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Research Paper

Soil physico-chemical properties as affected by integrated use of blended fertilizer, cattle manure, vermicompost and mineral nitrogen and phosphorus in potato (*Solanum tubersoum*) in acidic soil of south-western Ethiopia

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ABSTRACT

A field experiment was conducted in *Belg* (February to May) and *Meher* (June to October) seasons of 2020 at Abelo kebele in Masha district of Ehiopia, to determine the effects of blended mineral NPSB fertilizer, cattle manure (CM), vermicompost (VC) and mineral NP on soil physico-chemical properties with a view to generate new data and extend community service to farmers. The fertilizer treatments consisted of 7.5 t CM/ha combined with 75% and 50% of recommended dose of NP fertilizers (RDF), 7.5 t VC/ha combined with 75, 50 and 25% of NP, 5 t VC/ha combined with 75% NP, 100 kg NPSB/ha + 61.5 kg P/ha + 146 kg N/ha, 150 kg NPSB + 53.7 kg P/ha + 138 kg N/ha, 200 kg NPSB + 46 kg P/ha + 128 kg N /ha, 100% of NP (165 kg N/ha+60 kg P/ha) and no-fertilizer treatment (control), making a total of 11 treatments. The experiment was laid out in a randomized complete-block design with 3 replications. Results indicated that the application of 75% of NP (124 kg/ha + 45 kg P/ha) combined with 7.5 t/ha VC significantly increased the soil *p*H (6 and 7.29%), organic carbon (62.3 and 119%), total N (85 and 135%), available P (64.72 and 62.66%), cation-exchange capacity (CEC) (16.5 and 31.92%), exchangeable Ca^{+2} (16.3 and 18.25%), exchangeable Mg^{+2} (19.8 and 141.42%), exchangeable K^{+} (7.14 and 18.33%) and reduced the bulk density (7.87 and 9.52%), exchangeable acidity (368 and 455%), exchangeable aluminum (377 and 249%) in *Belg* and *Meher* seasons, respectively. Thus, the use of 7.5 t VC/ha combined with 75% of mineral nitrogen (124 kg N/ha + 45 kg P/ha) could significantly enhance the soil physico-chemical properties of acidic soil over sole application of either 200% mineral NPSB or 150% mineral NPSB or 100% NP or control treatment.

Key words : Blended fertilizer, Cattle manure, Soil chemical properties, Soil physical properties, Vermicompost

In Ethiopia, potato is an important staple food crop, which is grown in 4 major areas such as the central, eastern, north-western and southern parts of the country and these areas together cover approximately 83% of the potato farmers (CSA, 2017). However, with rapid population growth, fallow periods practiced in south-western Ethiopia are replaced by continuous and intensive cropping without restoration of the soil fertility that has depleted the nutrient base of most soils. Soil-fertility replenishment has, therefore, been singled out as the necessary option for potato production (Isreal *et al.*, 2016). Hence, to realize this, soil-fertility-replenishment strategy that has the potential not only to supply nutrients but also can arrest the mining of soil fertility is preferable. Thus, there is a need to take measures to reverse this trend.

In view of decreased use of organic matter like crop residues and cattle manure, there is a great increase in nutrient depletion as organic manure is a key component of the soil and crop yield because it carries out many functions in agro-ecosystem (Zhu *et al.,* 2018). Further, along with NPK, sulfur and boron are also essential nutrients for plant growth, quality and yield of potato tubers that accumulate to the tune of 0.2 to 0.5% in plant tissue (Epstein and Bloom, 2005). Potato is considered as a heavy-nutrient requiring crop. Integrated plant-nutrient management with efficient recycling of organic materials such as animal manure in combination with mineral fertilizers is one of the options to enhance potato productivity. The integration of organic and synthetic sources of nutrients not only supplies the essential nutrients but also has some positive synergistic relations leading to increased crop yield and improved soil physical and chemical properties.

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The fertilizer use in potato production in the country in general and the study area, in particular, is also below the recommended rates (165 kg N/ha and 60 kg P/ha). The situation is compounded by the low soil *p*H which in most cases results in low soil fertility. In view of this fact, identifying the optimum dose of integrated nutrients application is crucial and is required for maintaining a sufficient amount of nutrients in the soil for increased yield of the crop. Therefore, a study was carried out to determine the effect of combined application of cattle manure and vermicompost with blended nitrogen, phosphorus, sulphur and boron (NPSB) and mineral NP fertilizers on selected soil physico-chemical properties in acidic soil of southwestern Ethiopia, with a view to generate new data on fertilizer-use management and to extend community services to farmers as well.

MATERIALS AND METHODS

The experiment was conducted on farmer's field at Abelo kebele (7º44'1714" N' and 35º30'16" E') during 2020 *Belg* (February to May) and *Meher* (June to October) cropping seasons. The rainfall pattern of the area is characterized by biomodal distribution with the small rainy season in *Belg* and the main rainy season in Meher. Urea (46% N), triple superphosphate (20% P) and NPSB (18.1% N, 15.7% P, 6.7% S, 0.71% B) blended fertilizer were used as inorganic fertilizers. whereas cattle manure (CM) and vermicompost (VC) were used as organic fertilizer. Improved potato variety 'Belete' was used as a test crop.

Treatment combinations were consisted of no fertilizer (control) (T_1), 165 kg N/ha + 60 kg P/ha (T_2), 100 kg NPSB/ha + 61.5 kg P/ha + 146 kg N/ha (T_3), 150 kg NPSB/ha + 53.7 kg P/ha + 138 kg N/ha (T_4), 200 kg NPSB/ha + 46 kg P/ha + 128 kg N /ha (T_5), 124 kg N/ha + 45 kg P/ha + 5 t vermicompost/ha (T_6), 82.5 kg N/ha + 30 kg P/ha +7.5 t cattle manure/ha (T_7), 41.25 kg N/ha + 15 kg P/ha + 7.5 t vermicompost/ha (T_8), 124 kg N/ha + 45 kg P/ha + 7.5 t cattle manure/ha (T_9), 82.5 kg N/ha + 30 kg P/ha + 7.5 t vermicompost/ha (T_{10}) and 124 kg N/ha + 45 kg P/ha + 7.5. t vermicompost/ha (T_{11}). Where 61.5 kg P /ha and 146 kg N/ha, 53.7 kg P /ha and 138 kg N/ha, 46 kg P/ha and 128 kg N/ha were added respectively to the blended fertilizer as triple superphosphate for 100 kg NPSB/ha, 150 kg NPSB /ha and 200 kg NPSB/ha in order to bring the macronutrients of blended fertilizer equal to the recommended N and P.

Soil samples were analysed for selected physico-chemical properties. Micronutrients (Fe, Mn, Cu and Zn) were extracted from the soil samples with DTPA. Soil data were subjected to ANOVA using SAS software program version 9.2. Homogeneity of variances was calculated using the F-test and since the F-test had shown heterogeneity of the variances of the 2 seasons for post-harvest soil parameters, a separate analysis was used for the 2 seasons. The least significant difference (LSD) test at $P<0.05$ probability level was employed to separate treatment means where significant treatment differences occurred.

RESULTS AND DISCUSSION

Soil physico-chemical properties before planting of potato

The results of the initial soil test showed that, the bulk density (BD) was 1.37 g/cm^3 in *Belg* and 1.38 g/cm^3 in *Meher* season and particle density (PD) was 2.58 g/cm^3 in *Belg* and 2.60 g/cm^3 in *Meher*, while total porosity was 46.80% in *Belg* and 46.92% in *Meher* (Table 1). The total porosity of such magnitudes is classified as high according to the rating of Hillel (2004) which could be due to continuous cultivation causing disintegration of the soil structure and exposure of surface soil to the direct raindrops. Thus, the soil was good for optimum movement of air and water through it and there seemed no problem on tuber growth and expansion in the soil. Soil particle size analysis showed that the texture of soil was sandy clay loam having 57% sand, 18% silt and 25% clay in *Belg*, and 56% sand, 16% silt and 28% clay in Meher seasons.

The soil at the site was acidic with *p*H of 5.01 (strongly acidic) in *Belg* and 4.8 (very strongly acidic) in Meher season. The low status of organic carbon of 12 g/kg in *Belg* and 10.2 g/kg in *Meher* seasons was recorded. The C : N ratio both in *Belg* and *Meher* seasons indicate that there is net mineralization of applied cattle manure and vermicompost. The available phosphorus was also low, being (5.5 ppm) in the soil of *Belg* and 5 ppm in *Meher* seasons. This could be due to the poor management of crop residues, poor land-management practices, slash-and-burn agricultural systems, low soil organic matter, high soil erosion, low inherent fertility of soil and fixation of phosphorus in acidic soil, resulting in nutrient reduction and the decline in overall soil fertility. Thus, the added organic and mineral fertilizers were expected to show positive effect on both the crop and the soil. Low status of total N content of 1.0 and 0.8 g /kg soil in Belg and Meher seasons, respectively, could possibly be due to either low initial organic matter content of the soil which contributes about 90–95% of soil nitrogen or leaching of nitrate by torrential rainfall prevalent in the experimental areas (Ahmad and Arshad, 2015). The soil analysis also revealed that, in both seasons the cation-exchange capacity (CEC) values of 20 $cmol_{(+)}$/kg soil in *Belg* and 19.3 $cmol_{(+)}$/kg soil in *Meher* seasons were medium in status. The soil had also relatively medium exchangeable calcium (6.5 $cmol_{(+)}$/kg soil) in *Belg* and 6.3 $cmol_{(+)}$/kg soil in *Meher*; moderate in exchangeable magnesium (2.1 $cmol_{(+)}$/kg soil) in *Belg* and (1.4 $cmol_{(+)}$/kg soil) in *Meher*. High content of exchangeable acidity (3.83 cmol$_{(+)}$/kg soil) in *Belg* and 3.82 cmol$_{(+)}$/kg soil in *Meher* and exchangeable aluminum (2.01 cmol$_{(+)}$/kg soil) in *Belg* and (2.46 cmol$_{(+)}$/kg soil) in *Meher* season were recorded. High concentration was 6 mg/kg soil of micronutrient cations Cu in *Belg* and 8 mg/kg soil in *Meher;* of Fe 80 mg/kg soil in *Belg* and 120 mg/kg soil in *Meher*, and of Zn 1.2 mg/kg soil in *Belg* and 1.5 mg/kg soil in *Meher* seasons and of Mn 20 mg/kg soil in *Belg* and 25 mg/kg soil in *Meher* due to increased availability at low *p*H with cations being less strongly bound to the soil and readily exchangeable.

Soil physical properties after harvesting of potato

Fertilizer treatments had highly significant (P<0.01) effect on the bulk density of soil both in Belg and Meher seasons, but the effect was non-significant on the total porosity of soil in both seasons (Table 2). The lowest bulk density (1.27 g/cm^3) was recorded due to the application of 7.5 t VC/ha in combination with 75% mineral NP, while the highest bulk density (1.44 g/cm^3) was obtained from the control plots in Belg. Similarly, the lowest bulk density (1.27 g/cm^3) in Belg was obtained with the application of 7.5 t VC/ha in combination with 75% and 50% mineral NP. On the other hand, the highest bulk density (1.38 g/cm^3) was observed in the control treatment followed by 1.32 g/cm^3 from the application of 100% of the recommended rate of NP fertilizers. The low bulk density of plots supplied 7.5 t VC/ha was owing to the availability of organic matter to the soil at a proper time and in proper proportions.

Incorporation of vermicompost increased the dissolved organic carbon, surface area, water-holding capacity and field capacity which, in turn, decreased the bulk density of the soil. These results corroborate the findings of Xiao *et al.* (2018), who reported increase in dissolved organic carbon from 26.12 mg/kg soil of forest land to 52.55 mg/kg soils of rice which reduced bulk density of forest land from 1.73 to 1.62 g/cm^3. These advantages were secured owing to improvement in soil organic matter and water-holding capacity with a concomitant decrease in bulk density and increase in infiltration rate of water. Our results confirm with the findings of Khan *et al.* (2010), who also reported that application of 30 t VC/ha and 60 kg P/ha showed advantages in improving the soil organic matter by 5% and water-holding capacity by 23% with a concomitant decrease in bulk density by 8% and increase in infiltration rate of water by 15% as compared to control treatment.

Soil chemical properties after harvesting of potato

Soil pH, exchangeable acidity and exchangeable aluminum:

The fertilizer management had highly significant (P<0.01) effect on *p*H, exchangeable acidity and exchangeable aluminum in both the seasons (Table 3). The highest soil *p*H of 5.6 in *Belg* and 5.5 in *Meher* season were obtained at 7.5 t VC/ha used in combination with 75% of mineral NP, which was at par with those of 50% NP + 7.5 t vermicompost/ha in *Belg* season and 200 kg NPSB/ha +

Table 1. Selected physico-chemical properties of topsoil of experimental site before planting of potato.

Soil parameters	*Belg* value	*Meher* value	References	Soil parameters	*Belg* value	*Meher* value	References
Sand	5 7%	56%		*p*H	5.01	4.8	
Silt	1 8%	16%		OC (g /kg)	12	10.2	
Clay	2 5%	28%		N (g /kg)	1	0.8	
Textural class	Sandy clay loam	Sandy clay loam		C : N	12	12.75	Hazelton and Murphy (2007)
BD (g/cm^3)	1.37	1.38	Baruah and Barthakur (1997)	Available P (ppm)	5.5	5.0	Jones and Benton (2003)
PD (g/cm^3)	2.58	2.6	Baruah and Barthakur (1997)	CEC	20	19.3	Hazelton and Murphy (2007)
Total porosity (%)	46.80	46.92	Hillel (2004)				
Exchangeable Mg^{+2}	2.1	1.4	FAO (2006)				
Exchangeable K^+	0.42	0.36	FAO (2006)				
Exchangeable Ca^{+2}	6.5	6.3	FAO (2006)				
Exchangeable Al^{+3}	2.01	2.46	Hazelton and Murphy (2007)				
Exchangeable acidity	3.82	3.83	Hazelton and Murphy (2007))				
Cu (DTPA)	6	8	Jones and Benton (2003)				
Fe (DTPA)	80	120	Jones and Benton (2003)				
Zn (DTPA)	1.2	1.5	Jones and Benton (2003)				
Mn (DTPA)	20	25	Jones and Benton (2003)				

cmol$_{(+)}$/kg soil unit for cation-exchange capacity (CEC), exchangeable Ca^{+2}, exchangeable Mg^{+2}, exchangeable K^+, exchangeable Al^{+3} exchangeable acidity; mg/kg soil unit for Cu, Fe, Zn and Mn; DTPA, diethylene triaminepenta acetic acid

46 kg P/ha + 128 kg N/ha, 75% NP + 5 t vermicompost/ha, 50% NP + 7.5 t cattle manure/ha, 25% NP + 7.5 t vermicompost/ha, 75% NP + 7.5 t cattle manure/ha and 50% NP + 7.5 t vermicompost/ha in *Meher* season. The lowest values of soil *p*H of 4.98 in *Belg* and 5.15 in Meher were recorded under control which were statistically at par with that of 100% NP (165 kg /ha + 60 kg P/ha) in *Belg* and those of 100% NP (165 kg N/ha + 60 kg P/ha), 100 kg NPSB/ha + 61.5 kg P/ha + 146 kg N/ha and 150 kg NPSB/ ha + 53.7 kg P/ha + 138 kg N/ha in Meher season. This might be so, because vermicompost is a potential source of basic cations and that particularly cause an effect opposite to that of the chemical fertilizers and hence, tend to maintain the soil *p*H by bringing a balance between acidic and basic cations released. Vinod *et al.* (2018) reported that, the application of 100% NPK/ha+ 100% vermicompost/ha increased the soil *p*H from 7.1 to 7.4 in the control treatment. The highest exchangeable acidity of 3.16 $cmol_{(+)}$/kg soil in *Belg* and 2.82 $cmol_{(+)}$/kg soil in Meher season were recorded for no-fertilizer treatment (control). These values were in statistical at par with those obtained at 100% NP (165 kg N/ha + 60 kg P/ha), 100 kg NPSB/ha + 61.5 kg P/ ha + 146 kg N/ha and 150 kg NPSB/ha + 53.7 kg P/ha + 138 kg N/ha in *Belg* and *Meher* seasons both, while the

Table 2. Effect of blended NPSB, cattle manure, vermicompost and mineral NP on bulk density (BD) (g/cm^3), particle density (PD) (g/cm^3) and total porosity (TP) (%) of soil after potato harvesting in *Belg* and *Meher* seasons.

Treatment	Belg season			Meher season		
	BD	PD	TP	BD	PD	TP
No fertilizer (control)	1.44^{a}	2.78	48.26^{f}	1.38^{a}	2.62	47.11^{g}
100% NP	1.42^{ab}	2.76	48.61^{ef}	1.37^{ab}	2.62	47.61^{fg}
100 kg NPSB/ha + adjusted NP	1.41^{ab}	2.75	48.67^{ef}	1.37^{b}	2.62	47.85^{fg}
150 kg NPSB/ha + adjusted NP	1.40^{ab}	2.73	48.8^{def}	1.36^{b}	2.64	48.35^{ef}
200 kg NPSB/ha + adjusted NP	1.39^{abc}	2.69	48.41^{f}	1.35^{c}	2.64	48.95^{de}
50% NP + 5 t VC/ha	1.37^{bcd}	2.71	49.34^{cdef}	1.35^{c}	2.66	49.33^{de}
50% NP + 7.5 t CM/ha	1.35^{cde}	2.70	49.94^{bcde}	1.33^{d}	2.66	49.88^{cd}
25% NP + 7.5 t VC/ha	1.33^{de}	2.68	50.20^{bcd}	1.31^{e}	2.66	50.6^{bc}
75% NP + 7.5 t CM/ha	1.32^{ef}	2.67	50.77^{abc}	1.30^{ef}	2.66	51.07^{b}
50% NP + 7.5 t VC/ha	1.28^{fg}	2.62	51.22^{ab}	1.29^{f}	2.66	51.53^{ab}
75% NP + 7.5 t VC/ha	1.27^{g}	2.65	52.17^{a}	1.26^{g}	2.66	52.43^{a}
SEm±						
CD (P=0.05)	0.047	NS	1.466	0.013	NS	1.048

Means followed by the same letter within a column are non-significantly (P>0.05); VC, vermicompost; CM, cattle manure, 61.5 kg P/ha + 146 kg N/ha adjusted NP for 100 kg NPSB/ha; 53.7 kg P/ha + 138 kg N/ha adjusted NP for 150 kg NPSB/ha; 46 kg P/ha + 128 kg N/ha adjusted NP for 200 kg NPSB/ha; NS, non-significant

Table 3. Soil pH, exchangeable acidity (Ea $cmol_{(+)}$/kg soil) and exchangeable aluminum (Eal $cmol_{(+)}$ /kg soil) of soil after potato harvesting as influenced by use of mineral NPSB, cattle manure, vermicompost and mineral NP in Belg and Meher seasons.

Treatment	Belg season			Meher season		
	*p*H	Ea	Eal	*p*H	Ea	Eal
No fertilizer (control)	4.98^{h}	3.16^{a}	2.25^{a}	4.98^{h}	2.82^{a}	2.12^{a}
100% NP	4.99^{gh}	2.84^{ab}	2.14^{a}	4.99^{gh}	2.40^{a}	1.90^{a}
100 kg NPSB/ha + adjusted NP	5.01^{fgh}	2.42^{ab}	1.92^{a}	5.01^{fgh}	2.26^{a}	1.88^{a}
150 kg NPSB/ha + adjusted NP	5.50^{ef}	2.28^{ab}	1.90^{a}	5.03^{efg}	2.19^{a}	1.83^{a}
200 kg NPSB/ha + adjusted NP	5.51^{ef}	2.21^{b}	1.85^{a}	5.04^{ef}	0.94^{b}	0.72^{b}
50% NP + 5 t VC/ha	5.52^{de}	0.95^{c}	0.72^{b}	5.05^{de}	0.92^{b}	0.68^{b}
50% NP + 7.5 t CM/ha	5.53^{bcd}	0.92^{c}	0.69^{b}	5.06^{cde}	0.86^{b}	0.61^{b}
75% NP + 5 t VC/ha	5.55^{bcd}	0.87^{c}	0.62^{b}	5.08^{bcd}	0.81^{b}	0.44^{b}
75% NP + 7.5 t CM/ha	5.55^{cd}	0.82^{c}	0.44^{b}	5.10^{ab}	0.80^{b}	0.43^{b}
50% NP + 7.5 t VC/ha	5.56^{ab}	0.95^{c}	0.44^{b}	5.10^{ab}	0.767^{b}	0.41^{b}
75% NP + 7.5 t VC/ha	5.60^{a}	0.82^{c}	0.42^{b}	5.13^{a}	0.69^{b}	0.70^{b}
SEm±						
CD (P=0.05%)	0.04	0.855	0.739	0.037	0.743	0.714

Means followed by the same letter within a column are non-significantly different (P>0.05); VC, vermicompost; CM, cattle manure, 61.5 kg P/ha + 146 kg N/ha adjusted NP for 100 kg NPSB/ha; 53.7 kg P/ha + 138 kg N/ha adjusted NP for 150 kg NPSB/ha; 46 kg P/ha + 128 kg N/ha adjusted NP for 200 kg NPSB/ha lowest exchangeable acidity values of 0.82 $cmol_{(+)}$/kg soil in Belg and of 0.69 $cmol_{(+)}$/kg soil in Meher seasons were recorded at 7.5 t VC/ha used in combination with 75% of mineral NP, which were statistically similar to those recorded at 50% NP + 7.5 t/ha vermicompost, 75% NP + 7.5 t/ha cattle manure, 25% NP + 7.5 t/ha vermicompost, 50% NP + 7.5 t/ha cattle manure and 75% NP + 5 t/ha vermicompost in Belg and 50% NP + 7.5 t/ha vermicompost, 75% NP + 7.5 t/ha cattle manure, 25% NP + 7.5 t/ha vermicompost, 50% NP + 7.5 t/ha cattle manure, 75% NP + 5 t/ha vermicompost and 200 kg NPSB/ha + 46 kg P/ha + 128 kg N/ha in Meher season. The highest exchangeable aluminum of 2.25 $cmol_{(+)}$/kg soil in Belg and of 2.12 $cmol_{(+)}$/kg soil in Meher season was obtained in the control treatment, being is statistically at par with some selected treatments in Meher season. On the other hand, the lowest exchangeable aluminum of 0.42 $cmol_{(+)}$/kg soil in Belg and of 0.70 $cmol_{(+)}$/kg soil in Meher season was recorded at 7.5 t/ha VC used in combination with 75% of mineral NP which is statistically the same as 25% or 50% NP + 7.5 t/ha vermicompost, 50% or 75% NP + 7.5 t/ha cattle manure, 75% NP + 5 t/ha vermicompost and 200 kg NPSB/ha + 46 kg P/ha + 128 kg N/ha in Belg and Meher seasons.

The higher exchangeable acidity with either or application of mineral fertilizers alone might be due to the acidifying effect of nutrient uptake from the soil which adds hydrogen ions to the soil lowering *p*H values. On the other hand, the decrease in exchangeable acidity might be due to the increase in organic anions, rise in *p*H and basic cations by vermicompost addition which resulted in precipitation of exchangeable and soluble Al as insoluble Al hydroxides, thus reducing the concentrations of Al in the soil solution. Reported that, the highest exchangeable acidity values of 2.88 $cmol_{(+)}$/kg soil and Al (2.16 $cmol_{(+)}$/kg soil) were recorded in plots treated with fertilizer combination of a high dose of S (30 kg S/ha) without compost that showed an increase of 23.6% over the control. However, the lowest exchangeable acidity of 1.87 $cmol_{(+)}$/kg soil and Al (1.37 $cmol_{(+)}$/kg soil) were observed in plots treated with high doses of compost (10 t/ha compost) without S fertilizer that showed a decrease of 19.7% from the control.

Organic carbon, total nitrogen and available phosphorus:

The fertilizer-management treatments significantly (P<0.01) affected organic carbon, total nitrogen and available phosphorus (Table 4). The highest organic carbon values of 19.47 g/kg soil in Belg and of 22.3 g/kg soil in Meher season were obtained at 7.5 t VC/ha used in combination with that of 75% of the recommended rate of mineral NP (124 kg N/ha and 45 kg P/ha). These values were statistically at par with those obtained with 50% NP + 7.5 t vermicompost/ha in Belg and of 50% NP + 7.5 t vermicompost/ha and 75% NP + 7.5 t cattle manure/ha in Meher. In contrast, the lowest organic carbon content of 18.13 g/kg soil in Belg and 17.21 g/kg soil in Meher season were recorded in the control.

The increased organic matter with higher doses of vermicompost and cattle manure improved soil properties like water-holding capacity, water infiltration, particle-binding capacity (aggregate stability) that determine the microbial biomass and mineral nutrient reserves. In line with this result, reported the highest organic carbon (3.08%) at the combined application of 2.0 t VC/ha with 92 kg N/ha. Parthasarathi *et al.* (2008) also reported that, the application of vermicompost plus NPK provided higher

Table 4. Influenced of blended NPSB, cattle manure, vermicompost and mineral NP on organic carbon (OC g/kg soil), total nitrogen (TN g/kg soil) and available phosphorus (AvP mg /kg soil) contents of soil after potato harvesting in Belg and Meher seasons

Treatment	Belg season			Meher season		
	OC	TN	AvP	OC	TN	AvP
No-fertilizer (control)	18.13[d]	1.4[d]	6.38[cd]	17.22[f]	1.5[b]	7.47[g]
100% NP	18.17[d]	1.45[cd]	6.83[cd]	18.38[ef]	1.6[ab]	7.64[g]
100 kg NPSB/ha + adjusted NP	18.4[cd]	1.52[bcd]	6.85[cd]	19.24[de]	1.7[ab]	7.71[g]
150 kg NPSB/ha + adjusted NP	18.5[cd]	1.52[bcd]	7.11[bcd]	19.93[cd]	1.7[ab]	8.97[f]
200 kg NPSB/ha + adjusted NP	18.67[c]	1.52[bcd]	7.28[bcd]	20.18[cd]	1.7[ab]	10.84[e]
50% NP + 5 t VC/ha	18.7[c]	1.52[bcd]	7.28[bcd]	20.67[bc]	1.7[ab]	10.83[e]
50% NP + 7.5 t CM/ha	18.7[c]	1.62[bc]	7.82[abc]	20.79[bc]	1.73[ab]	10.83[e]
75% NP + 5 t VC/ha	18.75[bc]	1.65[abc]	7.99[abc]	20.94[bc]	1.73[ab]	11.18[d]
75% NP + 7.5 t CM/ha	18.76[bc]	1.68[ab]	8.17[ab]	21.48[ab]	1.73[ab]	12.54[c]
50% NP + 7.5 t VC/ha	19.21[ab]	1.72[ab]	8.35[ab]	21.64[ab]	1.77[ab]	12.83[b]
75% NP + 7.5 t VC/ha	19.48[a]	1.85[a]	9.06[a]	22.34[a]	1.88[a]	13.37[a]
CD (P=0.05%)	0.047	0.021	1.25	0.12	0.027	1.735

Means followed by the same letter within a column are non-significantly different (P>0.05); VC, vermicompost; CM, cattle manure, 61.5kg P/ha + 146 kg N/ha adjusted NP for 100 kg NPSB/ha; 53.7 kg P/ha + 138 kg N/ha adjusted NP for 150 kg NPSB/ha; 46 kg P/ha + 128 kg N/ha adjusted NP for 200 kg NPSB /ha organic carbon (1.5%) than the plots treated only with NPK (0.25%). In addition, Wani *et al.* (2017) reported the highest organic carbon (1.43%) with the application of 100% organic manure (FYM 50% + vermicompost 25% + poultry manure 25%) as compared to NPK (recommended as per package of practices) through inorganic fertilizer (1.18%). Besides, Vinod *et al.* (2018) reported the maximum carbon content (0.84%) when fertilized with 100% NPK + 100% vermicompost followed by 50% NPK + 50% vermicompost (0.75%), while the minimum value of carbon (0.60%) was found in the control. The highest total nitrogen contents of 1.85 g/kg soil in Belg and 1.88 g/kg soil in Meher were obtained at 7.5 t VC/ha used in combination with 75% of recommended rate of mineral NP (124 kg N/ha and 45 kg P/ha) which were in statistically at par with those obtained at 50% NP + 7.5 t vermicompost/ha in Belg season and all the treatments except the control in Meher season. However, the lowest total nitrogen contents of 1.4 g/kg soil in Belg and of 1.5 g/kg soil in Meher season were recorded in the control. Such a response may be owing to the addition of vermicompost that increased the levels of total nitrogen over the initial soil values. Our results support the findings of Irungbam *et al.* (2017), who reported the maximum increase in total nitrogen content (0.075 %) in soil with the application of one-third of the recommended N, each from cattle manure, vermicompost, neem cake and rock phosphate + Phosphorus-solubilizing bacteria + Azotobacter and one purely inorganic nutrient treatment over initial soil content (0.06%). The highest available phosphorus of 9.06 mg/kg soil in Belg and 13.37 mg/kg soil in Meher were obtained at 7.5 t VC/ha used in combination with 75% of recommended rate of mineral NP of 124 kg N/ha and 45 kg P/ha) which were in statistically at par with those of 25% or 50% NP + 7.5 t vermicompost/ha, 50% or 75% NP + 7.5 t cattle manure/ha in Belg season. On the other hand, the lowest available phosphorus of 6.38 mg/kg in Belg and of 7.47 mg/kg in the Meher were recorded in control, being statistically at par with several other treatments.

Vermicompost application increases at the phosphorus contents of the soil which, influences nutrient availability by controlling net mineralization-immobilization patterns and also interact with soil minerals in complexing P-fixing cations thereby reducing P-sorption capacity. The use of vermicompost improved the soil structure, nutrient exchange and overall soil health. This amendment added to soil is often viewed as a way to improve soil fertility and increase the amounts of soil organic carbon and other major nutrients such as phosphorus. Similarly, Kumar *et al.* (2017) reported the maximum increase in available phosphorus (14.5 mg/kg soil) after harvesting in treatment consisting of 100% NP + 25% N vermicompost + 30 kg S/ha + 5 kg Zn/ha and minimum (13.4 mg/kg soil) with 100% NPK. In addition, Vinod *et al.* (2018) reported the maximum available phosphorus (24.03 kg/ha soil) with 100% NPK + 100% vermicompost and the minimum available phosphorus (16.00 kg/ha) in the control.

Cation-exchange capacity, exchangeable calcium and exchangeable magnesium

Fertilizer-management practices had highly significant (P<0.01) effect on cation-exchange capacity, exchangeable

Table 5. Influenced of blended NPSB, cattle manure, vermicompost and mineral NP on cation-exchange capacity (CEC $cmol_{(+)}$/kg soil), exchangeable calcium (EX-Ca^{+2} $cmol_{(+)}$/kg soil) and exchangeable magnesium (EX- Mg^{+2} $cmol_{(+)}$/kg soil) of soil after potato harvesting in Belg and Meher seasons

Treatment	Belg season			Meher season		
	CEC	EX-Ca^{+2}	EX-Mg^{+2}	CEC	EX- Ca^{+2}	EX-Mg^{+2}
No-fertilizer (control)	17.00^{h}	5.93^{g}	1.24^{e}	19.17^{e}	5.58^{f}	3.04^{d}
100% NP	17.93^{gh}	6.19^{gf}	1.37^{de}	20.21^{de}	6.60^{e}	3.12^{cd}
100 kg NPSB/ha + adjusted NP	18.26^{efg}	6.40^{efg}	1.38^{de}	22.02^{cd}	6.65^{de}	3.16^{bcd}
150 kg NPSB/ha + adjusted NP	18.66^{efg}	6.49^{def}	1.40^{cde}	22.01cd	6.96^{cde}	3.22^{abcd}
200 kg NPSB/ha + adjusted NP	19.23^{defg}	6.61^{cdef}	1.43^{cd}	23.61^{bc}	7.03^{bcde}	3.25^{abcd}
50% NP + 5 t VC/ha	19.61^{ef}	6.77^{cde}	1.47^{cd}	23.95^{ab}	7.06^{bcd}	3.25^{abcd}
50% NP + 7.5 t CM/ha	22.14^{a}	6.81^{bcde}	1.52^{bcd}	24.20^{ab}	7.17^{bc}	3.38^{ab}
75% NP + 5 t VC/ha	20.53^{cd}	6.96^{bcd}	1.58^{bc}	24.88^{ab}	7.21^{bc}	3.30^{abc}
75% NP + 7.5 t CM/ha	21.26^{bc}	7.14^{abc}	1.66^{ab}	24.90^{ab}	7.37^{bc}	3.35^{abc}
50% NP + 7.5 t VC/ha	22.14^{ab}	7.35^{ab}	1.70^{a}	25.46^{a}	7.45^{b}	3.38^{ab}
75% NP + 7.5 t VC/ha	23.3^{a}	7.56^{a}	1.76^{a}	25.53^{a}	8.01^{a}	3.42^{a}
SEm±						
CD (P=0.05)	2.085	0.547	0.180	1.812	0.44	0.242

Means followed by the same letter within a column are non-significantly different (P>0.05); VC, vermicompost; CM, cattle manure; 61.5kg P/ha+146 kg N/ha adjusted NP for 100 kg NPSB/ha; 53.7 kg P/ha + 138 kg N/ha adjusted NP for 150 kg NPSB/ha; 46 kg P/ha + 128 kg N/ha adjusted NP for 200 kg NPSB/ha calcium and exchangeable magnesium but the effect on percent base saturation in the soil was non-significant after potato harvesting (Table 5). The highest cation-exchange capacity of 23.3 $cmol_{(+)}$/kg soil in Belg and of 25.53 $cmol_{(+)}$/kg soil in Meher were recorded at 7.5 t VC/ha used in combination with 75% of recommended rate of mineral NP (124 kg N/ha and 45 kg P/ha), being statistically at par with those of 50% NP + 7.5 t vermicompost/ha in Belg and of 50% of NP + 7.5 t vermicompost/ha, 75% NP + 7.5 t cattle manure/ha, 25% NP+7.5 t vermicompost/ha in Meher. However, the lowest values of CEC in Belg and Meher were recorded for the control treatment which were statistically similar to that obtained by the use of 100% mineral NP in Belg as well as Meher seasons. It is to be noted that earthworms grind composting material into very fine form with the help of their gizzard, increasing the surface area and consequently the cation-exchange capacity of the vermicasts which are then transformed into vermicompost. The use of vermicompost therefore, increased the surface area of soil and consequently the cation exchange capacity of the soil. The result obtained is in accordance with those of Parthasarathi *et al.* (2008), who reported high CEC (27 $cmol_{(+)}$/kg soil) of soil under the application of combined use of 50% vermicompost + 50% NPK as compared to control (25 $cmol_{(+)}$/kg soil) in clay-loam soil.

The highest exchangeable calcium amounting to 7.56 $cmol_{(+)}$/kg soil in Belg and 8.02 $cmol_{(+)}$/kg soil in Meher were obtained at 7.5 t/ha vermicompost combined with 75% of recommended rate of mineral NP (124 kg N/ha and 45 kg P/ha) which were in statistically at par with those of 75% of NP + 7.5 t cattle manure/ha or 50% NP + 7.5 t vermicompost/ha in Belg season, while the lowest exchangeable calcium of 5.93 $cmol_{(+)}$/kg soil in Belg and 5.58 $cmol_{(+)}$/kg soil in Meher were obtained for the control. This study indicated that soil exchangeable Ca^{+2} can be significantly increased by the application of vermicompost, mineral nitrogen and phosphorus which could be an alternate amendment for acidic soils in low-input agriculture. Clearly, vermicompost which is locally available, in combination with mineral N P was found to be better in improving the exchangeable Ca^{+2}. In this context, reported that, exchangeable Ca^{+2} (2.69%) was significantly higher in plots treated with vermicompost plus NPK than that found in the control (1.70%).

Similarly, the highest values of exchangeable magnesium i.e. 1.76 $cmol_{(+)}$/kg soil in Belg and 3.42 $cmol_{(+)}$/kg soil in Meher season were obtained at 7.5 t VC/ha used in combination with 75% of recommended rate of mineral NP which were statistically at par with that of 100% NP in Belg and with a number of the other treatments in Meher season. On the other hand, the lowest exchangeable magnesium of 1.24 $cmol_{(+)}$/kg soil in Belg and of 3.04 $cmol_{(+)}$/kg soil in Meher season was recorded for the control treatment. This increment in exchangeable magnesium probably was due to the maximum release of Mg^{+2} from vermicompost.

Exchangeable potassium, available potassium and per-cent base saturation

The highest exchangeable potassium of 0.45 $cmol_{(+)}$/kg soil) in Belg and of 0.35 $cmol_{(+)}$/kg soil in Meher season

Table 6. Influenced of application of blended NPSB, cattle manure, vermicompost and mineral NP on exchangeable potassium (EX-K^+ $cmol_{(+)}$/kg soil), available potassium (AvK ppm) and per cent base saturation (PBS %) of soil after potato harvesting in Belg and Meher seasons

Treatment	Belg season			Meher season		
	EX-K^+	AvK	PBS	EX-K^+	AvK	PBS
No-fertilizer (control)	0.32^{f}	67.41^{g}	41.96	0.28^{e}	62.496^{c}	46.59
100% NP	0.36^{ef}	68.05^{g}	44.72	$0.30d^{e}$	64.91^{abc}	50.13
100 kg NPSB/ha + adjusted NP	0.38^{cde}	69.36^{g}	44.72	0.35^{d}	62.751^{c}	49.79
150 kg NPSB/ha + adjusted NP	0.38^{cde}	70.26^{ef}	44.423	0.32^{cd}	63.69^{c}	47.76
200 kg NPSB/ha + adjusted NP	0.39^{cde}	70.8^{e}	43.9	0.33^{cd}	63.84^{bc}	44.94
50% NP + 5 t VC/ha	0.39^{cde}	71.77^{d}	44.05	0.32^{cd}	63.49^{c}	44.52
50% NP + 7.5 t CM/ha	0.40^{bcd}	72.48^{cd}	43.49	0.33^{cd}	64.13^{bc}	44.52
75% NP + 5 t VC/ha	0.41^{abcd}	73.07^{c}	43.66	0.334^{bc}	64.64^{bc}	44.52
75% NP + 7.5 t CM/ha	0.42^{abc}	74.73^{b}	41.96	0.344^{ab}	66.35^{abc}	44.54
50% NP + 7.5 t VC/ha	0.43^{ab}	75.35^{b}	43.49	0.345^{ab}	69.00^{ab}	44.52
75% NP + 7.5 t VC/ha	0.45^{a}	79.02^{a}	41.96	0.355^{a}	69.95^{a}	44.54
SEm±						
CD (P=0.05)	0.06	0.984	NS	0.01	5.28	NS

Means followed by the same letter within a column are non-significantly different (P>0.05); VC, vermicompost; CM, cattle manure; 61.5kg P/ha+146 kg N/ha adjusted NP for 100 kg NPSB/ha; 53.7 kg P/ha + 138 kg N/ha adjusted NP for 150 kg NPSB/ha; 46 kg P/ha + 128 kg N/ha adjusted NP for 200 kg NPSB/ha, NS, non-significant were obtained at 7.5 t VC /ha used in combination with 75% of recommended rate of mineral NP which were statistically at par with those obtained at 50% NP + 7.5 t vermicompost/ha and 75% NP + 7.5 t cattle manure/ha in both seasons (Table 6). Similarly, Ansari (2008) also reported the maximum exchangeable potassium in postharvest soil (20.21 mg/kg soil) with the combined use of 4 t/ha vermicompost and 150 N-10.4 P-99K-18S kg/ha and the minimum (11.60 mg/kg soil) was noted in the control. On the other hand, the lowest values of exchangeable potassium, i.e. 0.32 $cmol_{(+)}$/kg soil, in Belg season and 0.28 $cmol_{(+)}$/kg soil in Meher seasons were obtained from the control which was statistically similar to that of 100% NP (165 kg N/ha + 60 kg P/ha) in both the seasons.

This increment in exchangeable potassium may be owing to the increase in vermicompost decomposition, reduction of potassium fixation and release of potassium from the interaction of organic matter with clay besides, the direct potassium addition to the pool of soil. Similarly, the highest available potassium values of 79.02 ppm in Belg and of 69.95 ppm in Meher season were obtained at 7.5 t VC/ha used in combination with 75% of recommended rate of mineral NP which were in statistically at par with those obtained at 50% of NP + 7.5 t vermicompost/ha or 75% of NP + 7.5 t cattle manure/ha in Belg season. On the other hand, the lowest values of available potassium of 62.50 ppm in the Belg season and of 67.42 ppm in Meher were obtained control treatment. This increment in available potassium might be due to large quantities of potassium added from weathering of rock or mineralization of vermicompost that exceeds uptake of available potassium by plants. In conformity with this result, Karmegam and reported 100 kg available K/ha after harvesting in soil collected from the plots treated with chemical fertilizers which were higher than in the control plots and lower than in the plots that received chemical fertilizer + vermicompost mixture. The available K in the soil which received VC prepared using *P. ceylanensis* + ½ dose of recommended NPK/ha was 110 kg/ha.

Thus, the soil physical and chemical properties after potato harvesting in both the seasons of Belg and Meher were significantly affected by the fertilizer management treatments. The soil test results after potato harvesting revealed significant increase in soil pH, OC, TN, available P, CEC, exchangeable calcium, exchangeable magnesium, exchangeable potassium, while significant reduction in soil bulk density, exchangeable acidity and exchangeable Al^{+3} due to combined application of 7.5 t VC + 75% of inorganic NP than the use of either 100% of recommended rate of NP or no-application of NP (control) in both seasons. Hence, among the range of treatments tested the application of 7.5 t/ha VC + 75% of recommended rate of N (124 kg N/ha + 45 kg P/ha) was found to be the best treatment to enhance the physico-chemical properties of the soil.

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