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Effect of Soil Acidity Amelioration on Soil Properties and Yield of French Bean (*Phaseolus vulgaris* L.) under Rainfed Condition in Arunachal Pradesh

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Abstract

Under rainfed conditions yield potential of French bean reduced in the acid soil of Arunachal Pradesh due to low fertility and metal toxicity. Therefore, the current experiment was conducted in ICAR, Basar, Research Farm during *rabi* season (October–January) of 2018, 2019 and 2020 to study the effect of soil amelioration using organic amendments combined with inorganic fertilizer on the yield of French bean and important soil properties. The soil amendment treatments i.e., control, vermicompost (Vc), vermicompost+lime (Vc+lime), 50% RDF (Recommended dose of fertilizer), 50% RDF+lime, 50% RDF+Vc, 75% RDF, 75% RDF+lime, 75% RDF+Vc, 100% RDF were laid in randomized block design with three replications. The doses of vermicompost, lime and RDF were 2.5 t ha^{-1}, 400 kg ha^{-1} and 50-50-50 NPK kg ha^{-1}. Results showed soil pH recorded maximum and exchangeable aluminum, exchangeable acidity and total acidity recorded minimum in 75%RDF+lime. The soil organic carbon, soil cation exchangeable capacity, soil moisture content and soil available nutrients (N, P, K, S, Fe, Mn, Zn, Cu) recorded maximum and soil bulk density recorded minimum in 75%RDF+Vc. Vermicompost along with 75%RDF was most effective in increasing the yield (4.85 t ha^{-1}). The study indicates soil acidity amelioration using vermicompost and/or lime along with inorganic nutrients reduced soil acidity and improved the soil fertility making the soil environment favorable to achieve an optimum yield of French bean in acid soils of Arunachal Pradesh.

Keywords: Acid soil, amelioration, Arunachal Pradesh, french bean, fertilizer, yield

1. Introduction

Acid soil is problematic soil globally occupying about 30-40% of arable land in the world (Bian et al., 2013). In Arunachal Pradesh, acid soil covers 81% of the total geographical area (8.37 mha^{-1}) (Bhattacharyya et al., 2015). The limiting factor of acid soil is low soil fertility due to soil nutrient deficiencies and metal ion toxicity (Bordoloi and Sharma, 2022, Fekadu et al., 2019, Bian et al., 2013, Haynes and Mokolobate, 2001). Acid soilin Arunachal Pradesh with the dominance of $Fe^{2/3+}$ and $Al^{3+}$is a major soil problem affecting crop production potential under rainfed (Bhagawati et al., 2016, Maji et al., 2012) and reduced manure application (Avasthe et al., 2013).

The major causes of soil acidity are weathering of acid parent material (quartzite, schist, etc) (Bandyopadhyay et al., 2018, Maji et al., 2012) leaching of basic cations, heavy rainfall and the perpetual use of acid-forming mineral fertilizer (Artiola et al., 2019, Zhang, 2017). Reports have shown French bean crop growth and performance in acid soil are related to nutrient imbalance and Al toxicity (Kumar et al., 2021, Dida and Etisa, 2018, Kumar et al., 2016). To improve the production in acidic soils, improvement of nutrient balance and amelioration of Al toxicity is essential. For years organic and inorganic soil amelioration methods like manure treatment and liming separately or together (Shahane and Shivay, 2022, Lynrah and Nongmaithem, 2017) have been the common approaches to amend acid soil problems (Dejene et al., 2016). But reports have shown integration of organic and inorganic soil amendment materials is more effective in reducing the soil exchangeable acidity and Al^{3+} activity in acid soils (Meena and Prakash, 2021, Possinger et al., 2020, Chaudhari et al., 2020, Singh et al., 2018). Reports have shown sole application of organic manure or lime without inorganic manure recorded lower yield in French bean production (Pooja et al., 2022; Sachan and Krishna, 2021, Paul et al., 2017, Das et al., 2014). Across the globe, reports show acid soil amelioration with vermicompost improved soil fertility because of the formation of soil Fe/Al- organic complex which reduced metal ion activity and toxicity (Lehmann and Kleber, 2015, Sharma et al., 2018). Basic cations become low or unavailable to crops in acid soil and lime application makes it available for crop uptake at the time of plant growth metabolism (Dahal et al., 2019, Bhindhu et al., 2018, Behera and Shukla, 2015) and increase crop yield in acid soils (Barman et al., 2014). Both vermicompost and lime play different roles in improving the soil's chemical and physical properties in acid soil (Ray et al., 2021, Bekele et al., 2018).

Soil acidity adversely limits the optimum and sustainable production of French bean crops (Kumar et al*.,* 2021). As acid soil is associated with poverty most tribal farmers of Arunachal Pradesh are marginal farmers who barely choose vegetable crop due to low production under rainfed condition. Hence the state needs rapid growth for achieving self-reliance on vegetable crops. Therefore, in the current experiment vermicompost and/or lime along with inorganic fertilizer was applied to French Beans to study the effect of soil acidity amelioration on soil properties, the effect of soil acidity amelioration on yield, and the relation of soil acidity and soil properties with yield.

2. Materials and Methods

2.1. Study area and field experiment with experimental design

The three-year study was undertaken during 2018–2021 at Research Farm, Basar, ICAR RC for NEH Region, Arunachal Pradesh Center, Indialocated at 27°59.53' N and 94°41.27' Eat an altitude of 616 m amsl (Chandra et al., 2022).The study area is located under Sub-tropical Hill Zone under Thermic Per-humid Mid-hills and Valleys (Chandra et al., 2022). The soil order falls under Ultisol and Alfisol (Maji et al., 2001). The region receives 2467 mm average annual rainfall with minimum and maximum temperature15.9°C and 24.2°C. As per the data recorded in Agromet Observatory, ICAR-RC NEH, Arunachal Pradesh Centre, during three-year study the average rainfall, max temperature and minimum temperature received during cropping seasons were 55.7 mm, 9.82°C and 22.7°C during 2018–21, respectively (Table 1). Initial soil parameters data is given in Table 2.

French bean cultivar (selection-9) was grownin the second week of October during*rabi* season (October–January) in 2018, 2019 and 2020. The seed rate was 70 kg ha^{-1} and the spacing maintained was 30×30 cm^2. Soil acidity amendments (inorganic and organic) along with nutrient levelsweretreated on prepared beds, viz. control, vermicompost (Vc), vermicompost+lime (Vc+lime), 50% Recommended dose of fertilizer (RDF), 50% RDF+lime, 50% RDF+Vc, 75% RDF, 75% RDF+lime, 75% RDF+Vc, 100% RDF laid in Randomized Block Design (RBD) withthree replication. Lime at 400 kg $ha^{-1}$and decomposed vermicompostat 2.5 t ha^{-1} was applied in rows before sowing of seeds. The details of vermicompost are given in Table 3. The recommended dose of fertilizer (50:50:50 NPK kg ha^{-1}) was supplied from urea, sSngleSuper Phosphate (SSP), and Murate of Potash (MOP).A complete dose of phosphorous and potassium and half dose of nitrogen were applied before sowing in a row as initial basal dressing.Another half dose of nitrogen was applied twenty-two days after sowing (DOS) during hoeing as per the treatment schedule.

Table 1: Weather data of three cropping seasons from October–January (2018–2021)

Year	Mean Temperature (°C)		Mean Relative humidity (%)		Total Rainfall (mm)
	Maximum	Minimum	RH1	RH2	
2018–19	22.4	9.02	98.6	61.3	47.8
2019–20	22.4	10.3	98.2	66.2	68.7
2020–21	23.3	10.4	97.8	66.2	50.8

Table 2: Initial soil properties of experimental plot

Sl.No.	Initial soil properties	Values
1.	pH(1:2.5)	4.94
2.	EC(1:2.5) ds m^{-1}	0.11
3.	Ex Acidity (cmol (p+) kg^{-1})	2.12
4.	Ex. Al (cmol (p+) kg^{-1})	1.97
5.	Total Acidity (cmol (p+) kg^{-1})	4.09
6.	Soil Organic Carbon (%)	0.45
7.	CEC (cmol (p+) kg^{-1})	6.40
8.	Soil Base Saturation (%)	22.1
9.	Soil Moisture (%)	13.0
10.	Soil BD (gcc^{-1})	1.36
11.	Soil Available N (kg ha^{-1})	219
12.	Soil Available P (kg ha^{-1})	22.8
13.	Soil Available K (kg ha^{-1})	230
14.	Soil Available S (ppm)	14.1
15.	DTPA extractable Fe (ppm)	17.9
16.	DTPA extractable Mn (ppm)	3.19
17.	DTPA extractable Zn (ppm)	0.72
18.	DTPA extractable Cu (ppm)	0.49

Table 3: Details of vermicompost

Sl.No.	Detail of vermicompost	Values
1.	OC (%)	9.8–13.4
2.	Moisture (%)	38.0
3.	Nitrogen (%)	0.51–1.61
4.	Phosphorus (%)	0.19–1.02
5.	Potassium (%)	0.15–0.73
6.	Calcium (%)	1.18–7.61
7.	Magnesium (%)	0.09–0.56
8.	Sodium (%)	0.05–0.15
9.	Zinc (%)	0.004–0.11
10.	Copper (%)	0.002–0.004
11.	Iron (%)	0.20–1.33
12.	Manganese (%)	0.01–0.20

2.2. Collection and analysis of soil sample

The yield of French bean was determined after four plucking at harvest. Soil samples were collected from two soil depthsof 0–15 cm and 15–30 cmatharvest of a crop and passed through 2mm mesh screenand stored for analysis of soilacidity, soil chemical and physical parameters. Soil exchangeable (Ex.) acidity and Ex. Al in soil was determined by the method described by Mclean (1965). The soil pH, CEC, organic carbon, base saturation, moisture content, bulk density, soil available N, soil available P, soil available K, soil available S and soil available micro-nutrient (Fe, Mn, Zn and Cu) properties were determined by pH meter, neutral normal ammonium acetate, Walkley and Black wet digestion, base cations calculation, gravimetric, core sampler, 0.32% Alkaline $KMnO_4$, Bray's P-1 reagent, Nuetral N NH_4OAc, turbidometric and DTPA-Tea extraction methods given by Singh et al. (2005).

2.3. Statistical analysis

Randomized block design one factor analysis of variance (ANOVA) method was conducted to evaluate the effects of soil acidity amendments along with nutrient level treatments on yield, soil acidity and soil properties. Tukey'sstudentized range test was conducted to indicate between-group differences at $p<0.05$ significance. Simple correlation analysis was carried out to show the relationships of yield with soil acidity and soil properties at $p<0.01$ significance. The statistical analysis was performed using SAS9.1.

3. Results and Discussion

3.1. Soil acidity parameter (pH, Ex. AL, Ex. Acidity)

Soil acidity amendments (organic and inorganic) along with nutrientlevels is afeasible approach for enhancing soil productivity and sustainability.The different combinationsof soil acidity amendments with nutrient-level treatments had a significant effect on soil acidity parameters (Table 4). Soil pH recorded maximum in 75% RDF+lime (5.21) followed by 50% RDF+lime, 75% RDF+Vc, 50% RDF+Vc, and 100% RDF and minimum in control at both soil depths. From control to 75% RDF+limesoil pH increasedby 3.78% and 3.57% at 0–15 and 15–30 cm soil depth due tothe neutralization of H^+ by lime (Dahal et al., 2019, Bhindhu et al., 2018, Bekele et al., 2018) and hydrolysis reaction of fertilizer (Curtin et al., 2020) and ion uptake by plants (Purbasha et al., 2017). The contemporary report revealed application of lime to acid soils increased Ca^{2+} and/or Mg^{2+} ions and reduced Al^{3+}, H^+, Mn^{2+}, and Fe^{2+} ions in the soil solution (Kisinyo et al., 2014, Vaide et al., 2011). Along the soil profile soil pH decreaseas root density decreases which reduces the ion uptake (Purbasha et al., 2017) (Table 4). Soil Ex. Al, Ex. acidity and total acidity significantly recorded minimum in the combined application oflime with fertilizer treatment (75% RDF) followed by combined application of vermicompost with fertilizer treatment (75% RDF) and minimum in control at both soil depth (Table 4). The reduction in soil acidity parameter is because of hydroxylions production from lime hydrolysis reaction which reacts with Al^{3+}, $Fe^{2/3+}$ and H^+ (Bekele et al., 2018), and, the formation of organic-metal ion bonds from the dissolution of organic compoundsin vermicompost (Ray et al., 2021, Vaide et al., 2011). The result indicates that lime combined with 75% RDF is a better approach to reducing soil acidity.

3.2. Soil chemical and physical parameters

The combined application of soil acidity amendment (lime and/or vermicompost) along with nutrient level treatments had a significant effect on changes in soil chemical (SOC, CEC, Base saturation) and physical (bulk density and moisture content) properties (Table 5). The result shows soil organic carbon (SOC) recorded maximum in 75% RDF+Vc (1.02 and 0.86%) followed by 100% RDF, 75% RDF+lime, 50% RDF+Vc, 75% RDF, 50% RDF+lime, Vc+lime, 50% RDF, Vc and control (Table 5). Soil CEC and base saturation also recorded maximum in 75% RDF+Vc (7.04 and 7.10 cmol (p^+) kg^{-1}, 30.7 and 26.3%) at 0–15 and 15–30 cm soil depth, respectively. Application of vermicompost along with 75% RDF increased the SOC, CEC and BS from control by a magnitude of 42.7 and 49.8%, 10.6 and 11.1%, and 32.3 and 32.1% at 0–15 and 15–30 cm soil depth. Along the depth, SOC and base saturation decreased while soil CEC increased. The high SOC in 75% RDF along with vermicompost might be due to the association of organic molecules with soil minerals which reduces organic matter mineralization rates (Possinger et al., 2020, Varadachari et al., 2000). The high CEC in vermicompost and Ca^{2+}/Mg^{2+} cation released from limecaused a rise in soil pH which contributed to the increase in soil CEC and base saturation in the 75% RDF application along with vermicompost and lime, compared to sole fertilizer or vermicompost or lime application (Kumar et al., 2021, Bhindhu et al., 2019, Ray et al., 2021, Pubasha et al., 2018, Vaide et al., 2011). Soil moisture content recorded maximum in 75%RDF+Vc followed by 100% RDF, 75% RDF+lime, 50% RDF+Vc, 75% RDF, 50% RDF+Vc, Vc+lime, 50%

Table 4: Effect of acid soil amelioration with lime, vermicompost and fertilizer on the soil acidity parameters

Treatments \ Soil Depths	Soil pH (1:2.5)		Soil EC (1:2.5) (ds m^{-1})		Soil Ex. acidity (cmol (p+) kg^{-1})		Soil Ex. Al (cmol (p+) kg^{-1})		Soil total acidity (cmol (p+) kg^{-1})	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Control	5.02±0.007^{g}	5.04±0.010^{g}	0.12±0.001^{j}	0.11±0.001^{j}	2.17±0.001^{a}	1.77±0.01^{a}	0.80±0.005^{a}	0.79±0.005^{a}	2.98±0.006^{a}	2.57±0.02^{a}
VC	5.04±0.007^{f}	5.05±0.010^{f}	0.13±0.001^{i}	0.12±0.001^{i}	2.05±0.001^{b}	1.70±0.01^{b}	0.78±0.005^{b}	0.78±0.005^{b}	2.84±0.006^{b}	2.48±0.02^{b}
VC+LIME	5.07±0.007^{e}	5.08±0.010^{e}	0.13±0.001^{h}	0.12±0.001^{h}	1.86±0.001^{c}	1.54±0.01^{c}	0.75±0.005^{c}	0.75±0.005^{c}	2.62±0.006^{c}	2.29±0.02^{c}
50% RDF	5.06±0.007^{d}	5.17±0.010^{d}	0.13±0.001^{g}	0.12±0.001^{g}	1.78±0.001^{d}	1.47±0.01^{d}	0.76±0.005^{c}	0.73±0.005^{c}	2.54±0.006^{d}	2.21±0.02^{d}
50% RDF+LIME	5.16±0.007^{c}	5.11±0.010^{c}	0.13±0.001^{f}	0.12±0.001^{f}	1.60±0.001^{g}	1.32±0.01^{g}	0.62±0.004^{e}	0.60±0.004^{e}	2.23±0.005^{h}	1.93±0.02^{h}
50%RDF+VC	5.14±0.007^{c}	5.15±0.010^{c}	0.14±0.001^{e}	0.13±0.001^{e}	1.69±0.001^{f}	1.40±0.01^{f}	0.59±0.004^{f}	0.57±0.004^{f}	2.29±0.005^{g}	1.97±0.02^{g}
75% RDF	5.11±0.007^{d}	5.12±0.010^{d}	0.15±0.001^{d}	0.14±0.001^{d}	1.74±0.001^{e}	1.44±0.01^{e}	0.62±0.004^{e}	0.60±0.004^{e}	2.37±0.005^{f}	2.04±0.02^{f}
75% RDF+LIME	5.21±0.007^{a}	5.22±0.010^{a}	0.14±0.001^{c}	0.13±0.001^{c}	1.53±0.001^{i}	1.26±0.01^{i}	0.47±0.003^{h}	0.45±0.003^{h}	2.00±0.004^{j}	1.72±0.01^{j}
75%RDF+VC	5.18±0.007^{b}	5.19±0.010^{b}	0.15±0.001^{b}	0.14±0.001^{b}	1.56±0.001^{h}	1.29±0.01^{h}	0.50±0.003^{g}	0.48±0.003^{g}	2.07±0.004^{i}	1.78±0.02^{i}
100% RDF	5.10±0.007^{e}	5.07±0.010^{e}	0.15±0.001^{a}	0.14±0.001^{a}	1.79±0.001^{d}	1.48±0.01^{d}	0.65±0.004^{d}	0.62±0.004^{d}	2.44±0.005^{e}	2.11±0.02^{e}

*The treatment details are 100% RDF is 50-50-50 kg NPK ha^{-1}, lime application in furrow is 0.4 t ha^{-1} and vermicompost application is 2.5 t ha^{-1}. The superscript in small letters indicates significance at 5% level among the treatments.*The data is pool of three years (2018–2021)

Table 5: Effect of acid soil amelioration with lime, vermicompost and fertilizer on the soil's chemical and physical properties

Treatments \ Soil Depth	Soil organic carbon (%)		Soil CEC (cmol (p+) kg^{-1})		Soil base saturation (%)		Soil bulk density (g cc^{-1})		Soil moisture (%)	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Control	0.702±0.004^{j}	0.642±0.004^{j}	6.36±0.025^{i}	6.39±0.025^{i}	23.2±0.16^{g}	19.9±0.19^{g}	1.36±0.013^{a}	1.37±0.008^{a}	13.5±0.07^{j}	14.5±0.07^{j}
VC	0.722±0.005^{i}	0.672±0.004^{i}	6.41±0.025^{h}	6.44±0.025^{h}	25.1±0.16^{f}	21.5±0.20^{f}	1.35±0.008^{a}	1.38±0.008^{a}	15.4±0.08^{i}	18.4±0.10^{i}
VC+LIME	0.772±0.005^{g}	0.722±0.005^{g}	6.55±0.026^{g}	6.58±0.026^{g}	27.2±0.17^{d}	23.3±0.22^{d}	1.32±0.007^{b}	1.34±0.008^{b}	20.9±0.11^{g}	24.0±0.13^{g}
50% RDF	0.742±0.005^{h}	0.682±0.004^{h}	6.43±0.025^{h}	6.46±0.025^{h}	25.9±0.17^{e}	22.2±0.21^{e}	1.34±0.008^{c}	1.36±0.008^{c}	18.1±0.09^{h}	19.4±0.10^{h}
50% RDF+LIME	0.802±0.005^{f}	0.762±0.005^{f}	6.66±0.026^{f}	6.69±0.026^{f}	27.3±0.18^{d}	23.4±0.22^{d}	1.30±0.007^{d}	1.32±0.007^{d}	24.2±0.13^{f}	27.1±0.14^{f}

Table 5: Continue...

Soil Depth / Treatments	Soil Organic Carbon (%)		Soil CEC (cmol (p+) kg^{-1})		Soil Base Saturation (%)		Soil Bulk Density (gcc^{-1})		Soil Moisture (%)	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
50%RDF+VC	0.852±0.005^{e}	0.812±0.005^{e}	6.78±0.027^{d}	6.81±0.027^{d}	27.2±0.17^{d}	23.3±0.22^{d}	1.21±0.007^{e}	1.23±0.007^{e}	29.4±0.16^{d}	31.7±0.17^{d}
75% RDF	0.872±0.006^{d}	0.822±0.005^{d}	6.73±0.027^{e}	6.76±0.027^{e}	25.9±0.17^{e}	22.3±0.21^{e}	1.28±0.007^{f}	1.30±0.007^{f}	26.7±0.14^{e}	27.7±0.15^{e}
75% RDF+LIME	0.922±0.006^{c}	0.862±0.006^{c}	6.88±0.027^{c}	6.90±0.027^{c}	28.5±0.18^{c}	24.4±0.23^{c}	1.24±0.007^{g}	1.26±0.007^{g}	30.7±0.16^{c}	33.4±0.18^{c}
75%RDF+VC	1.002±0.007^{a}	0.962±0.006^{a}	7.04±0.028^{a}	7.10±0.028^{a}	30.7±0.20^{a}	26.3±0.25^{a}	1.14±0.006^{i}	1.16±0.006^{i}	37.9±0.20^{a}	39.2±0.21^{a}
100% RDF	0.962±0.006^{b}	0.912±0.006^{b}	6.94±0.027^{b}	6.96±0.028^{b}	29.1±0.19^{b}	25.0±0.24^{b}	1.20±0.007^{h}	1.22±0.007^{h}	35.2±0.19^{b}	35.7±0.19^{b}

The treatment details are 100% RDF is 50-50-50 kg NPK ha^{-1}, lime application in-furrow is 0.4 t ha^{-1} and vermicompost application is 2.5 t ha^{-1}. The superscript in small letters indicates significance at 5% level among the treatments. *The data is the pool of three years (2018–2021)

RDF, Vc and control at both the soil depth. Soil bulk density recorded minimum in 75% RDF+Vc followed by 100% RDF, 50% RDF+Vc, 75% RDF+lime, 75% RDF, 50% RDF+lime, Vc+lime, 50% RDF, Vc and control at both the soil depth (Table 5). The attainment of high soil moisture content and low bulk density in vermicompost application along with 75% RDF attributes to higher SOC and CEC in the same treatment. This findingindicates that vermicompost along with 75% RDF treatment is a better conditioner compared to limealong with 75% RDF treatment in acid soil of Arunachal Pradesh (Bandyopadhyay et al., 2018).

3.3. *Soil available nutrients (N, P, K, S, Fe, Mn, Zn, Cu)*

The combined application of soil acidity amendment (lime and/or vermicompost) along with nutrient level treatments had a significant effect on the change in the soil available nutrients (Table 6). The soil available macro-nutrient (N, P, K and S) was recorded maximum in75% RDF+Vc followed by 100% RDF, 75% RDF+lime, 50% RDF+Vc, 75% RDF, 50% RDF+Vc, Vc+lime, 50% RDF, Vc and control at both the soil depth. Similarly, soil-available micro-nutrient (Fe, Mn, Zn and Cu) recorded maximum of75% RDF+Vc followed by 100% RDF, 75% RDF+lime, 50% RDF+Vc, 75% RDF, 50% RDF+Vc, Vc+lime, 50% RDF, Vc and control at both the soil depth with the exception inthe soil available Zn and Cu where 75% RDF+Vc was at par with 100% RDF at both soil depth. Along the depth, soil available nutrients observed a decreasing trend. Application of vermicompost along with fertilizer (75% RDF) increased soil available N, P, K and S from control by 20.0, 41.7, 17.3 and 42.9% and 19.5, 44.1, 17.0 and 34.1% at 0–15 and 15–30 cm depth, respectively. The magnitude of soil available Fe, Mn, Zn and Cu increasein vermicompost along with fertilizer (75% RDF) treatment from control was 16.0, 28.3, 28.5 and 24.9% and 26.7, 25.4, 27.5 and 25.0% magnitude at 0–15 and 15–30 cm soil depth, respectively. Compared to the sole application of fertilizer, vermicompost and lime, the application of vermicompost along with 75% RDF in acid soil had the highest soil available nutrients because of addition of nutrients from fertilizer and vermicompost decomposition (Adisu et al., 2019,Kadam and Pathade, 2014). Vermicompost consist of water-soluble nutrients (N, P, K, S, Ca, Mg, etc.) which is released into soil slowly (Adisu et al., 2019, Bekele et al., 2018, Lim et al., 2014, Kadam and Pathade, 2014). The lower soil available nutrients at lower surface soil (0–15 cm) compared to sub-surface soil (15–30 cm) might be due to higher SOC and CEC.

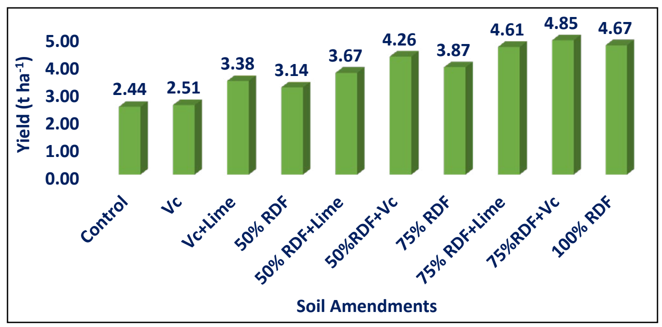

Figure 1: Effect of soil nutrient management on yield of French bean in acid soil of Arunachal Pradesh, India; *The data given are significant at 0.05 level of significance; *The treatment details are 100% RDF is 50-50-50 kg NPK ha^{-1}, lime application in furrow is 0.4 t ha^{-1} lime and vermicompost application is 2.5 t ha^{-1}; *The data is pool of three years (2018-2021)

3.4. *French bean yield*

The yield of French bean in vermicompost along with 75% RDF treatment (4.85 t ha^{-1}) was significantly higher than 100% RDF, 75% RDF+lime and control by 3.85, 5.20 and 98.7%. Compared to lime along with 75% RDF and sole vermicompost application,

Table 6: Effect of acid soil amelioration with lime, vermicompost and fertilizer on soil available macro and micro nutrients

Soil Depths / Treatment	Soil available N (kg ha^{-1})		Soil available P (kg ha^{-1})		Soil available K (kg ha^{-1})		Soil available S (ppm)	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Control	220±0.89^{j}	215±0.87^{j}	22.3±0.09^{i}	20.6±0.08^{i}	231±0.93^{j}	211± 0.85^{j}	14.2± 0.06^{j}	12.3± 0.05^{j}
Vc	226±0.91^{i}	222±0.89^{i}	24.0±0.09^{h}	23.0±0.09^{h}	233±0.94^{i}	224± 0.90^{i}	15.3± 0.06i	13.4± 0.05^{i}
Vc+Lime	237±0.95^{g}	232±0.93^{g}	27.9±0.11^{d}	27.1±0.10^{d}	238±0.96^{g}	231± 0.93^{g}	17.1± 0.07^{g}	14.3± 0.06^{g}
50% RDF	232±0.93^{h}	229±0.92^{h}	25.4±0.10^{g}	24.1±0.09^{g}	236±0.95^{h}	224± 0.90^{h}	16.9± 0.07^{h}	13.8± 0.06^{h}
50% RDF+Lime	240±0.97^{f}	234±0.94^{f}	26.5±0.10^{f}	25.4±0.10^{f}	242±0.97^{f}	232± 0.94^{f}	18.2± 0.07^{f}	14.7± 0.06^{f}
50% RDF+Vc	250±1.01^{d}	244±0.98^{d}	28.8±0.11^{c}	27.9±0.11^{c}	252±0.98^{d}	244± 0.98^{d}	20.7± 0.08^{c}	16.0± 0.06^{c}
75% RDF+Lime	254±1.02^{c}	247±0.99^{c}	29.0±0.11^{b}	28.1±0.11^{b}	255±1.03^{c}	247±1.00^{c}	19.9±0.08^{d}	16.5±0.07^{d}
75% RDF+Vc	264±1.06^{a}	257±1.03^{a}	31.6±0.12^{a}	29.7±0.12^{a}	271±1.09^{a}	257±1.04^{a}	20.3±0.08b	17.1±0.07^{b}
100% RDF	260±1.05^{b}	252±1.01^{b}	29.6±0.11^{c}	27.2±0.11^{c}	262±1.05^{b}	251±1.01^{b}	21.5±0.09a	16.9±0.07^{a}

Table 6: Continue...

Soil Depths / Treatment	Soil available Fe (ppm)		Soil available Mn (ppm)		Soil available Zn (ppm)		Soil available Cu (ppm)	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Control	18.1±0.07^{h}	16.1±0.06^{h}	3.21±0.01^{i}	3.18±0.01^{i}	0.70±0.003^{i}	0.69±0.003^{i}	0.497±0.002^{h}	0.496±0.002^{h}
Vc	18.3±0.07^{g}	17.4±0.07^{g}	3.33±0.01^{h}	3.30±0.01^{h}	0.73±0.003^{h}	0.72±0.003^{h}	0.542±0.002^{g}	0.542±0.002^{f}
Vc+Lime	18.5±0.07^{e}	18.0±0.07^{e}	3.63±0.01^{f}	3.60±0.01^{f}	0.77±0.003^{f}	0.77±0.003^{f}	0.553±0.002^{e}	0.551±0.002^{e}
50% RDF	18.4±0.07^{f}	17.7±0.07^{f}	3.49±0.01^{g}	3.46±0.01^{g}	0.75±0.003^{g}	0.74±0.003^{g}	0.546±0.002^{f}	0.545±0.002^{f}
50% RDF+Lime	18.7±0.08^{e}	18.0±0.07^{e}	3.69±0.01^{e}	3.66±0.01^{e}	0.78±0.003^{f}	0.76±0.003^{f}	0.556±0.002^{d}	0.554±0.002^{d}
50% RDF+Vc	19.1±0.08^{d}	18.3±0.07^{d}	3.77±0.02^{d}	3.70±0.01^{d}	0.83±0.003^{d}	0.81±0.003^{d}	0.560±0.002^{c}	0.558±0.002^{c}
75% RDF+Lime	19.3±0.08^{c}	18.3±0.07^{c}	3.85±0.02^{c}	3.78±0.02^{c}	0.85±0.003^{c}	0.83±0.003^{c}	0.563±0.002^{b}	0.561±0.002^{b}
75% RDF+Vc	21.0±0.08^{a}	20.4±0.08^{a}	4.12±0.02^{a}	3.99±0.02^{a}	0.90±0.004^{a}	0.88±0.004^{a}	0.621±0.003^{a}	0.620±0.003^{a}
100% RDF	19.5±0.08^{b}	18.5±0.08^{b}	3.96±0.02^{b}	3.81±0.02^{b}	0.87±0.004^{b}	0.85±0.003^{b}	0.565±0.002^{b}	0.564±0.002^{b}

The treatment details are 100% RDF is 50-50-50 kg NPK ha^{-1}, lime application in-furrow is 0.4 t ha^{-1} and vermicompost application is 2.5 t ha^{-1}. The superscript in small letters indicates significance at 5% level among the treatments.*The data is the pool of three years (2018–2021)

vermicompost along with 75%RDF treatment recorded higher yield which attributes to higher SOC, soil CEC and soil fertility in the same treatment that must have enhanced plant nutrient uptake (Kadam and Pathade, 2014). From the correlation (r) study, it is shown thatan increase SOC, soil CEC and soil fertility increasedthe yield of French beans in acid soil under rainfed conditions of Arunachal Pradesh. Reports have shown that the combined use of chemical fertilizer and organic manure (vermicompost) increased French bean crop productivity and profitability in the Northeast of India (Kumar et al., 2020, Kadam and Pathade, 2014).

3.5. Relationship of French bean yield with soil acidity and soil chemical and physical properties

The yield of French bean was significantly positively correlated with soil pH, EC, SOC, CEC, BS, soil moisture content, soil available nutrient (N, P, K, S, Fe, Mn, Zn and Cu) but negatively correlated with soil exchangeable acidity, soil exchangeable Al, total acidity and soil bulk density (Table 7). Therefore, soil conditioners like vermicompost and lime must be added along with fertilizer o obtain the optimum yield of French bean in acid soil.

Table 7: Simple correlation coefficient (r) of yield of French bean with soil properties in acid soil

Soil Properties	French bean yield	
	Soil depths	
	0–15 cm	15–30
pH (1:2.5)	0.97	0.65
EC (1:2.5) ds m^{-1}	0.87	0.86
Ex acidity (cmol (p+) kg^{-1})	-0.83	0.83
Ex. Al (cmol (p+) kg^{-1})	-0.85	0.90
Total Acidity (cmol (p+) kg^{-1})	-0.86	-0.88
OC (%)	0.97	0.96
CEC (cmol (p+) kg^{-1})	0.98	0.97
Base Saturation (%)	0.90	0.90
Soil Moisture (%)	0.98	0.98
BD (g cc^{-1})	-0.92	0.93
Soil available N (kg ha^{-1})	0.88	0.98
Soil available P (kg ha^{-1})	0.83	0.91
Soil available K (kg ha^{-1})	0.98	0.96
Soil available S (ppm)	0.96	0.97
DTPA extractable Fe (ppm)	0.96	0.89
DTPA extractable Mn (ppm)	0.87	0.96
DTPA extractable Zn (ppm)	0.95	0.97
DTPA extractable Cu (ppm)	0.95	0.79

*Correlation between the soil parameters and French bean yield is significant at 0.01 level of significance.*The data is the pool of three years (2018–2021)

4. Conclusion

This study demonstrated combined rates of vermicompost (2.5 t ha^{-1}), lime (400 kg ha^{-1}) and 75% RDF (50-50-50 kg ha^{-1} N-P-K) could ameliorate soil acidity and Al toxicity and improve soil fertility holding a promising alternative to amend acid soil for optimum French bean yield.

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