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Research Article
Vermicompost and Blended NPS Fertilizers Effect on Soil Physicochemical Properties and Potato (*Solanum tuberosum* L.) Tuber Yield

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Abstract
Background and Objective: Improved soil fertility management is an integral part of crop production. Thus, this study was conducted to investigate the effect of integrated vermicompost and blended NPS fertilizer application on soil physicochemical properties and potato tuber yield. **Materials and Methods:** The treatment levels consisted of 4 rates of blended NPS fertilizers (0, 150, 200 and 250 kg NPS ha^{-1}) and 4 rates of vermicompost (0, 4, 6 and 8 t ha^{-1}) in factorial combination in randomized complete block design with 3 replications. **Results:** Soil analysis before planting and after harvesting revealed the incorporation of vermicompost and NPS fertilizer increased OC, CEC, available P and K and total N content of the soil. The organic carbon, available P and available K were increased by 8.7, 14.9 and 13.0% over the initial status, respectively. Furthermore, the integrated use of various rates of vermicompost (VC) and low rates of inorganic fertilizer is better than independent use of inorganic fertilizer. The organic carbon, soil pH, available P and K, CEC and exchangeable bases (Na, K, Ca and Mg) increased due to the application of vermicompost. Combined application of 250 kg ha^{-1} blended NPS fertilizer and 8 t ha^{-1} vermicompost gave significantly maximum yield for marketable tuber yield (27.4 t ha^{-1}) and total tuber yield (27.9 t ha^{-1}). **Conclusion:** The finding suggests combined use of 250 kg ha^{-1} blended NPS fertilizer with 8 t ha^{-1} vermicompost increased significantly tuber yield and fertility status of the soil. The regression analysis showed at every increase in levels of both factors, there is a corresponding linear increase in tuber yield.

Key words: Fertility management, soil analysis, soil fertility, tuber yield, regression analysis, vermicompost

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Potato (S*olanum tuberosum* L.) is a vital food-security crop and substitute for cereal crop considering its high yield and great nutritive value[1]. In permanent agricultural systems, soil fertility is maintained through applications of manure, other organic materials, inorganic fertilizers, lime and the inclusion of legumes in the cropping systems or a combination of these. Growing crops implies that nutrients (N, P, K, etc.) are removed from the soil through agricultural produce (food, fibre and wood) and crop residues[2]. Understanding of physical and chemical condition of any soil is essential for the proper implementation of different management practices as it affects the soil productivity[3].

The amount and availability of plant nutrients in the soil, significantly influence plant growth rate, maturity time, size of plant parts and biochemical content of plants and seed capabilities[4]. Based on the national soil database, the EthioSIS soil fertility mapping project in Ethiopia reported that there is deficiencies of K, S, Zn, B and Cu including N and P in Ethiopian soils and hence recommended customized and balanced fertilizers (EthioSIS, 2013)[5]. In Ethiopia, a report indicated that potato productivity has been limited partly due to soil fertility which plays a major role in influencing the growth and production performance of potato[6]. Besides, the increase in the cost of mineral fertilizers, coupled with related ecological concerns has changed agricultural practice using mineral fertilizer to integrated nutrient management strategy using the combinations of both mineral fertilizer and vermicompost nutrient sources[7].

Vermicomposting is a bio oxidative process that involves earthworms and associated microbes. This biological organic waste decomposition process yields the biofertilizer namely the vermicompost. Vermicompost is a finely divided, peat-like material with high porosity, good aeration, drainage, water-holding capacity, microbial activity, excellent nutrient status and buffering capacity thereby resulting in the required physiochemical characters congenial for soil fertility and plant growth[8]. The use of organic manure with the combination of chemical fertilizers helps in improving physic-chemical properties of the soil, improves the efficient utilization of applied fertilizers resulted in higher seed yield and quality, provide the conducive environmental condition for microorganisms and soil structural properties[9] and the integrated vermicompost and inorganic fertilizers were used to maintain soil fertility for sustainable production of soybeans[10]. Integrated application of organic and inorganic fertilizers improves the productivity of crops as well as the fertility status of the soil[11].

However, for future potential applicability of integrated fertility management, specifically the combined use of NPS fertilizer and vermicompost and about its effects on soil physical and chemical properties of soil fertility and potato yield performance. Because of this, the present study was initiated to investigate the effect of the rate of vermicompost and blended NPS fertilizer on soil physical and chemical properties as well as potato tuber yield.

MATERIALS AND METHODS

Description of the study area: The experiment was conducted at Gitilo Dale area, Horo Guduru Wollega Zone, Western, Ethiopia during the 2019 cropping season. The experimental site is located at 09°32'299"N-037°03'911"E and an altitude of 2795 m above sea level (m.a.s.l) and receives an annual rainfall of 1650-1780 mm, especially in July and August being the peak rainy months. The average temperature of the area is 22°C and the pH of the area was 4.8[12].

Experimental materials: An improved potato variety known as 'Gudanie' (accession No. CIP-386423.13) which was released in 2006 by Holeta Agricultural Research, Ethiopia Centre (HARC) was used as planting material. The variety was selected based on its high yield, wider adaptation and moderate resistance to late blight in the highlands of Horo Guduru Wollega Zone than other varieties. Blended NPS was used as a source of (19% N, 38% P_2O_5 and 7% S) and taken from Horo Buluk farmers union and vermicompost (27 kg t^{-1} N, 17.5 kg t^{-1} P_2O_5 and 17.5 kg t^{-1} K) was used. Vermicompost worm species name *Aesinia fetida* and obtained from Gudar Lime Factory (Oromia Agricultural and Natural Resource Bureau 2011 unpublished).

Experimental design and treatments: The experiment was laid out as a Randomized Complete Block Design (RCBD) in a 4×4 factorial arrangement and replicated 3 times per treatment. Each factor consists of 4 levels of vermicompost and 4 levels of NPS fertilizers treatments. The levels were 0, 4, 6 and 8 t ha^{-1} vermicompost and 0, 150, 200 and 250 kg ha^{-1} NPS (Nitrogen, Phosphorus and Sulfur). Hence, there were 16 treatments combinations in Table 1. Each treatment was applied to a plot with a gross area of 8.75 m^2 (with 2.5 m length and 3.75 m width) containing 5 rows, with each row accommodating 8 plants with a total population of 40 plants per plot at the spacing of 0.75 and 0.30 m between rows and plants, respectively. The spacing between plots and adjacent blocks were 1 and 1.5 m, respectively. The full dose of

Table 1: Description of treatment combination

Treatments	Description
1	Control (0 fertilizer)
2	150 kg ha^{-1} NPS blended fertilizers
3	200 kg ha^{-1} NPS blended fertilizers
4	250 kg ha^{-1} NPS blended fertilizers
5	4 t ha^{-1} vermicompost
6	4 t ha^{-1} vermicompost+150 kg ha^{-1} NPS blended fertilizers
7	4 t ha^{-1} vermicompost+200 kg ha^{-1} NPS blended fertilizers
8	4 t ha^{-1} vermicompost+250 kg ha^{-1} NPS blended fertilizers
9	6 t ha^{-1} vermicompost
10	6 t ha^{-1} vermicompost+150 kg ha^{-1} NPS blended fertilizers
11	6 t ha^{-1} vermicompost+200 kg ha^{-1} NPS blended fertilizers
12	6 t ha^{-1} vermicompost+250 kg ha^{-1} NPS blended fertilizers
13	8 t ha^{-1} vermicompost
14	8 t ha^{-1} vermicompost+150 kg ha^{-1} NPS blended fertilizers
15	8 t ha^{-1} vermicompost+200 kg ha^{-1} NPS blended fertilizers
16	8 t ha^{-1} vermicompost+250 kg ha^{-1} NPS blended fertilizers

vermicompost and NPS as per treatment were applied as a basal dressing at planting. The experiment was conducted under the rainfed condition from 22 May to 14 September, 2019.

The land was prepared according to the crop requirement as recommended by Holeta Agricultural Research Center. Tubers with a medium size (25-75 g) and well-developed sprouts of each variety were planted at a spacing of 75 cm by between rows 30 cm and a depth of 15 cm. Fungicide (Ridomil MZ 65WP) was sprayed 2 times at the rate of 2.5 kg ha^{-1} at the interval of 7 days using 400-500 L of water ha^{-1} to control late blight (*Phytophthora infestans*) disease. Other recommended cultural practices such as weeding, cultivation and ridging were applied to all plots during the period of the study as recommended. Vermicompost was prepared 14 days before the experiment started. The original raw materials used for preparing the vermicompost were cow dung, chopped dried broad leaves grasses. Following steps were followed for vermicompost preparation:

- The vermicomposting unit was in a cool, moist and under corrugated iron house shady site
- Three days after extraction, the cow dung was mixed with water and chopped dried nontoxic leaves (such as eucalyptus, neem, citrus and like bones etc.) were mixed in the proportion of 3: 1 and kept for partial decomposition for 15-20 days and gets ready in 45-50 days
- A layer of 15-20 cm of chopped dried leaves/grasses was kept as a bedding material at the bottom of the bed
- Beds of partially decomposed material of size 182.88× 60.96×60.96 cm were made
- Each bed was contained 1.5-2.0 q of raw material (cow dung, chopped dried broad leaves grasses) and the number of beds can be increased as per raw material availability and requirement
- Red earthworm (1500-2000 of numbers) which is adult (3-5 month ages, length 0.8-10 cm, weight 0.5-0.6 g) was released on the upper layer of bed and 10 earthworms are required to decompose 1 kg of leaves
- Water was sprinkled using the watering can immediately after the release of worms
- Beds were kept moist (60-70% moisture content) by the sprinkling of water (daily) and by covering with polythene
- The bed was turned once after 30 days for maintaining aeration and for proper decomposition until the compost matured 45-50 days
- Matured and well-decomposed product (vermicompost with no odour, brown or brown-black colour, not compacted or rolled) was used for the experiment

Soil sampling and analysis: The composite surface soil samples (0-20 cm depth) were collected randomly from 10 spots of the experimental site in a zigzag pattern before planting and after harvesting using an auger throughout the experimental units for determination of selected physicochemical properties of the soil. Then, the collected samples were air-dried at room temperature under shade and ground to pass through a 2 mm sieve. The soil of the experimental site was analyzed before and after planting. For the determination of Organic Carbon (OC) and total Nitrogen (N), the soil was ground to pass through a 1 mm sieve. The soil samples were analyzed for particle size distribution (soil texture), soil Ph, Cation Exchange Capacity (CEC) (meq/100 g soil), organic carbon (%), available sulfur (ppm) available potassium (ppm) available phosphorus (ppm) total nitrogen (%) at Nekemte Soil Laboratory (http://iqqo.org/?q=nek) and soil science laboratory, Wollega University Shambu Campus (https://wollegauniversity.edu.et/).

Soil pH was measured in the supernatant suspension of 1:2.5 soils and water mixture by using a pH meter. Soil pH was determined by ES ISO 10390: 2014 (1:2.5). Soil texture was determined by using Bouyoucos Hydrometer Method following the textural triangle[13] as described by Rowell[14]. Soil organic carbon content was determined by using the Walkley and Black method[15] and soil organic matter content was calculated by multiplying the OC (%) by a factor of 1.724. Total nitrogen of the soil was determined by ES ISO 11261: 2015 Kjeldahl Method[16]. The available sulfur content in the soil was determined turbid metrically using a spectrophotometer method. Available phosphorus was determined by Bray II methods[17]. Cation Exchangeable Capacity (CEC) was determined by Ammonium Acetate Method[18].

Data collection: Five plants were selected randomly from central rows of a plot for recording observations on marketable and unmarketable tuber yield (t ha^{-1}).

Data analysis: All crop data were subjected to analysis of variance, using R-software version 3.4.0[19]. Means were separated using Least Significant Difference (LSD) at 5% levels of significance. Regression analysis was done using vermicompost and NPS blended fertilizer treatments on tuber yield to identify the influence of both factors on tuber yield.

RESULTS AND DISCUSSION

Soil analysis result before planting: The soil analysis of the selected physicochemical properties of the soil sample taken before planting is presented in Table 2. The results indicate that the soil has 59, 16 and 25% sand, silt and clay, respectively and could be categorized as sandy clay loam soil based on the USDA[14] textural soil classification system. According to Hazelton and Murphy[20], the experimental soil has moderate CEC (15 meq/100 g soil). The rating made by FAO[21] indicates that the content of available potassium is very low (0.512 meq/100 g). According to the rating of Tekalign[22], the Organic Carbon (OC) content (2.03%) could be categorized as medium. Furthermore, based on Zbíral *et al.*[23] the soil of the experimental site is strongly acidic in reaction (pH of 4.98), medium in total N (0.095%) and very low in available S (11.53 mg kg^{-1}).

Moreover, the results of the analysis also indicated that the soil has a medium content of available phosphorus (14.05 mg kg^{-1}) according to the rating of Cottenie[24]. The low potassium content may be attributed to the nature of the clay which is kaolinite, having poor retention capacity of potassium ions and hence high susceptibility to leaching of the cation[25] due to heavy rainfall in the study area. At increased soil acidity (low pH), phosphorus is fixed to surfaces of Fe and Al oxides and hydrous oxide, which are not readily available to plants[26]. Potatoes can grow under a wide range of soil pH varying from neutral to alkaline reaction[27]. However, the optimum soil pH for potato production ranges from 5.0-6.5[28], which varies from strongly acidic to slightly acidic reaction[20]. Therefore, the pH of the experimental soil was suitable for potato production. However, the medium contents of available phosphorus, organic carbon and total nitrogen content indicate that the application of supplemental fertilizer is important for optimum production of crops. The physiochemical characteristics of the prepared vermicompost were determined in the soil laboratory and the result showed that it has a pH of 7.25, organic matter content of 6.72%, available P content of 24.34 mg kg^{-1}, total N content of 0.336% and a cation exchange capacity of 29 cmol (+) kg^{-1} described in Table 2 and 3. Similarly, the organic C and/or organic matter are high, implying that this organic fertilizer can be a good source of plant nutrients. Therefore, the application of inorganic NPS fertilizers along with vermicompost with very high nutrient content is justified to produce a good yield of potato at the study site.

Soil analysis result after harvesting: Analysis of variance showed significant ($p<0.05$) difference both for the main effect of vermicompost (VC) and NPS fertilizer on chemical properties of the soil in Table 4. The different doses of vermicompost (4, 6 and 8 t ha^{-1}) gave the highest value of chemical properties of the soil than that of control treatment.

Table 2: Physical and chemical properties of soil collected from the experimental site before-planting at Gitilo, Ethiopia, 2019

Properties	Result	Rating	References
Physical properties (%)			
Sand (%)	59		-
Silt (%)	16		-
Clay (%)	25		-
Textural class	Sandy clay loam		Bouyoucos[13]
Chemical properties			-
pH (1: 2.5 H_2O)	4.98	Strongly acidic	Hazelton and Murphy[20]
Organic matter (OM) (%)	1.90	Medium	EthioSIS[5]
Organic carbon (OC) (%)	2.03	Medium	Tekalign[22]
CEC (meq/100 g soil)	15	Medium	-
Total nitrogen (TN) (%)	0.095	Medium	EthioSIS[5]
Available nitrogen (N) (mg kg^{-1})	0.045	Low	EthioSIS[5]
Available phosphorus (P) (mg kg^{-1})	14.05	Medium	Cottenie[24]
Available potassium (K) (meq/100 g)	0.512	Very low	EthioSIS[5]
Available sulfur (S) (mg kg^{-1})	11.53	Very low	EthioSIS[5]
EC (meq/100 g)	0.72	Non-saline	-

Table 3: Some physical and chemical properties of the soil and vermin compost before planting at Gitilo, Ethiopia, 2019

						Particles size (%)								
Types	pH (H_2O)	OM (%)	TN (%)	Ava. P (mg kg^{-1})	Ava. N (mg kg^{-1})	Sand	Silt	Clay	Class	OC (%)	Ava. S (mg kg^{-1})	Ava. K (meq/100 g)	CEC (meq/100 g)	EC (meq/100 g)
Soil	4.98	1.90	0.095	14.05	0.045	59	16	25	SCL	2.03	11.53	0.512	15	0.72
Vermicompost	7.25	6.72	0.336	24.34	0.251	51	19	30		5.92	18.06	9.01	29	1.20

SCL: Sandy clay loam, OM: Organic matter, TN: Total nitrogen, Ava. P: Available phosphorus, Ava. K: Available potassium, Ava. S: Available sulfur, OC: Organic carbon, CEC: Cation exchange capacity and EC: Electric conductivity

Table 4: Analysis of variance for soil properties as influenced by vermicompost and NPS blended fertilizer at Gitilo, Ethiopia, 2019

		Mean square							
Source of variations	DF	OM (%)	TN (%)	Ava. P (mg kg^{-1})	OC (%)	Ava. S (mg kg^{-1})	Ava. K (meq/100 g)	CEC (meq/100 g)	EC (meq/100 g)
Replication	2	0.0018	0.0001	0.0047	0.0033	0.0008	0.0000	0.006	0.0003
VC	3	0.5857**	0.0021**	0.6793**	8.5642**	0.5857**	0.0347**	13.9668**	1.1112**
NPS	3	0.1856**	0.0008**	0.1472**	0.6942**	0.1856**	0.0021**	1.7507**	0.2012**
VC*NPS	9	0.0985**	0.0004^{NS}	0.0376**	0.0309**	0.0985**	0.0002**	0.1772**	0.0682**
Error	30	3.2120	0.0002	0.0018	0.0031	3.2120	0.0000	0.0024	0.0003
Total	45	4.0836	0.0036	0.8706	9.2957	4.0826	0.037	15.9031	1.3812
CV (%)		0.88	12.58	0.26	0.44	0.88	0.73	0.30	1.58

DF: Degree of freedom, NS: Non significant difference at p = 0.05, *Significant at p = 0.05, **Significant at p = 0.01, VC: Vermicompost, NPS: Nitrogen, phosphorus, sulfur fertilizer, Ava. P: Available phosphorus, pH: Soil pH, Ava. N: Available nitrogen, Ava. P: Available phosphorus, TN: Total nitrogen, VC: Vermicompost, NPS: Nitrogen, phosphorus, sulfur, OC: Organic carbon, CEC: Cation exchange capacity, Ava. K: Available potassium, Ava. S: Available sulfur and EC: Electric conductivity

Thus there was a significant increase in OC, available P, N, S, K, CEC and pH of the soil with increasing in NPS blended fertilizer and VC levels from 0-250 kg ha^{-1} and 4-8 t ha^{-1}, respectively. The highest value of OM, OC, available P, N, S, K and CEC were recorded from the application of vermicompost 8 t ha^{-1} followed by application of 6 t ha^{-1} vermicompost. An increasing vermicompost application form 0-8 t ha^{-1} increased total nitrogen from 0.097-0.123% compared to the control in Table 5 indicating that application of 8 t ha^{-1} vermicompost brought about 26.8% (0.026 total nitrogen content of the soil) increments compared to the control. Improvement in the soil nutrient contents with an application of organic manure might be a result of the build-up in the organic carbon[29]. Solubilization of different organic nitrogenous compounds was done into a simple and available form, conversion of unavailable P into available form at the time of decomposition of manure[30]. However, the application of NPS blended fertilizer shows a non-significant effect on total nitrogen up to 200 kg ha^{-1} (Table 5).

Besides this, the interaction effect of vermicompost and NPS blended fertilizer significantly ($p<0.05$) influenced the soil properties such as OC, soil pH, available N, P, S, K, CEC and EC of the soil increased with the incorporation of VC in conjunction with inorganic fertilizer in Table 4. Combined application of vermicompost with NPS fertilizer led to an increase in pH level after harvesting from 4.92-6.75 which was different from the initial soil sample pH (4.98). This result is in agreement with Kingery *et al.*[31], report who indicated that the application of organic manure over many years had an average surface soil pH of 6.3 compared to fields receiving only chemical fertilizers (pH 5.8).

The ideal soil pH is close to neutral and neutral soils are considered to fall within a range from a slightly acidic pH of 6.5 to a slightly alkaline pH of 7.5. It has been determined that most plant nutrients are optimally available to plants within this 6.5-7.5 pH range. Lower pH increases the solubility of Al, Mn and Fe, which are toxic to plants in excess. Nitrogen, K and S are major plant nutrients that appear to be less affected directly by soil pH than many others but still are to some extent. Phosphorus, however, is directly affected[32]. While soil pH was observed to reduce with the application of organic or inorganic fertilizer compared to the initial soil condition before planting in (Table 5) suggesting that combined application is advisable to increase the pH level. Tolanur and Badanur[33] reported that cation exchange capacity, available P and K and organic carbon significantly increased with organic manure in conjunction with inorganic fertilizer. Shivanand[34] also reported that application of organic material like FYM or VC in combination with inorganic fertilizer improved soil chemical properties like CEC, available P and K and exchangeable Ca and Mg.

The highest organic carbon (4.17%) and organic matter (3.02%) of soil were recorded in this study from plots receiving 8 t ha^{-1} VC plus 250 kg ha^{-1} NPS fertilizer. The increase in organic carbon content may be attributed to the application of organic manure and the combined use of organic manure and inorganic fertilizer. This finding is consistent with Omar *et al.*[35] and Singh *et al.*[7] report. While plots without fertilization showed the lowest organic carbon (2.00%) and organic matter (1.90%). Application of 8 t ha^{-1} vermicompost with 250 kg ha^{-1} recorded significantly higher available N (0.10 mg kg^{-1}) than control (0.05 mg kg^{-1}) treatments followed by 8 t ha^{-1} vermicompost with 200 kg ha^{-1} (0.09 mg kg^{-1}). Nitrogen and phosphorus availability recorded after harvesting revealed that the highest nitrogen (0.098%) was found in 250 kg ha^{-1} NPS+8 t ha^{-1} vermicompost and the lowest (0.046%) was observed in the control (Table 5). Similarly, the highest available P (15.030 mg kg^{-1}) of the soil was obtained from the application of 8 t ha^{-1} vermicompost +250 kg ha^{-1} NPS blended fertilizer followed by 8 t ha^{-1} VC+200 kg ha^{-1} NPS blended fertilizer. The increase in available P might be attributed to a combination of vermicompost and NPS blended fertilizer, which helped in releasing the higher amount of P from the soil. The highest organic matter (3.02%), CEC (18.29 meq/100 g), available sulfur (14.04 mg kg^{-1}), K (0.67 meq/100 g) and electric conductivity (1.91 meq/100 g) was recorded from the combination of 8 t ha^{-1} vermicompost and 250 kg ha^{-1} NPS blended fertilizer rates (Table 5). Similarly, soil available P and K increased significantly with the application of vermicompost in combination with NPS fertilizers over the inorganic fertilizer alone. This finding agrees with Tolanur and Badanur[33].

The application of organic or inorganic fertilizers is widely known to ameliorate soil N or P status[36]. This explains why plots that received vermicompost alone or NPS+ vermicompost had higher N and P contents after harvesting. Similarly, the amount of available phosphorus ranged from 14.00 mg kg^{-1} in the control to 15.03 mg kg^{-1} in 250 kg ha^{-1} NPS+8 t ha^{-1} vermicompost. However, there was no significant difference in the soil total N concentration among the treatment combination. The available P was increased by 3.27% (0.46 mg kg^{-1}) over the initial status of the soil (Table 2 and 5). This might be due to the reduced P fixing capacity of the soil. This finding is supported by Tolanur and Badanur[33], who reported that the increased available P content of the soil might be due to the release of organic acids during decomposition which in turn helped in releasing P availability. Furthermore, various other studies have also shown the importance of organic nutrient sources, particularly when combined with mineral fertilizer in improving the fertility status of the soil[7,33]. Generally, the results indicated that combined use of various rates of VC and inorganic fertilizer was better than the application of NPS fertilizers alone.

Marketable tuber yield ha^{-1} (t ha^{-1}): There was a highly significant ($p<0.001$) difference both for the main effects and interaction effects of different rates of NPS fertilizers with various rates of vermicompost for marketable tuber yield per ha in Table 6. Therefore, the lowest marketable tuber yield was recorded from the unfertilized plot (8.2 t ha^{-1}). It showed the application of 8 t ha^{-1} vermicompost yielded about 98.58% marketable tuber yield increments compared to the control (Table 6). A similar report by Alemayehu *et al.*[37] and Yourtchi *et al.*[38] reported that nitrogen fertilization significantly influenced marketable tuber yield. There was a report by Zelalem *et al.*[39] and Israel *et al.*[40] that N and P fertilization significantly influenced productivity of potato measured in terms of marketable and total tuber yields. And another study showed that frequent use of organic amendments can sustain soil N fertility and increase marketable potato yields by 2.5 to 16.4 t ha^{-1}, compared to the un-amended and unfertilized soil[41].

Unmarketable tuber yield ha^{-1} (t ha^{-1}): Analysis of variance showed highly significant ($p<0.001$) difference both for the main effects as well as interaction effect of vermicompost and NPS fertilizer on unmarketable tuber yield. An increasing vermicompost application form 0-8 t ha^{-1} reduced unmarketable tube yield compared to the control (Table 6).

Total tuber yield (ha^{-1}): ANOVA showed significant ($p<0.01$) difference both for the main effect of vermicompost and NPS fertilizer on total tuber yield as well as the interaction effect of different rates of NPS fertilizer with various rates of vermicompost showed a significant effect ($p<0.01$) on total tuber yield (Table 6). Total tuber yield increased as the rate of vermicompost increased from 0-8 t ha^{-1} which was a higher yield than that of the yield of control treatment. The lowest total tuber yield was recorded from control (No NPS fertilizer application).

Besides this, total tuber yield significantly increased with the application of 250 and 200 kg ha^{-1} NPS when combined with 8 t ha^{-1} of vermicompost, 27.9 and 27.3 t ha^{-1}, respectively and both are statically similar, compared with other treatments and no fertilization. The lowest total tuber yield 9.8 t ha^{-1}) was found in control (12.0 t ha^{-1}) (Table 6). Harris[42] indicated that tuber yield is considered to be a product of three major processes: Radiation interception, conversion of interception radiation to dry matter and the partitioning of dry matter between tuber and rest of plant. Results demonstrated that the integrated application of 20 or 30 t ha^{-1} FYM+66.6% of the recommended inorganic NP

Table 5: Soil fertility status after harvest as influenced by vermicompost and NPS blended fertilizer interaction at Gitilo, Ethiopia, 2019

Treatments		Particle size				Soil physicochemical properties									
VC ($t\ ha^{-1}$)	NPS ($kg\ ha^{-1}$)	Sand	Silt	Clay	Class	pH H_2O	OM (%)	Ava. N ($mg\ kg^{-1}$)	TN (%)	Ava. P ($mg\ kg^{-1}$)	CEC (meq/100 g)	OC (%)	Ava. S ($mg\ kg^{-1}$)	Ava. K (meq/100 g)	EC (meq/100 g)
0	0	58.00	16.33	25.67	SCL	4.92^{m}	1.90^{i}	0.05^{k}	0.07^{c}	14.00^{k}	15.04^{l}	2.00^{l}	11.50^{j}	0.51^{j}	0.71^{l}
0	150	57.33	16.67	26.00	SCL	5.02^{l}	1.93^{hi}	0.05^{jk}	0.10^{b}	14.04^{k}	15.11^{kl}	2.04^{kl}	11.56^{ij}	0.52^{i}	0.75^{k}
0	200	57.67	16.33	26.00	SCL	5.02^{l}	1.91^{i}	0.05^{j}	0.10^{b}	14.14^{j}	15.15^{k}	2.07^{k}	11.60^{i}	0.53^{h}	0.81^{j}
0	250	57.33	16.34	26.33	SCL	5.14^{k}	1.95^{gh}	0.06^{i}	0.10^{b}	14.15^{ij}	15.67^{j}	2.120^{j}	12.04^{h}	0.53^{gh}	0.84^{i}
4	0	57.00	16.00	27.00	SCL	5.25^{j}	1.97^{g}	0.07^{h}	0.069^{b}	14.17^{hij}	15.87^{i}	2.37^{i}	12.08^{gh}	0.52^{i}	0.86^{i}
4	150	56.67	16.33	27.00	SCL	5.36^{i}	1.98^{fg}	0.07^{gh}	0.099^{b}	14.08^{hij}	16.00^{h}	2.38^{i}	12.15^{g}	0.54^{g}	0.89^{h}
4	200	56.67	17.00	26.33	SCL	5.41^{hi}	2.01^{f}	0.07^{fg}	0.10^{b}	14.20^{ghi}	16.50^{g}	2.88^{h}	12.13^{gh}	0.55^{f}	0.91^{h}
4	250	57.33	16.34	26.33	SCL	5.48^{fg}	2.12^{e}	0.07^{f}	0.11^{b}	14.25^{fg}	16.520^{g}	2.93^{g}	12.49^{f}	0.55^{ef}	1.03^{g}
6	0	56.33	17.00	26.67	SCL	5.46^{gh}	2.12^{e}	0.07^{f}	0.11^{b}	14.22^{gh}	16.02^{h}	2.87^{h}	12.51^{f}	0.55^{e}	1.03^{g}
6	150	57.33	16.33	26.34	SCL	5.52^{f}	2.15^{de}	0.08^{e}	0.11^{b}	14.28^{f}	17.00^{f}	3.40^{f}	12.58^{ef}	0.56^{d}	1.06^{f}
6	200	57.33	16.34	26.33	SCL	5.73^{e}	2.16^{cd}	0.08^{d}	0.11^{b}	14.35^{e}	17.34^{de}	3.72^{e}	12.63^{e}	0.57^{d}	1.09^{de}
6	250	57.00	16.33	26.67	SCL	5.73^{e}	2.18^{cd}	0.09^{d}	0.11^{b}	14.40^{de}	17.317^{e}	3.74^{de}	13.03^{d}	0.57^{d}	1.12^{d}
8	0	57.00	16.00	27.00	SCL	5.81^{d}	2.19^{c}	0.08^{d}	0.11^{b}	14.42^{d}	17.42^{cd}	3.78^{cd}	13.35^{c}	0.62^{c}	1.07^{ef}
8	150	57.33	16.33	26.33	SCL	6.32^{c}	2.25^{b}	0.09^{c}	0.11^{b}	14.51^{c}	17.45^{c}	3.80^{c}	13.42^{c}	0.63^{c}	1.36^{c}
8	200	57.67	16.00	26.33	SCL	6.50^{b}	2.27^{b}	0.09^{b}	0.11^{b}	14.58^{b}	18.00^{b}	4.01^{b}	13.85^{b}	0.65^{b}	1.59^{b}
8	250	56.67	16.66	26.67	SCL	6.75^{a}	3.02^{a}	0.10^{a}	0.15^{a}	15.03^{a}	18.29^{a}	4.17^{a}	14.04^{a}	0.67^{a}	1.91^{a}
CV		1.61	3.72	2.36		0.63	0.88	2.65	12.58	0.26	0.30	0.92	0.44	0.73	1.58
LSD		1.54	1.02	1.04		0.06	0.03	0.00	0.02	0.06	0.08	0.05	0.09	0.01	0.03

Means within the same column followed by the same letter or by no letters do not differ significantly at the 5 % v level of the test, CV: Coefficient of variation, LSD: Least significant difference, SCL: Sandy clay loam, Ava. N: Available nitrogen, Ava. P: Available phosphorus, TN: Total nitrogen, VC: Vermicompost, NPS: Nitrogen, phosphorus, sulfur, OC: Organic carbon, CEC: Cation exchange capacity, Ava. K: Available potassium, Ava. S: Available sulfur and EC: Electric conductivity

Table 6: Interaction effect of vermicompost and NPS fertilizers on marketable tuber yield ha^{-1}, unmarketable tuber yield ha^{-1} and total tuber yield ha^{-1} at Gitilo, 2019

	Marketable tuber yield ha^{-1} ($t\ ha^{-1}$)				Unmarketable tuber yield ha^{-1} ($t\ ha^{-1}$)				Total tuber yield ha^{-1} ($t\ ha^{-1}$)			
	NPS ($kg\ ha^{-1}$)				NPS ($kg\ ha^{-1}$)				NPS ($kg\ ha^{-1}$)			
Vermicompost ($t\ ha^{-1}$)	0	150	200	250	0	150	200	250	0	150	200	250
0	8.2^{f}	11.6^{e}	12.0^{e}	58.5^{g}	77.2^{ef}	79.6^{ef}	81.6^{e}	1.2^{b}	9.8^{f}	12.9^{e}	13.3^{e}	13.6^{de}
4	11.3^{e}	14.1^{cd}	17.4^{b}	72.0^{f}	97.6^{d}	110.1^{c}	117.6^{bc}	0.8^{ef}	12.0^{e}	15.1^{cd}	18.4^{b}	19.6^{b}
6	12.7^{cde}	18.8^{b}	18.9^{b}	80.4^{ef}	116.9^{bc}	118.0^{bc}	118.7^{bc}	0.7^{ef}	13.4^{de}	19.5^{b}	19.7^{b}	19.6^{b}
8	14.5^{c}	19.1^{b}	26.7^{a}	93.3^{d}	119.7^{b}	173.5^{a}	167.6^{a}	0.5^{g}	15.6^{c}	19.7^{b}	27.3^{a}	27.9^{a}
LSD	1.814				0.17				1.87			
CV	6.62				10.99				6.46			

CV: Coefficient of variation, LSD: Least significant difference, NPS: Nitrogen, phosphorus, sulfur, means within the same column followed by the same letter do not differ significantly at the 5% level of significance

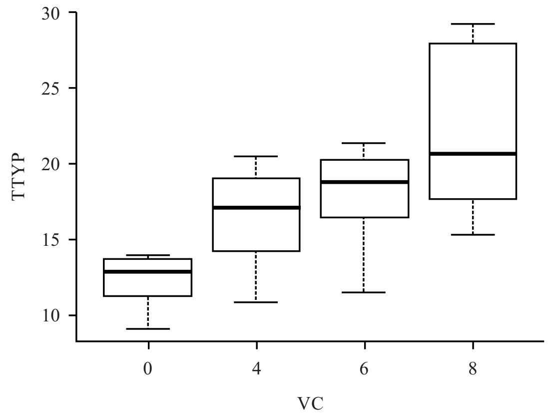

Fig. 1: Regression plot of the effect of vermicompost (VC) on the total tuber yield per plot (TTYP) of potato

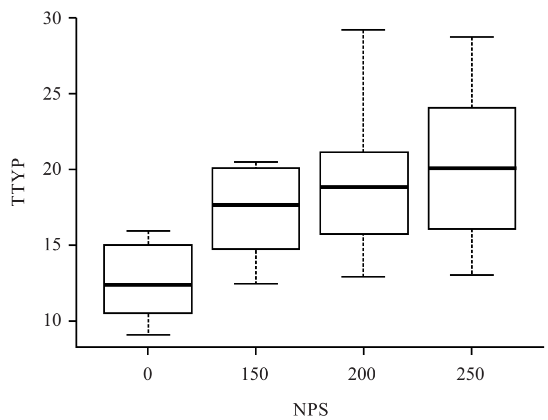

Fig. 2: Regression plot of the effect of NPS rate on the total tuber yield per plot (TTYP) of potato

fertilizers significantly increased total tuber yield over the application of a full dose of inorganic NP fertilizers without FYM in vertisol in Ethiopia[43]. Another study indicated that manure application rates of <2 Mg C ha^{-1} can provide crop and soil benefits that appear to increase with multiple applications, while higher application rates provide stronger and more consistent effects on yields and especially soil biological properties related to nutrient cycling and organic matter dynamics[44].

Regression analysis of vermicompost and NPS rate on total tuber yield per plot (TTYP) showed that there is a significant linear response of tuber yield at every increase in the level of both fertilizers in Fig. 1 and 2 and the regression equation for both factors can be derived as:

$$Y = 7.69+4.16\ VC+4.52\ NPS$$

where, Y is tuber yield, VC is vermicompost and NPS is fertilizer. Thus, the result revealed a complementary effect of both fertilizers on improving tuber yield in potato though further investigation is required to what level the maximum yield could be achieved by further increases in both factor levels.

CONCLUSION

The incorporation of organic manure and inorganic fertilizer increased OC, CEC, available P and K and total N content of the soil and organic carbon, available P and available K were increased by 8.7, 14.9 and 13.0% over the initial status, respectively. The soil analysis further revealed that integrated use of various rates of VC and low rates of inorganic fertilizer is better than independent use of inorganic fertilizer. The organic carbon, soil pH, available P and K, CEC and exchangeable bases (Na, K, Ca and Mg) increased due to the application of organic manure. The extent of increase was however, higher when VC was applied in combination with inorganic fertilizer. As opposed to organic manure, the application of inorganic fertilizer had no significant effect on the nutrient content of the soil. The main effects of vermicompost and NPS fertilizer rate and their interaction was highly significant ($p<0.01$) for unmarketable, marketable yield and total potato tuber yield (t ha^{-1}). Thus, the study suggests that combined application of 250 kg ha^{-1} blended NPS fertilizer and 8 t ha^{-1} vermicompost has resulted from significantly maximum yield for marketable tuber yield (27.4 t ha^{-1}) and total tuber yield (27.9 t ha^{-1}). The regression analysis showed that there is a significant linear increase of tuber yield at every level increase of both fertilizers and ate complementing effect.

SIGNIFICANCE STATEMENT

This study discovers the synergistic effects of vermicompost and NPS fertilizers in increasing tuber yield of potato and soil fertility for more sustainable production. This study can be a background for researchers in exploring the appropriate rate suitable to their environment and crop to achieve maximum productivity.

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