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Effect of Different Rates of Vermicompost and Inorganic Np Fertilizers on Yield and Yield Component of Potato (*Solanum tuberosum* L.) at Masha District, South West Ethiopia

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Abstract: Declining soil fertility is one of the major problems causing yield reduction in Ethiopia. Farmers at Masha apply both organic and inorganic fertilizers to overcome the problem and increase yield of potato. Still, information on the application of Vermicompost and chemical fertilizer is inadequate to the area to increase the yield of potato crop. Therefore, an experiment was conducted at Masha, Southern Ethiopia during the 2017 cropping season with the objective of assessing the effect of vermicompost and mineral NP fertilizers on yields and yield component of potato. There were fifteen treatments comprising of three levels of Vermicompost (0, 5, 7.5 t ha^{-1}) with five levels of combined mineral NP fertilizers [0, 25%, 50%, 75%, 100% of blanket recommended rates of NP (110 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1})] in randomized complete block design in factorial arrangement with three replications. The improved potato variety "Jalane" was used as a test crop. The results showed that the main effect of vermicompost and mineral NP fertilizers was significant ($P<0.01$) on tuber number per hill, tuber size category and tuber yield (tha^{-1}). The highest marketable tuber number per hill (8.38), highest total tuber per hill (11.69) and highest large sized tuber (69.21%) were recorded from application of 7.5 t ha^{-1} vermicompost. The highest marketable tuber number per hill (8.42), highest total tuber number per hill (11.67) and highest large sized tuber (68.79%) were recorded from application of 100% mineral NP fertilizers. There was significant interaction effect of vermicompost and mineral NP fertilizers on days to 50% flowering, days to maturity and plant height. The maximum total and marketable tuber yields of 35.11t ha^{-1} and 33.97 t ha^{-1} recorded at the rate of 7.5 t ha^{-1} VC, respectively while the maximum total and marketable tuber yield of 37.97 t ha^{-1}and 36.78 t ha$^{-1,}$ respectively were obtained in response to the application of 100% blanket recommended mineral NP fertilizer rate. However, partial budget analysis indicated that application of 7.5 t ha^{-1} VC and 75% of blanket recommended mineral NP fertilizers gave the optimum net benefit with the marginal rate of return 282.2%. It could, thus, be tentatively concluded that application of 7.5 t ha^{-1} VC and 75% of blanket recommended mineral NP fertilizers resulted in optimum growth and yield of the crop.

Key words: Soil Fertility · Tuber Yield · Partial Budget · Marketable Yield

INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to the family *Solanaceae*, genus *Solanum* and accommodated in series *Tuberosa* [1]. Potato is an important food and cash crop in eastern and central Africa. It is playing a major role in national food security and nutrition, poverty alleviation and income generation and provides employment in the production, processing and marketing sub-sectors [2].

The area under potato production in Ethiopia in 2015/16 (2008 EC) was about 296, 577.59 hectares with annual production of 3, 657, 638.26 tonnes of yield [3]. The national average yield is 7.2 tons ha^{-1}, which was very low compared to the world's average of 16.4 tons ha^{-1} and to other potato producing countries of the world, such as the Netherlands (40 tons ha^{-1}), Germany (28 tons ha^{-1}), Egypt (17.4 tons ha^{-1}) and Burundi (11 tons ha^{-1}) [4].

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On the other hand, the potentially attainable average yields of the crop on research and farmers' fields are 40 and 20 tons' ha^{-1}, respectively [5]. The gap between the potential yield and the current average national yield per unit area of land could be attributed to many diverse and complex biotic, abiotic and human factors. The major ones are shortage of arable land in the high lands [6, 7], unavailability and high cost of seed tubers, shortage of adaptable and high yielding varieties [8, 9], occurrence of diseases and insect pests [10], insufficient transportation and marketing facilities [11, 12], little information on agro-ecology based fertilizer rate (both minerals and organic) [13].

Ensuring food security is one of the greatest challenges facing the world community including Ethiopia [14]. Sustainable food production to feed the ever increasing human population is a critical issue today. The dual challenge of meeting human food requirements and maintaining or even improving the quality of environment is the basic objective of sustainable crop production. Soil fertility replenishment in Sub Saharan Africa (SSA) is increasingly viewed as critical to the process of poverty alleviation [15].

The average plant nutrient depletion in East Africa, particularly of Ethiopia is estimated to be around 47–88 kg ha^{-1} $year^{-1}$ in general and 100 kg ha^{-1} $year^{-1}$ in particular on the highlands [16]. Major factors contributing to such depletion are soil erosion, soil acidity, fixation of phosphorus (P) and leaching in respect of nitrogen (N) and potassium (K), further accelerated by deleterious land use practices resulting from high population pressure. Tamirie [17] speculated that indiscriminate clearing of forests, complete removal of crop residues, uncontrolled grazing and low fertilizer inputs, absence of soil and water conservation measures and crop rotations and above all poor soil management practices contribute to accelerated soil erosion. Soil erosion is particularly high on soils without crop cover thereby enhancing soil nutrient depletion, which emphasizes the need for optimum nutrient management for higher crop productivity.

Most Ethiopian soils are deficit in major nutrients, especially nitrogen and phosphorus [18]. Fertilizer application has significantly improved growth and yields of Anchote [19]. However, despite potential for increasing yields and farmer's income using fertilizer; most small scale farmers do not have the required resources to make or purchase fertilizer [10]. This is mainly due to limited access to modern research-led agricultural technologies, including inputs such as mineral and organic fertilizers [20]. In Ethiopia, the amounts of fertilizers applied to the potato crop are very low. Gildemacher *et al*. [21] estimated that the amounts of Vermicompost (VC), nitrogen and phosphorus applied to the potato crop by smallholder farmers were only 3 t ha^{-1}, 30.6 kg N ha^{-1} and 76.5 kg P_2O_5 ha^{-1}, respectively. Moreover, though fertilizer use in Ethiopia has increased notably since 1990, Mulat *et al*. [22], there is no concomitant attainable yield increase, especially in potato [10, 23]. Furthermore, no mineral fertilizers other than those carrying nitrogen (urea) and phosphorus (DAP) are applied in the country [24].

Although potato is a major crop produced in Sheka Zone, its productivity is less than its potential due to poor fertility of the soil, leaching of major nutrients which enhance production of the crops, fixation of P, constraints of soil acidity, high cost of planting materials, disease and pest, unavailability of high yielding variety, shortage of vermicompost to cover the outfield and high cost of chemical (inorganic) fertilizers to apply at the required rate. Generally, there is little information on balanced use of organic and inorganic fertilizer on potato production in Sheka Zone. Hence, conducting systematic investigation in this line is vital to come up with conclusive recommendations that would help to increase the yield of the potato crop in the study area. Thus, this research was initiated with the following objectives:

- To assess the effects of rates of VC and mineral NP fertilizers on yield and yield components of potato,

MATERIALS AND METHODS

Description of the Study Site: The experiment was conducted in Masha Woreda at Tepi Agricultural Research Center (TARC) during March to August in 2017, Sheka Zone, Southern Nations Nationalities and Peoples Regional States (SNNPRs). It is located at 677 km South of Addis Ababa and 87 km from Masha town, found at 7°44'N latitude and 35°29E longitude. The altitude of the area is 2223 above sea level (m.a.s.l). The area receives an annual rainfall of 1800-2200 mm in bi-modal pattern which extends from march to September and annual mean temperature of 15-27°C. The soils of the area were Acrisoils [25]. Acrisoils are characterized by high kaolinitic clays, low cation exchange capacity, low base saturation and low pH values. This may be due to hot climate and high rainfall that result in intensive leaching. These soils were deep, well drained and reddish brown when moist and dark red when dry [25].

Table 1: Results of laboratory analysis of vermicompost (VC) used for the experiment

VC parameters	Values
pH	7.2
Total N (%)	1.71
Available P (%)	0.52
Exchangeable K (%)	2.55
Organic matter (%)	5.57

Experimental Material: The improved potato variety Jalene was used for study (test crop). The variety was released by the Holleta Agricultural Research Center (HARC) in 2002. It was one of the potential potato cultivar for Masha district South West Ethiopia. It was being cultivated widely and had been accepted by farmers due to its high yielding ability, consumer's preference, wider adaptation, better cooking ability and relatively its resistance to late blight compared to local and other improved potato varieties growing in the area. The adaptation area of the variety was 1600-2800 altitude (m.a.s.l), the variety matures at 90-120 days after planting. The planting date of the variety takes place in the first 10 days of March in the main season. The yield potential of the variety in the research field was 44.8 t ha^{-1}.

Nitrogen in the form of Urea (46% N) and phosphorous in the form of triple superphosphate (46% P_2O_5) were used as source of N and P, respectively. Well decomposed vermicompost was used. The vermicompost was analyzed for the pH, N, P, K and organic matter content before application.

Treatments and Experimental Design: The experiment consists of two factors. The treatments consisting of five levels of combined NP fertilizer 0, 25% (42 N kg /ha and 34 P_2O_5 kg/ha), 50% (83 N kg /ha and 68 P_2O_5 kg/ha), 75% (123 N/ha and 101.25 P_2O_5kg/ha) and 100 % (165 N kg/ha and 135 P_2O_5 kg/ha) of the recommended national fertilizer rates) and three levels of VC (0, 5 and 7.5 tone/hectare,) arranged in a randomized complete block design (RCBD) and replicated three times.

Each block and plots within block was spaced 1 m and 0.5 m apart, respectively. Each plot was consisting of four rows of 75 cm apart between each and plant was spaced 30 cm apart each other. There were 12 plants per row. The gross plot size was therefore, 4.5m × 3.6 m (16.2m^2). In each plot, one plant at the end of each row were left to avoid the border effect and from each plot the two central rows were considered for yield and yield related component. The net plot size for data collection was 3 x 3 (9 m^2).

Table 2: Physicochemical Properties of the Experimental Site before planting

Soil characters	Value	Rating	Reference
A. Particle size distribution			
Sand (%)	26		
Silt (%)	40		
Clay (%)	34		
Textural class		Clay loam	
B. Chemical analysis			
Soil pH	5.2	Strongly acidic	[31]
Organic carbon (%)	1.52	Medium	[3]
Total N (%)	0.15	Medium	[3]
Available P (mg kg^{-1})	5.30	Low	[28]
CEC [cmol (+) kg^{-1})	24.11	Medium	[32]
%Organic matter	2.61		

Soil Sampling and Analysis: Pre-plant soil samples were taken diagonally at 0-30 cm soil depth in three replications. The samples were bulked to make one composite sample for the determination of selected physicochemical properties of the experimental soil. Sampled soils were air-dried, ground and then sieved through a 2-mm sieve. These samples were analyzed for pH (1:2.5 soil: water suspension), organic carbon by rapid titration method [26], soil texture[27], available P by Olsen's method [28], total N by Kjeldahl method [29]. Cation Exchange Capacity (CEC) was measured by ammonium acetate method after saturating the soil with 1N NH_4OAC and displacing it with 1N NaOAC [30].

Experimental Procedures: In order to have a better seedbed for proper root development, the experimental field was ploughed by the tractor. Thirteen days prior to planting, Vermicompost (VC) was spread in the plots and thoroughly incorporated into the soil. A total of 45 experimental plots were laid out and the required numbers of ridges were marked and ridges were formed manually in each plot with the spacing of 75 cm between the ridges. When there was sufficient soil moisture, well sprouted medium-sized (40 to 60 g) tubers of the potato variety were planted on the ridges at the spacing of 75 cm between ridges and the intra row spacing of 30 cm on March 28, 2017 and harvested on August 22, 2017. The triple superphosphate (46% P_2O_5) was placed in bands below the seed piece and covered with soil on each ridge. Nitrogen was side-dressed in three splits, i.e. 1/4 at plant emergence; 1/2 at the first earthing up and the remaining 1/4 at 40 days after planting. All agronomic practices such as weed control and earthing up were done regularly during the growing seasons. When the plants reached physiological maturity (when 70% of the haulms dried up) tubers were harvested.

Data Collection

Days to 50% flowering: Days to flowering was recorded as the number of days from planting when 50% of the plants in each plot produced flowers.

Days to 90% Physiological Maturity: Was recorded when 70% of leaves from different treatments were turned to yellow.

Average Stems Number per Hill: The actual numbers of main stems per hill were recorded as the average stem count of five hills per plot at 50% flowering. Only stems that emerged independently above the soil as single stems were considered as main stems. Stems branching from other stems above the soil were not considered as main stems.

Plant Height (cm): Refers to the height from the base to the apex of the plant. It was measured using a measuring tape at 90% physiological maturity from the main stem originating directly from mother tubers to the apex of the plant by taking five sample plants from each plot.

Total Tuber Numbers/Hill: Was obtained by adding up the number of marketable and unmarketable tubers. This parameter constituted all tubers: small, medium, large, diseased, deformed etc that were produced by the plants.

Marketable Tuber Number/Hill: The number of tubers was counted as marketable which are greater or equal to 25g, free from disease and insect attack in each plot and divided to the respective number of plants harvested.

Unmarketable Tuber Number /Hill: The number of tubers counted as unmarketable which were diseased, insect attacked, deformed and weight less than 25 g.

Tuber Size Distribution in Weight: At harvest, tubers were collected from five randomly selected plants from each plot and were categorized as small (25-38g); medium (39-75g); and large (>75 g) [2]. The proportion of the weight of tubers in the different tuber size categories were converted to percentages.

Marketable Tubers Yield (t ha^{-1}): These were recorded as the weight of marketable tubers that are free from diseases, insect pests and greater than or equal to 25 g in weight [2]. These were taken from hills in the net plot area at harvest and converted to t ha^{-1}.

Unmarketable Tubers Yield (t ha^{-1}): Tubers yield recorded as unmarketable which were diseased, insect attacked, deformed and weight less than 25 g.

Total Tubers Yield (t ha^{-1}): It was recorded as the sum of marketable and unmarketable tuber yield from net plot area harvested and converted in to t ha^{-1}.

Statistical Data Analysis: All the measured parameters were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to the General Liner Model (GLM) of the GeneStat 15th edition [33] and interpretation were made following the procedure described by Gomez and Gomez [34]. Whenever the effects of the treatments were found to be significant, the means were compared using the Least Significant Differences (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

Phenological Parameters of Potato: There were significant ($P < 0.01$) differences in days to 50% flowering of potato due to the main effect of mineral NP fertilizers and vermicompost (VC) as well as interaction effect. Increasing the rates of VC reduced the number of days to 50% flowering across the increased rates of mineral NP fertilizers. Thus, due to the interaction effect of null t VC ha^{-1} and null mineral NP kg ha^{-1}, flowering was delayed almost five days as compared with the treatment that received 7.5 t VC ha^{-1} and 100% blanket recommended mineral NP fertilizers, (Table 3). The delayed flowering in null application of VC and mineral NP fertilizers might be due to lack of essential nutrients for metabolic process and differentiation of buds into flower buds, while earliness in flowering could be attributed to the enhancement of vegetative growth. The result was in conformity of the finding of Daniel *et al.* [35] who reported that the application of 10 t VC and 75% NP kg ha^{-1} fertilization enhanced the flowering duration of potato as compared to absolute control.

Days to 90% Physiological Maturity: There were significant ($P < 0.01$) differences in days to maturity of potato due to the main effect of mineral NP fertilizers and Vermicompost (VC) as well as interaction effect. Increasing the rates of VC reduced the number of days to maturity across the increased rates of mineral NP fertilizers. Thus, due to the interaction effect of null t VC ha^{-1} and null mineral NP kg ha^{-1}, maturity was

Table 3: Interaction effect of VC and mineral NP rates on days to 50% flowering of potato

	NP rate (%)				
VC (t ha^{-1})	0	25	50	75	100
0	64.67^{h}	60.33^{cdefg}	60.33^{cdefg}	56.00^{a}	59.00^{bcd}
5.0	59.00^{bcd}	59.67^{cde}	60.00^{cdef}	60.00^{cdef}	60.67^{defg}
7.5	62.00^{g}	59.67^{cde}	57.00^{def}	57.67^{b}	60.00^{cdef}

LSD (5%) VC× NP = 1.653 CV (%) = 1.7

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; Means in the table followed by the same letter(s) are not significantly different at 5% level of significance.

Table 4: Interaction effect of VC and mineral NP rates on days to 90 % maturity of potato

	NP (%) rate				
VC (t ha^{-1})	0	25	50	75	100
0	109.00^{h}	104.70^{efg}	104.30^{defg}	103.70^{bcdefg}	102.70^{abcde}
5	104.30^{defg}	103.70^{bcdefg}	104.00^{cdefg}	104.00^{cdfg}	105.30^{fg}
7.5	105.70^{g}	102.00^{abc}	101.00^{a}	102.00^{abc}	103.00^{abcde}

LSD (5%) VC× NP_2O_5 = 1.904 CV(%) =1.1

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; Means in the table followed by the same letter(s) are not significantly different at 5% level of significance

Table 5: Interaction effect of VC and mineral NP rate on plant height (cm) of potato

	NP (%) rate				
VC (t ha^{-1})	0	25	50	75	100
0	57.80^{h}	66.93^{g}	67.67^{g}	77.93^{bc}	77.87^{bc}
5	72.40^{ef}	73.33^{def}	74.00^{de}	74.92^{de}	75.90^{cd}
7.5	74.53^{de}	74.53^{de}	75.93^{cd}	79.97^{ab}	81.60^{a}

LSD (5%) VC× NP =2.876 CV(%)=2.3

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; Means in the table followed by the same letter(s) are not significantly different at 5% level of significance

delayed almost six days as compared with the treatment that received 7.5 t VC ha^{-1} and 100% blanket recommended mineral NP fertilizers (Table 4). The delayed maturity in response to null application of VC and mineral NP fertilizers could be due to slow vegetative growth and late formation of reproductive organs, while hastened maturity of the crop with the application of VC and mineral NP could be due to optimum availability of nutrients in vermicompost [36, 37] and could also be due to enhanced soil moisture holding capacity as a result of integrated mineral and organic fertilizer application [38]. The result of the experiment also confirmed the findings of Amir *et al.* [39] who reported that the application of 92 kg N ha^{-1} with 15 t ha^{-1} VC hastened the maturity of potato. As contrary to this result [40] reported that the application of N and P fertilizers delayed flowering and prolonged days required to attain physiological maturity of potato.

Growth Parameters of Potato

Plant Height: The analysis of variance of plant height showed highly significant (P<0.01) main effects of VC and mineral NP fertilizers and their interactions. Combination of 7.5 t VC ha^{-1} and 100% of recommended mineral NP fertilizers gave the maximum plant height (81.6 cm) followed by the application of 7.5 t VC ha^{-1} and 75% of the recommended mineral NP (79.97 cm) (Table 5). On the other hand, shortest plant height (57.8 cm) was observed from null application o f VC and mineral NP fertilizers. The possible reason for the increment of plant height with the application of VC and mineral NP might be due to better availability of N and P that come from both VC and mineral NP fertilizer which enhanced cell division, cell elongation and vegetative growth. The increment in plant height due to combination of fertilizers could clearly indicated the need for adding Vermicompost to the soil in concurrence with mineral fertilizers, which might have increased the availability of nutrients considerably resulting in a positive effect on growth parameters as reported by Yourtchi *et al.* [41]. In accordance with this result, Abou-Hussein *et al.* [42] found the highest stem height of potato with the application of cattle manure in combination with mineral NP fertilizers.

Application of organic fertilizer along with mineral fertilizers could also provide the micronutrients, which might have helped in enhancing of the metabolic activity in the early growth phase which in turn could have increased the overall plant height of potato [41]. The result of this study is in agreement with the findings of Alam *et al.* [43] in potato, Alam [44] and Azad [45] in cabbage who stated that combined application of manures and mineral fertilizers induced the plants to grow taller. Murakar *et al.* [46] also showed that application of vermicompost at the rate of 6-ton ha^{-1} led to increase in plant height of mulberry.

Average Stem Number per Hill: Although stems density is one of the most important yield components in potato, the results of the present study showed that main effect of VC and mineral NP fertilizer rate as well as the interaction of the two had not significant effect on the average stem number per hill. The potato crop is usually propagated by using underground storage organs known as tubers. Stem number is not increased with the application of nutrients. This could be due to the fact that stem number is determined very early in the ontogeny of yield [47]. It could also be due to the fact that this trait is not influenced much by mineral nutrition, as the stem number is the reflection of storage condition, physiological age of the seed of the variety [47, 48] and tuber size [49]. The number of stems per plant had direct relation with the number of sprouts per tuber not on the treatment applied [50] and the sprouts are the function of number of eyes on tubers. Stem density is positively correlated with eye number per tuber [51] and tuber size [49].

Lung'aho *et al.* [2] stated that stem number is basically determined by the number of eyes present on tubers and the physiological age of the tubers during the storage period rather than by manipulating the supply of fertilizers. Consistent with the results of this study, Assefa Nuru [52] reported that stem number per hill was not significantly affected by the application of nitrogen and phosphorus. It was also reported that seed tubers of different genetic composition are known to differ in stem numbers [53]. This study was also supported by the work of [54] who reported that the stem number was not significantly influenced much by mineral nutrients, possibly because stem number may be influence by other factors such as condition of seed tubers and physiological age of the seed tuber.

Yield Components of Potato

Total Tuber Number per Hill: Total tuber number per hill was significantly ($P < 0.01$) influenced by the rate of VC. This parameter was also significantly ($P < 0.01$) influenced by the rate of mineral NP fertilizer application. However, the two factors did not interact to significantly influence this parameter.

Total tuber number per hill increased significantly and linearly in response to increasing the rate of VC application from null up to the highest rate of the fertilizer. Thus, the lowest number of tubers per hill was obtained for the null VC treatment whereas the highest was obtained from treatment that received 7.5 VC t ha^{-1} (Table 6). Total tuber number per hill is also increased significantly and linearly in response to increasing the rate of mineral NP fertilizer application from null up to the highest rate of the fertilizer. Thus, the lowest number of tubers per hill was obtained for the null mineral NP fertilized treatment whereas the highest was obtained from treatment that received the highest mineral NP fertilizer (Table 6). The possible reason for the increment of tuber number at the highest rate of mineral NP fertilizer might be attributed to an increase in stolon number in response to mineral N and P application, which is known to influence the rate of gibrillic acid biosynthesis in the potato.

The involvement of gibberellins in regulating stolon number through stolon initiation was reported by Kandil *et al.* [55]. According to Amir *et al.* [39], N and P influenced tuber formation in potato by influencing the activity and phytohormone balance in the plant, especially, on the levels of gibberellic and abscissic acids and cytokinins. This is related to gibberellins enhancing stem organ elongation thus stimulate potato stolon initiation, growth and branching. Abscissic acid controls stolon growth. So the ceassation of stolon in apical growth in potato is accompanied by the increase of the ABA/GA ratio. Cytokinin is related to when potato plants transited to tuber formation activity of endogenous cytokinin increased substantially in stolons and developing tubers. These cytokinins are known in plants in stimulating cell division. Similar to the results of this study, Zelalem Aychew *et al.* [40], Sommerfeld and Knutson [56], Sparrow *et al.* [57] and Israel Zewide *et al.* [58] reported that the increasing the rates of phosphorus and nitrogen increased the number of potato tubers set per hill.

Marketable Tuber Number per Plant: Marketable tuber number was highly significantly ($P<0.01$) affected by the main effects of VC and mineral NP fertilization rates, however, their interaction was not significant. The marketable tuber number increased linearly for both VC and mineral NP fertilizers application. The highest marketable tuber number per plant was recorded in the treatment that received the highest VC t ha^{-1} and also for the highest mineral NP fertilizers respectively. While the lowest marketable tuber number was recorded in treatment that received no fertilizers for VC and mineral NP.

The possible reason for increased marketable tuber number might be due to applied fertilizer increased the size of the tuber and there by increased the weight of the tuber and also phosphorus fertilization increased the interception of solar radiation at low soil phosphorus conditions so it might have a positive effect on tuber set at certain conditions. The increased marketable tuber number in VC fertilization might be related to increment of soil micro and macro nutrients and its availability to the crop for ease of absorption. The result was in agreement with finding [59] who reported that marketable tuber numbers per hill increased by about 26, 51 and 98% as the level of potassium was increased from null to 100, 200 and 300 kg ha^{-1}, respectively. The result was in agreement with the finding of Gezahegn Garo *et al.* [60] who reported that application of 46 kg N ha^{-1} and 5 t ha^{-1} VC increased marketable root yield on sweet potato by 48.55% as compared to non-fertilized treatment.

Tubers Size Distribution in Weight: The size distribution of tuber was highly significantly (P<0.01) affected by VC and mineral NP fertilizer for medium sized and small sized tubers in main effect and significantly affected for large sized tuber (P<0.05) however, their interactions was not significant on tuber size distribution.

The highest proportion of large and medium sized tubers were recorded in response to the application of highest amount of VC (7.5 t ha^{-1}) and mineral NP fertilizers which might be due to the nutrient utilization efficiency of the crop and the applied fertilizer pronounced better nutrient availability to increase the tuber size. The increase in tuber size was also correlated to VC at increased rate which might have enhanced the available nitrogen and phosphorus to the soil which was immediately usable to the crop. Tuber size distribution varies with many factors among which soil fertility and population density are the major ones [10]. The more populated potato plants result in the more number of tubers which result in small tuber size or weight of tuber. Soil which is fertile with optimum nutrient content for potato plant growth that is well structured, good drainage to allow and proper root aeration, result in tuber development. The result of this study was in agreement with that of Haase *et al*. [61] who reported that decomposed cattle manure increased the number of tubers with diameters > 65 mm as a result of N mineralization. Taheri *et al*. [62] also found the highest ratio (13.07%) of number of large tubers as a result of application of 20 t ha^{-1} of compost combined with 225 kg ha^{-1} phosphorus × 50 kg ha^{-1} zinc.

Small sized tuber proportion significantly (P<0.01) affected by the main effect of application of VC and mineral NP fertilization. Large amount of small sized tubers was obtained from plots which received lowest application of VC and mineral NP while, low quantity of small sized tubers contributed by the high application of VC and NP fertilizers (Table 7). It was observed that as the rate of VC and mineral NP fertilizers increased, the proportion of small sized tubers reduced. The result was in line with the work of Hossain *et al*. [63] who found maximum tuber size with combined application of organic and inorganic fertilizers.

Table 6: Main effect of VC and mineral NP fertilizer rate on marketable, unmarketable and total tuber number per hill of potato

VC (t ha^{-1})	MTN per hill	UNMTN per hill	TTN per/hill
0	5.18^{c}	4.09	9.27c
5.0	6.63^{b}	4.05	10.68^{b}
7.5	8.38^{a}	3.31	11.69^{a}
LSD (5%)	0.52	0.78	1.09
NP (%)			
0	5.94^{c}	4.23	10.17^{c}
25	6.08^{c}	4.24	10.32^{c}
50	7.21^{b}	3.44	10.65^{bc}
75	7.26^{b}	3.79	11.05^{b}
100	8.42^{a}	3.25	11.67^{a}
LSD (5%)	1.24	0.44	0.62
CV (%)	8.80	21.04	10.32

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; NS= Non-significant. Means in the column followed by the same letter(s) are not significantly different at 5% level of significant.

Table 7: Main effect of VC and mineral NP fertilizers application on large, medium and small sized tubers of potato

VC (t ha^{-1})	Large Size (%)	Medium Size (%)	Small Size (%)
0	59.10^{c}	28.72^{a}	12.18^{a}
5.0	61.48 ^{bc}	28.30^{a}	10.22^{b}
7.5	69.21 ^{a}	23.15^{b}	7.64^{c}
LSD (5%)	2.64	1.99	1.62
NP (%)			
0	58.06^{c}	30.28^{a}	11.67^{a}
25	58.18^{c}	30.27^{a}	11.55^{a}
50	62.63^{b}	27.51^{b}	9.86^{ab}
75	67.13 ^{a}	23.24^{c}	9.64^{b}
100	68.79 ^{a}	22.83^{c}	8.38^{b}
LSD (5%)	2.96	2.23	1.81
CV (%)	5.7	10.1	21.4

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; Means in the table followed by the same letter(s) are not significantly different at 5% level of significance

Tuber Yield Parameters of Potato: The main effects of VC and mineral NP fertilizers highly significantly affected marketable and total tuber yields. However, their interaction did not significantly influence these parameters and the main effects as well as their interaction did not significantly influence the unmarketable tuber yields.

Total and marketable tuber yield increased significantly and linearly in response to increasing the rate of VC application from null up to the highest rate of the fertilizer. Thus, the lowest total (27.11 t ha^{-1}) and marketable (25.47 t ha^{-1}) tuber yield were obtained for the plot that received null VC rate whereas the highest total and marketable (35.11 t ha^{-1} and 33.97 t ha^{-1}) tuber yield were obtained from treatment that received 7.5 VC t ha^{-1} respectively (Table 8). Total and marketable tuber yield were also increased significantly and linearly in response to increasing the rate of mineral NP fertilizer application from null up to the highest rate of the fertilizer. Thus, the lowest total (24.02 t ha^{-1}) and marketable (22.66 t ha^{-1}) tuber yield were obtained for the null mineral NP fertilized treatment whereas the highest was obtained from treatment that received the highest mineral NP fertilizer (Table 8).

The possible reason for the increment in marketable and total tuber yield of potato by the application of either VC along with mineral fertilizer could be attributed to their favorable effects on yield components, like average number of tubers per hill and dry matter production. This might be due to VC fertilizer along with in mineral fertilizer enhance all nutrient requirement of the plant. This clearly showed that, the applied nutrients increased tuber quality and weight. This can be attributed to increased vegetative growth of the aerial parts and hence, prolonged the duration of photosynthesis. The marketable tuber yield was increased with increased rates of both VC and mineral NP fertilizer. This could be probably due to the fact that marketable tuber yield increased at highest nitrogen rate because nitrogen can trigger the vegetative growth and development. The increase in number of marketable tuber with increase in applied nitrogen was associated with decrease in the number of the small size tubers due to increase in the weight of individual tubers, thus increase marketable tuber yield.

Total tuber yields also followed similar trend and it was also highest in response to high rate of application resulted in highest marketable yield. This result corroborates with the study of Nyiraneza and Snapp [64] who reported that increase in yield of crop might be due to increased dry matter production and its distribution in plant parts. Tekalign Tsegaw and Hammes [7] also reported that the assimilation of dry matter and its distribution within the plant are important processes determining crop productivity. The results of this experiment also confirmed the observations of Sanchez and Jama [65] who reported that integration of organic and mineral NP fertilizers sustains crop production due to positive interaction and complementarities between them.

The result, therefore, clearly showed that the yield of potato could be maximized by the combined application of VC and mineral NP fertilizer. The above results are in agreement with the observation by Amir *et al.* [39] who reported that highest tuber yield of potato was obtained from the combined application of 20 t ha^{-1} cattle manure with 150 kg N ha^{-1}. Similarly, Nyiraneza and Snapp [65] reported that the combined application of 179 kg N ha^{1} fertilizer and 5.6 t ha^{-1} poultry manure consistently increased tuber yield by 20% over the use of inorganic N alone at 224 kg ha^{-1}. The result was also in agreement with the finding of Teshome Abdissa and Nigussie Dechassa [66] who reported that the application of 20 t Vermicompost ha^{-1} and 180 kg P_2O_5 ha^{-1} resulted in production of highest marketable root yield of sweet potato.

Table 8: Main effect of VC and mineral NP fertilizers application on total and marketable tuber yield (t ha^{-1}) of Potato

VC (t ha^{-1})	Marketable tuber yield (t ha^{-1})	Total tuber yield (t ha^{-1})
0	25.47[c]	27.11[c]
5.0	29.89[b]	31.00[b]
7.5	33.97[a]	35.11[a]
LSD (5%)	2.09	2.27
NP (%)		
0	22.66[d]	24.02[c]
25	25.10[c]	26.41[c]
50	28.12[b]	29.38[b]
75	34.59[a]	35.96[a]
100	36.78[a]	37.95[a]
LSD (5%)	2.33	2.53
CV (%)	9.0	9.4

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; Means in the column followed by the same letter(s) are not significantly different at 5% level of significance

CONCLUSION

The results showed that the main effect of VC and mineral NP fertilizers were significant ($P < 0.01$) on total tuber number per plant, marketable tuber number per plant, tubers size category, marketable tuber yield (t ha^{-1}) and total tuber yield (t ha^{-1}). Thus the highest total and marketable tuber number per plant was obtained for the treatments that received the highest rate of both VC and mineral NP fertilizers. There were significant interaction of VC and mineral NP fertilizers on days to 50% flowering, on days to maturity and plant height.

The results of the study have clearly demonstrated that potatoes respond vigorously to application of VC in combination with mineral NP fertilizers and farmers in the study area have to apply VC and 75% of mineral NP fertilizers than only applying of blanket recommended mineral NP fertilizers to obtain higher tuber yields and economic benefits. In this study, applying 7.5 VC t ha^{-1} and 100% of blanket recommended mineral NP fertilizer resulted in superior growth and yield of the crop. However, applying 7.5 VC t ha^{-1} in combination with 100% of blanket recommended mineral NP fertilizer is costly. Therefore; farmers in the study area should consider the cost of mineral fertilizer and long term soil fertility for bringing sustainable development. However, to reach a conclusive recommendation, it will be necessary to conduct further experiments on the crop using more rates of VC and mineral NP fertilizers for higher yield and long term soil fertility.

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