P_2O_5 ha^{-1} with 5.0 t VC ha^{-1} and 46:0 kg N: P_2O_5 ha^{-1} with 5 t VC ha^{-1}. The favorable effect of optimum level of nutrients through both inorganic and organic nutrient sources in improving vegetative growth could be one of the reasons for higher DBM production of groundnut as stated by Ramana et al. (2002). Particularly optimum N level promotes the development of source system and increases its photosynthetic efficiency leading to higher DBM production (Satapathy et al., 2005). The current finding aligned with that of Karunakaran et al. (2010) and Khaim et al. (2013) who reported that combined application of inorganic and organic fertilizers in groundnut and in soybean, respectively, improved biomass production. Olasan et al. (2018) revealed that plant biomass in the field has significant effect on yield as well as sizes of pods and seeds. However, it is imperative to note that high biomass production may not necessarily indicate high pod or seed yield. Agele et al. (2017) stated that it was dry matter partition, but not only biomass production that greatly determines the pod yield of cowpea. It is the dry matter partitioned in to harvesTable organs contribute yield of groundnut. In the current experiment, the high biomass recorded in treatment received 23:46 kg N: P_2O_5 ha^{-1} with 5.0 t VC ha^{-1} led to high pod yield, but the equivalently high bimass recorded at applicatin of 46kg N ha^{-1} and 5 t VC ha^{-1} withot P did not follow the same trend. The difference might be strongly related with the role P in assimilate patitin to pods and seed feeling. Though the biomass production was high the low pod yield might have also been attributed high fruit abortion and excessive vegetative growth on the expense of fruiting (Agele et al. (2017).

Harvest index. Harvest index (HI) is the partitioning of the assimilated products to the economically important parts that determines the productivity of any crop (Ramana et al., 2002). It is evident from the results that combined application of 46:46 kg N: P_2O_5 and 2.5 t VC ha^{-1} resulted in 21.5% increases in pod harvest index over the control (Table 6). The highest yield was also recorded at the above metioned dose of fertilizers. This indicated that balanced nutrient supply through combination of 46:46 kg N: P_2O_5 and 2.5 t VC ha^{-1} improved efficiency of the crop to convert photosynthesized products into pods.

Economic Analysis. The maximum net benefit obtained at 46:46 kg N: P_2O_5 with 2.5 t ha^{-1}, gave high MRRs of 671% suggesting for each $ invested, the producer would collect $ 0.25 after recovering the cost (Table 7). On the other hand, either 46:46 kg mineral N: P_2O_5 or 23:46 kg mineral N: P_2O_5 ha^{-1} (Table 7) could be profitably used by the groundnut farmers as alternatives when VC may not be accessible. This result agreed with the study by Girma & Gebreyes (2017) who reported high net benefit from the combined application of mineral NP fertilizers with VC for teff (*Eragrostis teff*). Similarly, Meena et al. (2015) reported that combined application of 75% RDF and 2.5 t ha^{-1} of VC with bio-fertilizers resulted in 42% increase net return over the control treatment in mungbean.

CONCLUSION

Groundnut (*Arachis hypogaea* L.) is produced with little or no fertilizer application in the study area. However, the soil in the study area has been shown to be low in the contents of N, P, and organic carbon, which necessitates application of fertilizers from external sources of fertilizers. Groundnut canopy spread was improved by application of N or VC application over the control. Combined application of 23:46 kg N: P_2O_5 ha^{-1} with 5 t VC ha^{-1} or 46:46 kg ha^{-1} N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1} was resulted in high plant height and number of branches $plant^{-1}$ of groundnut. The highest pod yield (3.05 t ha^{-1}), pod harvest index (51.9%), marginal rate of return (565%) of ground nut were obtained from combined application of 46 kg N, 46 kg 2.5 t VC ha^{-1}. It could thus, be concluded that combined application of 46:46 kg N: P_2O_5 ha^{-1} with 2.5 t VC ha^{-1} is optimum and economical to attain better productivity of groundnut in the study area and similar agro-ecologies.

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