Effects of integrated use of vermicompost and NPS blended fertilizer on potato (*Solanum tuberosum* L.) yield and residual soil physicochemical properties of soils in central highlands of Ethiopia

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Abstract

The deficiency of soil nutrients is the major constraint for potato production in Ethiopian highlands in general and in central highlands of Ethiopia in particular. To determine the optimum application rate of 45 days decomposed vermicompost and NPS blended fertilizer for sustainable potato production in central Ethiopian highlands at Debre Berhan. This experiment was conducted in 2019/20 main season by using Belete potato variety (CIP-393371.58) at Debre Berhan area. The rate of vermicompost was determined by based on its inorganic N content. Factorial combinations of three rates of vermicompost (2.5, 5, 7.5 t ha^{-1}) with three rates of inorganic NPS (25%, 50%, 75%), full dose of vermicompost (7.5 t ha^{-1}), recommended blended fertilizer 100% NPS (55.5:89.7:16.52 kg ha^{-1} NPS) and control treatments were laid as factorial Randomized Complete Block Design (RCBD) with three replications. The result of this experiment show that integrated use of 75% blended NPS fertilizer and 7.5 t ha^{-1} vermicompost increased the residual soil OC, total N, available P and available S by 54.29%, 242.86%, 172.38% and 22.08, respectively as compared to the control. But pH was decreased from 7.2-6.3 or by 12.5% and also exchangeable sodium was dramatically decreased, the correlation analysis result show that the total tuber yield was positively correlated with total N (r=0.56**), available P (r= 0.71**) and organic C (r= 0.62**). On top of this, Moreover, the results also showed that application of 7.5 t ha^{-1} VC +75% blended NPS fertilizer significantly increased marketable tuber number, marketable tuber yield and total tuber yield by 127.85%, 119.6 and 96.67%, respectively as compared to the unfertilized plot. It can be conclude that applications of vermicompost along with bended NPS fertilizer improve residual soil physiochemical properties which in turn increased crop yield. Hence , in order to maintain soil fertility and sustain potatoes plant crop production farmers of the study area and similar agro ecologies are advised to make integrated use of vermicompost at (7.5t ha^{-1}) and blended NPS fertilizer at

(75%). Nevertheless to develop concrete recommendation further research studies are needed over a long season with varieties and economic analysis.

Keyword: Debre Berhan, NPS, Potato, Selected Soil Properties, Vermicompost

Introduction

Potato (*Solanum tuberosum* L.) belongs to the family Solanaceae and genus *Solanum* (Rahman, *et al.*, 2916). It is native to South America (Rahman, *et al*., 2916). It has been introduced to Ethiopia in 1859 by a German Botanist called Schimper (Bekelech *et al*., 2021). Potato tuber contained mainly carbohydrate, protein and lipids. The relatively high carbohydrate (82 %) and low fat content (less than 1 %) of potato makes it an excellent energy source for human consumption and substantial amount of essential vitamins (B1, B3, B6 and C), minerals and micronutrient (iron) (FAOSTAT, 2017/18).

In the world, annual potato production is about 330 million metric tons with an area coverage of 18,651,838 ha. In Africa, the total production of potatoes is about 17,625,680 tons, with a total area coverage of 1,765,617 ha. Ethiopia is endowed with suitable climatic and edaphic conditions for potato production (Alemayehu and Jember, 2018). However, land coverage under potato production is estimated to be only about 66,923.33 ha, and the national average yield is about 13.77 t ha^{-1}, which is very low as compared to the world's average production of 17.4 t ha^{-1} (FAOSTAT, 2017/18). This is because of a lack of actionable and relevant data, poor linkage between researchers and farmers, lack of up-to-date data, the availability and high price of quality seed, a lack of improved varieties, poor soil fertility, low market value at the time of harvest, disease, and post-harvest loss (Bewket *et al*., 2018). Of this, potato production is constrained by poor soil fertility, which is a widespread problem in Ethiopia (Wagari *et al*., 2022).

Potato is one of the heavy nutrient feeders, i.e., it requires relatively large quantities of fertilizers due to a relatively poorly developed, coarse, and shallow root system (Bewket *et al*., 2018). Most Ethiopian potato producers only apply inorganic fertilizer, i.e., 165 kg/ha N and 195 kg/ha P_2O5. Thus, long-term use of inorganic fertilizer causes nutrient deficiencies and declines in soil physiochemical properties, biological activities, and thus overall total soil health, which leads to nutrient deficiencies and is one of the common causes of low crop yields (Zewudie *et al*., 2018). However, there is no hesitation that chemical fertilizers are playing a vital role in meeting the nutrient necessities of crops and thereby increasing their production Mekashaw *et al*. (2020) reported that the application of 55:89.7:16.52 kg ha^{-1} of blended NPS fertilizer rate is recommended for the production of the Belete variety on soil with low content of phosphorus and sulfur at Abaso kotu, Dessie Zuria district. In addition to the environmental impact discussed earlier, in the current situation the cost of inorganic fertilizer has also increased threefold and has escalated beyond the purchasing power of the majority of the farmers in Ethiopia (Bekele *et al*., 2019). However, there are ample evidence that using mineral and organic fertilizers for potato production results in improved crop performance in terms of growth and yield in various parts of the country (Mengistu *et al*., 2017, Guta, 2017, Shibabaw *et al*., 2018, Zewide *et al*., 2021). Bekele *et al*. (2019) reported that combined application of 46 t ha^{-1} N, 46 t ha^{-1} P_2O_5, and 2.5 t ha^{-1} vermicompost produced the highest groundnut yield at Bablie district in eastern Ethiopia. Wagari *et al*. (2022) recommended 250 $kgha^{-1}$ blended NPS fertilizer and 8 t ha^{-1} vermicompost, and this recommendation has been used by various researchers and potato producers in the Awi zone.

Vermicompost is a valuable source of nutrients and increased soil microorganisms, which were previously present in the soil (Zewudie *et al*., 2018). Vermicompost inputs, which are often proposed as alternatives, cannot meet crop nutrient demand for large-scale production because of their relatively low nutrient composition as compared to inorganic fertilizer, high application rate, high labor requirement, and slow and limited availability of nutrients, especially in the year of application (Shibabaw *et al*., 2018). Based on the foregoing, using only chemical fertilizers without supplementing organic sources has a negative impact on the natural environment, while also increasing the cost of chemical fertilizers and limiting their availability to smallholder farmers, resulting in significantly reduced soil fertility and production potential. The soil in the study area is also vertisols and highly compacted. Therefore, soil fertility replenishment through the application of mineral and organic fertilizer is the way to effectively address these problems (Bekelech *et al*., 2020).

Therefore, the combined application of inorganic and organic fertilizer is a feasible option for the farmers (Bekele *et al*., 2019). However, integrated nutrient management using vermicompost and blended NPS fertilizer for the enhancement of soil fertility and potato productivity in the country in general, the central highlands of Ethiopia and in Debre Berhan in particular, is very limited. Therefore, this experiment was carried out with the objective of evaluating the effect of integrated nutrient management (vermicompost and blended NPS fertilizer) on yield and yield traits of potato and selected soil physico-chemical properties at Debre Berhan in the central highlands of Ethiopia**.**

2. Materials and Methods

2.1. Description of the Study Area

The field experiment was conducted at central highland of Ethiopia at Debre Berhan around industrial area 09 kebele on farmer's field during the main crop growing season (July- November) of 2019/20. It is located at 131km northeast to Addis Ababa. The area is located at the highland elevation of 2780 m.a.s.l. between the range of 9°20'0"-10°5' 0" N and 39°20' 0" -39°40'0"E. The total rainfall 1045.5mm, mean maximum and minimum temperature were 18.6 and 8.2 ^{o}C, respectively. Soil of the experimental site is veretisol (Eyasu and Christ, 2014).

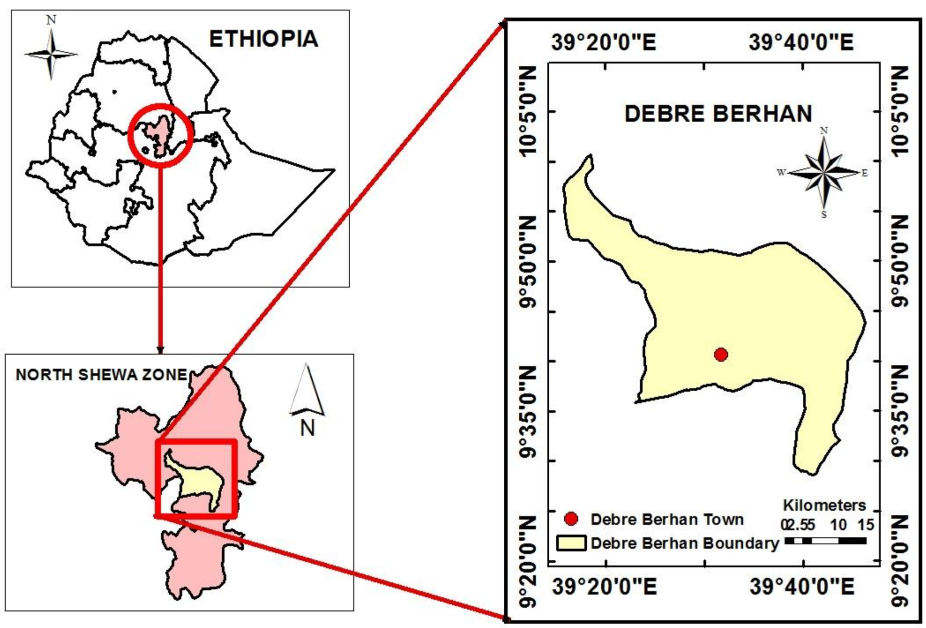

Fig.1. Map of the study area

The dominant crops grown by farmers around the experimental site are barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), teff (*Eragrostis tef),* lintel (*Lens culinaris*), chickpea (*Cicer arietinum***),** potato (*Solanum tuberosum* L.) and other vegetable crops. Farmers practice mostly monocroppings system (Eyasu and Christ, 2014).

2.2. Treatments and Experimental Design

This experiment had two factors, namely, rates of vermicompost and blended NPS fertilizer. The levels of blended NPS fertilizer application were developed according to the recommended blended NPS fertilizer rate for the Belete variety in that area. Accordingly, 25, 50, and 75% of the recommended blended NPS fertilizer application were used. According to nitrogen equivalence, 2.5, 5, and 7.5 t ha^{-1} of vermicompost were used. Then after, nine treatments were synthesized by factorial combination: three treatments, such as a full dose of vermicompost (7.5 t ha^{-1}), and a full dose of the recommended blended NPS fertilizer (55.5:89.7:16.52 kg ha^{-1} NPS). Control (unfertilized treatment) were included. In a factorial randomized complete block design with three replications, 12 treatments were used. Each plot was 4.5 m long and 3.60 m wide, with a total area of 16.2 m^2 and a net plot area of 9 m^2. The space between the adjacent plots was 1 meter, whereas the space between the adjacent blocks was 1.5 meters. Each plot had six rows, each with 12 plants, for a total of 72 plants per plot**.**

Table 3: Treatment combination and description.

Trt No.	Inorganic NPS (%)	vermicompost rate t ha^{-1}	Treatment description
1	0	0	Control
2	0	7.5	7.5 t ha^{-1} vermicompost
3	100	0	100% NPS RDF(55.5:89.7:16.52 kg ha^{-1} NPS)
4	25	2.5	25% NPS RDF + 2.5 t ha^{-1} vermicompost
5	25	5	25% NPS RDF + 5 t ha^{-1} vermicompost
6	25	7.5	25% NPS RDF + 7.5 t ha^{-1} vermicompost
7	50	2.5	50% NPS RDF + 2.5 t ha^{-1} vermicompost
8	50	5	50% NPS RDF + 5 t ha^{-1} vermicompost
9	50	7.5	50% NPS RDF + 7.5 t ha^{-1} vermicompost
10	75	2.5	75% NSP RDF + 2.5 t ha^{-1} vermicompost
11	75	5	75% NPS RDF + 5 t ha^{-1} vermicompost
12	75	7.5	75% NPS RDF + 7.5 t ha^{-1} vermicompost

RDF =recommended dose of fertilizer, NPS N=nitrogen, P=phosphorus. And sulfur

2.3. Soil Sampling and Vermicompost analysis

Prior to crop planting, six soil samples were collected at 0–20 cm depth in a zigzag pattern using an auger, and then a composite sample was formed for the determination of the properties of the experimental soil. After harvesting, the soil samples were collected per plot within the plot collect from three points and composited the sample that received the same treatment. The soil samples were air dried and ground to pass through a 2.0-mm sieve before laboratory analysis. Soil bulk density was measured from an undisturbed soil sample collected using core sampler (2.5 cm radius and 5.0 cm height) as described by Jamision *et al.* (1950), while particle density was measured using the pycnometer (Barauah, 1997). Total porosity was calculated from the values of bulk (Bd) and particle densities (Pd) (Hillel, 2003).This described as:

$$f(\%) = [1 - (Bd/Pd)] \times 100$$

Where, f = total porosity, Bd= bulk density and Pd = particle density. Soil pH (1:2.5) in soil and water suspension was measured using a pH meter. Organic carbon was measured by the rapid titration method (Walkley and Black, 1936). The determination of particle size distribution was carried out by the hydrometer (Bouyoucos, 1962). Once the sand, silt, and clay fractions were calculated in percent, the soil was assigned to a textural class based on the soil textural triangle (Rowell, 1994). Available P was determined by Olsen's method (Olsen *et al*., 1954), total N was determined following the Kjeldahl method (Jackson, 1958), and cation exchange capacity (CEC) and exchangeable bases were extracted by saturating the sample with 1N NH_4OAc (Chapman, 1965). Calcium (Ca) and magnesium (Mg) values were determined using an atomic absorption spectrophotometer (AAS), while potassium (K) and sodium (Na) were determined using a flame photometer (IITA, 1978) and analyzed at the Debre Zeyet Agricultural Research Center (DZARC) soil science laboratory.

Table 1: Selected soil physicochemical properties of the study site before planting.

Physicochemical properties of soil	Value	Rating	References	Methods of analysis
pH	8.5	Basic soil	Tekalign(1991	pH meter
A.P(mg kg^{-1})	6.5	Low	Olsen *et al*., (1954)	Olsen's method
Total N%	0.15	Medium	Murphy (1968)	Kjeldahl method
OC%	1.77	Medium	Murphy (1968)	wet oxidation method
OM	3.04	Medium	Murphy (1968)	

Ca cmol(+) kg^{-1}	3.2	Low	FAO (2006)	(AAS)
Mg cmol(+) kg^{-1}	2.7	Medium	FAO (2006)	(AAS)
Na cmol(+) kg^{-1}	3.2	High (poor)	FAO (2006)	flame photometer
K cmol(+) kg^{-1}	0.24	Low	Berhanu(1997)	flame photometer
S cmol(+) kg^{-1}	9.23	Very Low	EthioSIS, 2014	Melhlich 3
CEC cmol(+) kg^{-1}	18.10	Medium	Booker (1991)	Chapman
Pd(gcm^{-3})	2.64	Medium	Barauah *et al*, (1997)	
Bd(gcm^{-3})	1.4	Medium	Barauah *et al*, (1997)	
Tp%	46.96	Medium	Hillel D (2003)	
Sandy%	18.6			
silt%	34.76		SSSA(1959)	
clay%	46.64			
Textural class	Clay soil		Rowell(1994)	Bouyoucos hydrometric method

Key, Bd =bulk density, TP= total porosity, Pd= particle density, Tp%=percentage of total porosity, Av.P=available phosphorus and SSSA= soil science society of America

2.3.1. Vermicompost Sampling and Analysis

Table: 2 Chemical Properties of Vermicompost used for the experiment.

Para	$pH_{(H2O)}$	OC (%)	TN (%)	S (mg kg^{-1})	TP (mgkg^{-1})	Basic cations (cmol (+) kg^{-1})			
						Ca	Mg	K	Na
VC	7.5	23.2	2.06	21.35	930	24.3	11.15	6.2	4.2

Key, VC=vermicompost, OC = organic carbon, VC = vermicompost **.** *para =parameter and Sulfur*

2.4. Experimental Materials

Belete potato variety (CIP-393371.58) was used as a test crop, which was released by HARC (Holeta Agriculture Research Center) in 2009. It matures in about 95 to 100 days, the yield ranges from 29.13 t ha^{-1} under farmers and 48.8 t ha^{-1} under research center (MARD, 2012). NPS was used as inorganic fertilizer whereas, vermicompost (VC) was used as an organic fertilizer.

2.5. Experimental Procedures

Vermicompost was prepared from locally available organic input materials in the Debirezite agricultural research center's vermicomposting shed. The material includes Parthenium weed biomass collected before seed setting, semi-decomposed cow dung, and the earthworm (Eisenia foetida), which was used as raw material for vermicompost preparation. The selected experimental land was plowed to a fine tilth to a depth of 25–30 cm, harrowed using a tractor, and leveled and pulverized manually. The ridges were formed manually in each plot, with a spacing of 75 cm between ridges and 30 cm between plants. The space between the adjacent plots was 1 meter, whereas the space between the adjacent blocks was 1.5 meters. Well-sprouted medium-sized potato tubers with an approximate weight of 30 to 75 g and a sprout length of 1.5 to 2.5 cm were planted on the ridges and covered with soil (Lung'aho *et al*., 2007). Weeds were controlled by hoeing. The earthling-up was done as required to prevent exposure of tubers to direct sunlight, promote tuber bulking, and ease harvesting. The haulms were mowed two weeks before harvesting to thicken tuber periderm when the plants reached physiological maturity and senescence in order to reduce bruising and skinning during harvesting and post-harvest handling.

2.6. Data Collection and Measurement

Data on crop phenology, growth, yield, and yield components were measured from randomly selected plants on a plot basis. The net plot size was used for measuring the yield and yield components of potatoes. The following data were collected:

Marketable tuber number per hill: The number of tubers that were free from disease and insect pests and had a mean weight of at least 25 g was determined by counting among the total tubers harvested from the five plants, and then the average value was recorded.

Unmarketable tuber number per hill: The number of the tubers that are unhealthy, injured by insect pests, and less than 25 g in weight was determined by counting the total tubers harvested from the five plants, and then the average value was used.

Total tuber number per plant: The total tuber number was recorded as the sum of the numbers of marketable and unmarketable tubers per plant in each plot.

Marketable tuber yield (t ha^{-1}): It was determined as the total weight of healthy tubers and those having a weight greater than 25 g from the net plot area, and the value was converted into t ha^{-1}.

Unmarketable tuber yield (t ha^{-1}): The weight of unhealthy tubers those weighing less than 25 g was calculated from the net plot area and converted to t/ha.

Total tuber yield (t ha^{-1}): It was recorded as the sum of marketable and unmarketable tuber yields.

Harvest index: It was calculated as the ratio of the dry mass of tubers to the dry mass of total biomass and expressed as a ratio.

2.7. Data Analysis

The data were subjected to an analysis of variance using the statistical software SAS version 9.3.1 (SAS Institute, 2003). Differences among treatment means were delineated using the Least Significant Difference (LSD) at a 5% level of significance.

3. Results and Discussions

3.1. Effects of the treatments on residual soil chemical properties

3.1.1. Residual soil total nitrogen, available phosphorus, organic carbon and pH

Residual soil Total nitrogen. Total nitrogen in pre-sowing soil was 0.15%, while soil total nitrogen after harvest ranges from 0.14% to 0.48%. The highest residual soil N total was obtained from 7.5 t ha^{-1} of vermicompost plus 75% blended NPS fertilizer, while the lowest value was recorded from zero application of blended NPS fertilizer and vermicompost. The highest combined application of blended NPS fertilizer and organic vermicompost increased total N by 242.85% over the control. The present study is in line with Gurwinder *et al*. (2018), who found that application of organic material such as compost and manure significantly increased the total nitrogen and organic matter in the soil in northwestern Ethiopia.

Residual soil available phosphorus: Available P in pre-sowing soil was 6.5 mg kg^{-1}, while available P in harvested soil ranged from 6.41 to 17.46 mg kg^{-1}. The highest available P was obtained at a combined application of 75% blended NPS fertilizer and 7.5 t ha^{-1} vermicompost. Which implies that the 172.38% of available P increased as compared to the control plot. The result also showed an increase in the available P level when vermicompost application increased throughout the treatment except for the control. This is due to the highest concentration of nutrients from the blended NPS fertilizer and the addition of 930 mg kg^{-1} total phosphorus from the organic vermicompost fertilizer to optimize the availability of phosphorus in the soil. In addition to the combined application of blended NPS fertilizer, VC increases soil available P because of its richness in NPK micronutrients and beneficial soil microbes (phosphate solubilizing bacteria and Actinomycetes) (Ankushdee *et al*., 2020).

Residual soil available Sulfur: Residual soil after treatment, available sulfur in the experimental site ranges from 11.50 to 14.04 mkg^{-1}. The residual sulfur content of samples from all treatments was found to be below the critical level suggested by Kebede and Yamoah (2009) after applying vermicompost and blended NPS fertilizer. The highest value of valuable sulfur (14.04 mg kg^{-1}) was recorded from treatment with 7.5 t ha^{-1} VC+ 75% blended NPS fertilizer, and the lowest value (11.50 mg kg^{-1}) was recorded from the control treatment. The increase in residual soil available sulfur over the control might be due to the sulfur supplied to the soil from both vermicompost and chemical fertilizer (Wagari *et al*., 2022). It has been reported that the integrated use of vermicompost and blended NPS fertilizer increases the sulfur status of soil.

Residual soil Organic carbon: The organic carbon content in pre-sowing soil was 1.77 % while, it ranges from 1.75 - 2.7% in residual soil. This also indicates the contribution of the vermicompost in increasing soil organic carbon content. Highest organic carbon content (2.70%) was obtained at combined application of 75% blended NPS fertilizer and 7.5 t ha^{-1} vermicompost. while the lowest was obtained in the control plot. The highest combination treatment application increased the organic carbon content by 54.28% as compared to the control plot. This was due to high dose application of organic carbon 23.2% from the vermicompost. These results are consistent with those of Ejigu *et al*. (2021) study, who reported that, the application organic inputs combination with inorganic fertilizers exerted greater influence on soil organic carbon content in the soil.

Residual soil pH: The soil pH varied from 6.3 to 7.2 among the treatments. The lowest pH (6.3) was obtained on plots that received sole applications of vermicopost treatments, while the highest value (7.2) was in the control. The dramatic decrease in pH could be due to microbial degradation and the production of organic acids like humic acid (Demir, 2020). Application of vermicompost changes soil pH from alkalinity to neutrality, thus improving nutrient availability, especially for NPS and micronutrients (Zn and Fe). This move towards neutrality is also favorable for plant growth and a variety of beneficial microbial processes. Therefore, vermicompost should be regarded not only as a source of nutrients but also as a beneficial soil conditioner (Hoshang *et al.*, 2017). Compared to the highest combine application of vermicompost and blended NPS fertilizer, sole application of vermicompost reduce soil pH 4.5%.This is because of the rising of vermicompost rate in the soil caused in the decrease in pH of soil due to the fabrication of $NH4^{+}$, CO_2 and carbon-based acids through bacterial digestion could contribute to the reductions in the soil pH which is similar with (Getachew *et al*., 2019). In addition that application of 7.5t ha^{-} low pH than 100% NPS. This might be due to the artificial fertilizer especially Phosphorus fertilizer which has potential to build up sodium in soil and subsequently in plant (Dagne *et al*., 2019)

Table 4: The effects of blended NPS fertilizer and Vermicompost on Residual soil Av.P, Total N, OC, pH and Av. S

Treatment	Total N%	S(mg kg$^{-1)}$	Av. P (mg kg$^{-1)}$	OC%	pH
Control	0.14^{k}	11.50 ^{h}	6.41^{h}	1.75^{e}	7.2^{a}
7.5t ha^{-1}	0.18^{i}	12.04^{gh}	7.41f^{gh}	2.22^{cd}	6.3^{b}
100% NPS	0.16^{j}	12.08^{gh}	7.38^{gh}	2.14^{d}	6.5^{b}
2.5 t ha^{-1}VC+25% NPS	0.21^{h}	12.13^{fg}	8.26^{fg}	2.24^{dc}	7.1^{a}
2.5 t ha^{-1}VC+50% NPS	0.21^{h}	12.49^{ef}	9.17^{ef}	2.26^{dc}	7.1^{a}
2.5 t ha^{-1}VC+75% NPS	0.23^{g}	12.58^{de}	10.37^{de}	2.31^{cd}	7.1^{a}
5 t ha^{-1} VC+25% NPS	0.33^{f}	12.63^{d}	10.98^{d}	2.37^{bc}	7.1^{a}
5t ha^{-1} VC+50% NPS	0.33^{e}	13.03^{cd}	11.78^{cd}	2.49^{ab}	7.1^{a}
5t ha^{-1} VC+75% NPS	0.35^{d}	13.35^{c}	13.07^{c}	2.53^{ab}	7.0^{a}
7.5 t ha^{-1}VC+25% NPS	0.37^{c}	13.42^{b}	15.04^{b}	2.63^{ab}	7.0^{a}
7.5t ha^{-1}VC+50% NPS	0.46^{b}	13.85^{ab}	16.37^{ab}	2.65^{ab}	6.7^{b}
7.5t ha^{-1}VC+75% NPS	0.48^{a}	14.04 ^{a}	17.46^{a}	2.70^{a}	6.6^{b}
Mean	0.28	12.76	11.12	2.36	6.9^{b}
LSD (5%)	0.36	0.09	1.77	0.31	0.34
CV%	7.43	0.44	9.43	7.96	2.91

Means with followed by the same letter(s) in columns are not significantly different at 5% level of significance. O.C= organic carbon, pH=power of hydrogen. VC= vermicompost, NPS=nitrogen, phosphorus and sulfur

Residual soil Exchangeable calcium: Either the sole or combined application of vermicompost and blended NPS fertilizer increased soil fertility. Vermicompost alone increased soil Ex Ca by 53.33 percent more than the control. An increase of 341.51% above the control was recorded for soil from plots treated with the highest combined application of blended NPS fertilizer and vermicompost at rates of 75% and 7.50 t ha^{-1}. Probably, this higher Ex.Ca content from the combination of blended NPS fertilizer and vermicompost might be attributed to the release of Ca ions through the dissolution and mineralization of the vermicompost (Mengistu *et al*., 2017).

Residual soil Exchangeable Mg: In comparison to the control, combined or individual applications of blended NPS fertilizer and vermicompost increased soil Ex. Mg. The increment in soil exchangeable is due to vermicopost application, which varied from 9.62 to 78.71% over the control. This might be due to the high Ex.Mg content of applied vermicompost (11.15 cmol (+) kg^{-1}) and optimized soil organic matter content due to blended NPS fertilizer application (Urmi *et al.,* 2022).

Residual soil Exchangeable K: Application of both amendments (blended NPS fertilizer and vermicompost) either separately or in combination showed increased soil fertility (Ex. K takes command. The Ex. The soil K increased as the combined application of vermicompost and blended NPS fertilizer increased**.** The highest Ex. K (0.49 cmol (+) kg^{-1} soil) was recorded in the combined application of 75% blended NPS fertilizer and 7.5 t ha^{-1} vermicompost, while the lowest value (0.21 cmol (+) kg^{-1} soil) was recorded in the control. The highest value increased by 133.3% over the control check. On the other hand, using vermicompost alone increases Ex. K increased by 19.04% over the control, which could be attributed to the addition of Ex. K from vermicompost as a result of organic matter decomposition and mineralization in the soil system (Knife *et al*., 2019).

Residual soil Exchangeable Na: Both amendments (blended NPS fertilizer and vermicompost) have a significant impact on residual Ex Na. when used separately or in combination. This is because of soil microorganisms which is present vermicompost have capacity to solubilize exchangeable sodium and leach from the root zone which reduces its availability in the soil which is similar with (Justyna, 2019). Additionally, vermicomposting could improve the bacterial community and function of soil bacteria, which in turn would improve soil structure by releasing exoplysacchariddes, forming organic mineral complexes, and bonding soil particles into aggregates. Therefore, vermicompost can inhibit alkalization by increasing macro aggregates of alkaline soil (Demir *et al*., 2020). In addition, humic acid, which is present in vermicopost, plays an important role in the process of structural stabilization and improves nutrient availability and the chemical, biological, and physical properties of the soil. Therefore, vermicopost treatment can improve soil structure and increase nutrient availability, water retention capacity, and microbial activity in alkaline soil (Rady *et al*., 2016).

Table 5: The effects of blended NPS fertilizer and Vermicompost on Residual soil CEC and exchangeable bases (K, Na, Ca, and Mg).

Treatment	CEC	Ex .K	Ex .Na	Ex .Ca	Ex .Mg	PBS%
Control	18.33^{cd}	0.21^{i}	0.23^{fg}	3.30^{g}	3.43^{g}	39.11^{ef}
7.5t ha^{-1} VC	19.26^{cd}	0.26^{gh}	0.24^{ef}	5.39^{f}	3.96^{efg}	51.09^{de}
100% NPS	18.88^{cd}	0.25^{h}	0.23^{e}	5.06^{fg}	3.76^{fg}	49.31
2.5 t ha^{-1}VC+25% NPS	20.13^{bcd}	0.27^{g}	0.28^{cd}	5.41^{f}	4.26^{defg}	50.76^{de}
2.5 t ha^{-1}VC+50% NPS	20.26^{bcd}	0.33^{f}	0.28^{cd}	7.82^{e}	4.50^{cdef}	63.82^{d}
2.5 t ha^{-1}VC+75% NPS	20.40^{bc}	0.37^{e}	0.28^{cd}	8.16^{de}	4.73^{bcdef}	66.37^{c}
5 t ha^{-1} VC+25% NPS	20.53^{bc}	0.38^{de}	0.27^{c}	8.90^{de}	5.06^{abcd}	71.16^{bc}
5t ha^{-1} VC+50% NPS	21.73^{ab}	0.39^{cd}	0.27^{c}	9.81^{cd}	5.33^{abcd}	72.71^{bc}
5t ha^{-1} VC+75% NPS	21.93^{ab}	0.41^{bc}	0.27^{c}	11.10^{bc}	5.53^{abc}	78.93^{b}
7.5 t ha^{-1}VC+25% NPS	22.89^{a}	0.43^{b}	0.27^{c}	12.14^{b}	5.73^{abc}	81.12^{ab}
7.5t ha^{-1}VC+50% NPS	23.00^{a}	0.48^{a}	0.26^{ab}	14.43^{a}	5.93^{ab}	91.73^{ab}
7.5t ha^{-1}VC+75% NPS	23.13^{a}	0.49^{a}	0.25^{a}	14.57^{a}	6.13^{a}	92.69^{a}
Mean	20.86	0.35	0.26	11.92	4.86	67.4
LSD (5%)	2.05	0.026	0.05	1.93	1.14	7.49
CV%	5.82	4.3	12.45	9.64	9.92	9.64

Means followed by the same latter in column are not significantly different at 5% level of significance. CEC =cation exchange capacity, Ca= calcium, Mg=magnesium, Na=sodium and K=potassium and, PBS=percentage base saturation.

3.2. Effects of blended NPS fertilizer and Vermicompost Rates on Potato Yield and Yield Components

3.2.1. Unmarketable Tuber Number and tuber yield per Hill. The unmarketable tuber number and unmarketable tuber yield were not significantly affected by the treatments. The unmarketable tuber yield in potatoes is more importantly controlled through manipulating other factors such as disease incidence, harvesting practices, etc., rather than nutrient amendment (Zewide *et al*., 2018).

3.2.2. Marketable Tuber Numbers per Hill. The treatments had a highly significant (P 0.01) influence on marketable tuber numbers. The highest number of potato tubers (18.23/hill) were found when using 75% blended NPS fertilizer + 7.5 t ha^{-1} vermicompost, while the lowest number (8.00) was found when using the control.

Applying 75% blended NPS fertilizer plus 7.5 t ha^{-1} vermicompost significantly increased the number of tubers by 127.85% as compared to the control. This is because the combined application of organic and inorganic fertilizer increased essential soil nutrients and promoted biological activities, which ultimately promoted plant growth and production on a sustainable basis (Bekele *et al.*, 2019). Similarly, Mohammed *et al.* (2018) showed that the interaction effect of farmyard manure and blended NPS fertilizer significantly increased the total and marketable tuber number of potatoes.

3.2.3. Total Tuber Number per Hill. The treatments had a highly significant (P 0.01) influence on total tuber numbers per plant. The highest total tuber numbers per plant were obtained by applying 7.5 t ha^{-1} of vermicompost plus 75% blended NPS fertilizer. The lowest value was recorded in the control plot. This could be due to the presence of beneficial microorganisms which increased soil organic nitrogen, and solubilized, solubilize available P and sulfur that favorable for absorbing the important plant nutrient (Bewket *et al*., 2018).

3.2.4. Marketable tuber yield. On marketable tuber yield, the treatments had a highly significant (P 0.01) influence. The lowest marketable yield (18.88 t ha^{-1}) was recorded in the control, whereas the highest marketable yield (41.47 t ha^{-1}) was obtained from 7.5 t ha^{-1} of vermicompost + 75% blended NPS fertilizer. Applying 7.5 t ha^{-1} of vermicompost plus 75% blended NPS fertilizer resulted in increases in marketable potato yield of 119.65% over control. This may be due to the positive interaction and complementary effect between the cattle manure interaction and the complementary effect between vermicompost and blended NPS fertilizer in affecting and increasing the marketable tuber yield. In addition to this, the optimum nutrients contained in vermicompost and the immediate response of organic fertilizer may have led to a high leaf area index through improved leaf growth and photosynthesis (Ahmed *et al*., 2019). Besides this, organic fertilizer application may enhance microbial activities and conserve soil moisture, delay senescence, and increase the life span of the potato plant, which could result in a high marketable yield (Bekelech *et al*., 2020).

3.3.3. Total tuber yield

Application of the treatments had highly significant ($P < 0.01$) influence on total tuber yield. The highest total tuber yield (44.33 t ha^{-1}) was recorded at the 7.5 t ha^{-1} vermicompost + 75% blended NPS fertilizer while, the lowest value (22.5 t ha^{-1}) was found from the control. Applying 7.5 t ha^{-1} vermicompost + 75% blended NPS fertilizer increased the total tuber yield by 97.00 % over the control. This is due to higher fertilizer response further linked to the increase in total leaf area which in turn increased the amount of solar radiation intercepted and dry matter produced and assimilated to the tubers. Higher yield response with increasing the levels of both fertilizer types indicate the importance of higher rates of blended NPS fertilizer and organic vermicompost to obtain higher total tuber yield. (Wagari, *et al*., 2022). Because Vermicompost has ability to improving soil physical properties such as structure which in turn improves soil moisture and makes nutrients available. This result is supported by Mengistu (2017) the quantity of microorganisms, especially bacteria, and a high concentration of plant hormones Such as auxins, gibberellins and cytokinins in earthworm that present in vermicompost increases yield of potato. The yield obtained from sole vermicompost application was smaller than the yields produced from sole application of blended NPS fertilizer. This is due to Sole application of vermicompost is constrained by low availability of nutrients means that slow release of nutrient and does not gave immediate response to the current crop and temporary depletion nitrogen in the soil there for in the plant (Ahmed *et al*., 2019).

3.3.4. Harvest index in %

According to the analysis of variance, the treatments had a significant (P 0.01) influence on the harvesting index. The highest harvest index was recorded in the control treatment. Whereas the lowest harvest index (51.46) was recorded in the maximum combination of blended NPS fertilizer and vermicompost. This increase in dry matter percentage could be due to the combined effect of organic vermicompost that supplies macro- and micronutrients, the immediate response of blended NPS fertilizer, and the strong nutrient movement of assimilates from the photo synthetically active leaves to the tuber during the growth and development period (Zewide *et al*., 2018).

Table6: Effects of blended NPS fertilizer and Vermicompost on yield components of potato t ha^{-1}.

Treatment	MTN	UMTN	TMTN	MTY	UMTY	TTY t/ha	HI
Control	8.00^{d}	3.13	11.13^{cd}	18.88^{i}	3.66	22.54^{h}	75.06^{a}

7.5t ha^{-1}VC	9.93^{c}	3.53	13.46^{cd}	22.22^{h}	2.86	25.18^{gh}	67.20^{ab}
100% NPS	9.93^{c}	3.66	13.59^{cd}	22.59^{gh}	3.53	26.12^{gh}	65.03^{ab}
2.5 t ha^{-1}VC+25% NPS	10.20^{c}	3.53	13.76^{cd}	22.87^{gh}	3.53	26.40^{fg}	64.73^{ab}
2.5 t ha^{-1}VC+50% NPS	10.53^{c}	3.33	13.86^{c}	24.81^{fgh}	3.33	28.14^{def}	62.60^{ab}
2.5 t ha^{-1}VC+75% NPS	10.73^{c}	3.26	13.99^{c}	25.16^{efg}	3.26	28.42^{def}	61.36^{ab}
5 t ha^{-1}VC+25% NPS	10.82^{c}	3.20	14.02^{c}	27.03^{ef}	3.20	30.23^{def}	60.06^{ab}
5t ha^{-1}VC+50% NPS	11.00^{c}	3.20	14.02^{c}	27.77^{de}	3.20	30.97^{de}	57.74^{b}
5t ha^{-1}VC+75% NPS	11.02^{c}	3.13	14.20^{c}	30.37^{cd}	3.13	33.50^{cd}	55.63^{b}
7.5 t ha^{-1}VC+25% NPS	11.40^{c}	2.93	14.33^{c}	32.22^{c}	2.93	35.15^{c}	53.50^{bc}
7.5t ha^{-1}VC+50% NPS	14.33^{b}	2.93	17.26^{b}	35.92^{b}	2.93	38.85^{b}	51.83^{c}
7.5t ha^{-1}VC+75% NPS	18.23^{a}	2.86	21.09^{a}	41.47^{a}	2.86	44.33^{a}	51.46^{cd}
Mean	11.34	3.22	14.52	27.61	3.22	30.09	60.51
LSD (5%)	1.70	1.26	1.95	2.94	1.26	3.10	17.58
CV%	8.9	23.20	7.97	6.32	23.20	6.11	17.24

Means with followed by the same letter(s) in columns are not significantly different at 5% level of significance, mark =marketable, unmark= unmarketable, and HI= harvesting index

3.4. Correlation analysis

A correlation coefficient value (r) is computed to display the relationships between soil property and agronomic traits. The correlation analysis between agronomic parameters and selected residual soil property parameters revealed that it was negatively correlated with particle density, bulk density, and pH of the soil, with the exception of unmarketable tuber number and harvesting index, which are not significantly correlated with Pd (r = 0.15ns **; p 0.01); Bd (r = 0.12ns **; p 0.01) and Pd (r = 0.21ns **; p 0.01) and Bd (r = However, other agronomic trait were as positive correlated with most other selected soil physiochemical properties, this could be due to the increasing availability macronutrients from by the amendment.

Table 7: Correlation of agronomic parameters versus Postharvest residual soil physiochemical property.

Parameter	**Pd**	**Bd**	**TP**	**pH**	**TN**	**P**	**S**	**OC**
MTN	-0.37^{*}	-0.39^{*}	0.39^{*}	-0.74^{**}	0.32^{*}	0.52^{**}	0.87^{**}	0.46^{**}
UMTN	0.15^{ns}	0.12^{ns}	-0.08^{ns}	-0.19^{ns}	-0.25^{ns}	-0.28^{ns}	0.45^{ns}	-0.30^{ns}
TTN	-0.33^{*}	-0.36^{*}	0.37^{*}	-0.71^{**}	0.25^{**}	0.45^{**}	0.97^{**}	0.38^{*}
MTY	-0.49^{**}	-0.51^{*}	0.46^{**}	-0.72^{**}	0.58^{**}	0.72^{**}	0.91^{**}	0.64^{**}
UTY	0.620^{**}	0.61^{*}	-0.56^{**}	-0.51^{**}	-0.60^{**}	-0.59^{**}	0.55^{**}	-0.63^{**}
TTY	-0.46^{**}	-0.48^{*}	0.43^{**}	-0.72^{**}	0.56^{**}	0.71^{**}	0.96^{**}	0.62^{**}
HI	0.21^{ns}	-0.27^{ns}	-0.22^{ns}	0.47^{**}	-0.38^{*}	-0.50^{**}	-0.67	-0.37^{*}

Table cont'….

Parameter	CEC	Ca	Mg	Na	K
MTN	0.37^{*}	0.46^{**}	0.46^{**}	-0.41^{*}	0.52^{**}
UMTN	-0.24^{ns}	-0.29^{ns}	-0.16^{ns}	0.23^{ns}	-0.26^{ns}
TTN	0.31	0.40^{*}	0.43^{**}	-0.34^{*}	0.45^{**}
MTY	0.59^{**}	0.66^{**}	0.55^{**}	-0.62^{**}	0.70^{**}
UTY	-0.56^{*}	-0.58^{**}	-0.57^{**}	0.61^{ns}	-0.61^{**}
TTY	0.58^{**}	0.65^{**}	0.53^{**}	0.61^{**}	0.69^{**}
HI	-0.35^{*}	-0.48^{**}	-0.66^{**}	0.48^{**}	-0.53^{**}

* = Significant at $P \le 0.05$; ** = Significant at ≤ 0.01.

4. Conclusions and recommendation

The combined application of blended NPS fertilizer and vermicompost gave a better result than the application of sole, which indicates integrated nutrient management is the good method for soil fertility management. In the Debre Berhan central highlands of Ethiopia, the soil is Vertisol, so vermicompost would be a good amendment. Hence, the use of 75% blended NPS fertilizer plus 7.5 t VC ha^{-1} can be recommended for better potato production and productivity in the Debre Berhan central highlands of Ethiopia. Therefore, this work concludes that the integrated application of 7.5 t ha^{-1} vermicompost and 75% blended NPS fertilizer is found to be the good integrated nutrient management for potato production in the Debre Berhan central highlands of Ethiopia. But it would be difficult to draw a definite and widely applicable conclusion based on the research results of only one season and one site. Therefore, further studies are needed to better understand its effect on potato production and its economic feasibility.

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