FULL-LENGTH ARTICLE

Response of Potato (*Solanum tuberosum* L.) to Applications of Lime and Vermicompost at Acidic Soil of Bule District, Southern Highland of Ethiopia

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Abstract

Potato (*Solanum tuberosum* L.) is an important crop and plays a major role in national food and nutritional security, poverty alleviation, and income generation in Ethiopia. But its average productivity is low compared to other countries due to different factors including high soil acidity in the highlands of Ethiopia. This research was undertaken to assess the effect of lime and vermincompost (VC) on yield of potato under acidic soil conditions of Bule District, Southern Highland of Ethiopia. The experiment was laid out in a randomized complete block design with three replications. A total of twelve treatments from three rates of lime (0, 3.6 and 4.9) and four rates of vermicompost (0, 2.5, 5 and 7.5) replicated three times were implemented on 36 plots. The result showed that there were significant differences among treatments due to interaction effect of lime and vermicompost. Extended duration of maturity (126 days), maximum result of plant height (82.13cm), marketable tuber yield (33.33 tha^{-1}), total tuber yield (34.46 tha^{-1}), and minimum result of unmarketable tuber yield (1.03 tha^{-1}) were recorded due to application of maximum rate of lime and vermicompost while minimum result of these parameters were observed without their application. The findings indicate that lime and VC adjust the soil acidity to condition suitable for potato production. Therefore, the application of maximum rate of lime (5 tha^{-1}) and vermicomost (7.5 tha^{-1}) is recommended for high production of potato at the study area.

Key Words/Phrases: - Acid, Lime, Potato, Vermicompost, Yield

Introduction

Potato (*Solanum tuberosum* L.) is an important crop in Ethiopia and plays a major role in national food and nutritional security, poverty alleviation, and income generation (Abebe *et al*., 2012). In this country, with increasing urbanization, the use of potato not only as fresh tubers but also as processed products such as Chips, French fries and crisps is rising (Abebe *et al*., 2012). Ethiopia has possibly the greatest potential for potato production but average productivity is low compare to other countries in Africa. Some of the challenge includes: narrow genetic basis of potato varieties, inappropriate agronomic practices, soil nutrient depletion and soil acidity, moisture stresses, diseases, insect pests, poor seed quality, shortage of seed tubers of improved potato varieties, and susceptibility to diseases (Alemayehu *et al*., 2015). Among others soil acidity is the major constraints of potato production in the country (Alemayehu *et al*., 2015). Acid soils limit crop production on 30% to 40% of the world's cultivated land and up to 70% of the world's potentially arable land (Haug, 1983). It is becoming a serious challenge to small scale farmers for crop production in the highlands of Ethiopia (Kiflu *et al*., 2016). Currently, it is estimated that about 40% of the arable lands of Ethiopia are affected by soil acidity (Taye, 2007).

Soil acidity limits or reduces crop production primarily by impairing root growth as a result of the toxicity to roots of high concentrations of soluble aluminium (Al) (Tisdale *et al*., 1985). Moreover, low pH enhances the fixation of P through sorption by forming compounds with Al and irons (Fe). Hence, it is a serious threat to crop production in most highlands and a major crop production constraint in the small-scale farmers of the country. Based on the problem that soil acidity causes on a larger areas in Ethiopia, it needs due attention to be addressed by different coping mechanisms (Mesfin, 2007).

The productivity of crops in acid soils with Al toxicity and low soil availability of P may be improved by use of lime, fertilizers with liming effects, and/or organic materials (Ouma *et al*., 2013; Viterello *et al*., 2005). Lime is the most effective means of amending soil acidity (Kenyanjua *et al*., 2002). Application of lime containing Ca and/or Mg compounds to acid soil increases Ca^{2+} and/or Mg^{2+} ions and reduces Al^{3+}, H^{+}, Mn^{2+}, and Fe^{2+}. (The *et al*., 2006; Kenyanjua *et al*., 2002).

Vermicompost (VC) was reported to increase the pH of acid soils and improve soil fertility by supplying essential plant nutrients (Materechera, 2012). Similarly, Wael *et al*. (2011) reported that VC can be used to increase the pH in acidic soils and reduce Al and Mn toxicity due to its alkalinity properties. It has been reported that application of VC increases the supply of easily assimilated as well as micronutrients to plants besides mobilizing unavailable nutrients into available form (Zeinab *et al*., 2014). Vermicompost contains high levels of total and available N, P, K (Tesfaye, 2017), stimulates microbial activities and growth regulators (Chaoui, 2003). In acidic soils with high levels of exchangeable Al, organic matter (OM) in vermicomposts plays a significant role in the reduction of P adsorption and increased P availability due to cumulative effects of several mechanisms (Opala *et al*., 2010). These include release of organic P from decaying residues, blockage of P adsorption sites by organic molecules released from the residues, a rise in soil pH and complexation of soluble Al and Fe by organic molecules (Iyamuremye and Dick, 1996).

Bule district is found at Highland of Gedeo zone, Ethiopia where certified organic coffee (*Coffea arabica*) is partly produced. It is acidic area where inorganic fertilizer is prohibited to use to improve crop production and reduce soil acidity. This is to care the organic coffee consumers' demand. This factor is limited by regulations prohibiting the use of chemical fertilizers, especially nitrogen (EU-regulation 2092/91). Though Bule district is well known in potato production, its productivity is low due to soil acidity and unbalanced soil nutrient. At Bule district of Gedeo Zone, though the productivity of potato is hindered due to soil acidity and unbalanced soil nutrient, there is no finding to mitigate the problems. Therefore, the objective of the study was to assess the effect of lime and organic fertilizers (vermicompost) on potato yield and soil physicochemical properties of acidic soil of Bule District, Gedeo Zone, Southern of Ethiopia.

MATERIALS AND METHODS

Description of the study area

This study was conducted under rain fed condition during the rainy season of 2019 cropping season at Gedeo zone, Bule woreda, Gubato Hawarre Kebel. Bule Woreda is among the six Woredas in the Gedeo Zone of SNNPR. It is located in the southern part of Hawassa, 117 kilometers (km) from the region's capital and 27 km from the Zone's capital Dilla. Bule Woreda is bordered on the south, East and west by Oromia region and on the north by

Sidama Region. The Woreda has a total area of 27,300 (ha), with its altitude ranging between 2,001–3,000 meters above sea level (masl). It comprises 32 kebeles (three town administration kebele), of which 70% have a dega agro-ecology, while the remaining 30% can be characterized as weyina dega (mid altitude) agro-ecology. The area lies between 6^{o} 04'16" and 6^{o} 23'50" N latitude and from 38^{o} 16' 20" to 38^{o} 26'11" E longitude. Mean annual rainfall of the woreda is 1600mm, with minimum and maximum temperature of 12.6℃-20℃. (Bule Woreda BOA, 2017). The dominant soil type of the study area is Nitisols (Tarekegn, 2008).

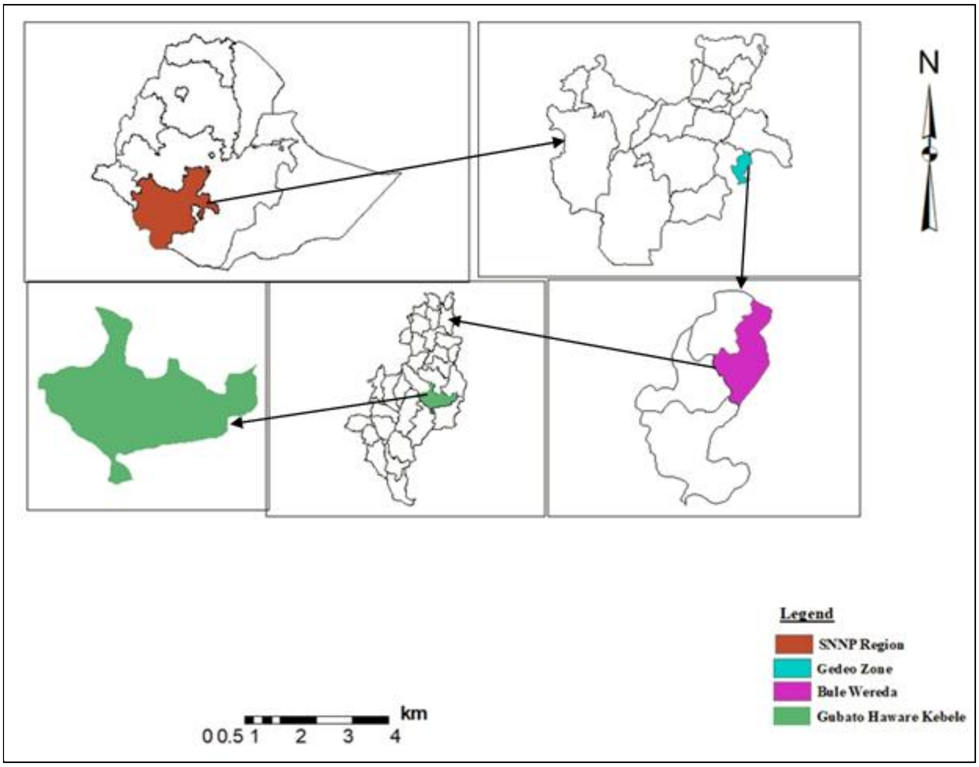

Fig. 1: Map of study site

Treatments, experimental design, and procedures

This article was emanated from the main effect of the following research. Gubato village farmer's land was selected purposely. Land preparation was carried out well in advance before sowing the potato crop. The experimental field was prepared following the conventional farmers' practices. The field was oxen ploughed three times before sowing which is commonly practiced by the local farmers. The seed bed was prepared by ploughing and harrowing using oxen and then was leveled manually. The experiment was laid out in factorial randomized complete block design with three replications; the plot size was 4.25m by 2.6m (11.05m^{2}). A total of twelve treatment from three rates of lime (0, 3.6 and 4.9) and four rates of vermcompost (0, 2.5, 5 and 7.5) was used for experiment. Potato variety of Gudene was used with intra and inters row spacing of 35cm and 70cm, respectively. The distance between adjust plots and blocks were 0.6m and 1m respectively. Each plots had 6 rows whereas each rows had 7 potato plants. There were a total of 42 potatoes per plot. The source of the potato was purchased from farmer produce Gudena variety. One month prior to planting, lime and vermicompost was applied to the plots per treatments assigned and thoroughly incorporated into the soil. All agronomic practice such as weed control, earthing up and disease and insect inspection was done regularly. At harvest, as pre sowing, the soil samples were collected and the same soils physicochemical were analyzed with the same procedures.

Data collections and measurements
The data collected were crop phenology, growth parameters, tuber yield and yield components of potato.

Crop phenology
Days to maturity: days to maturity was recorded when 75% of the plants in plots were ready for harvest as indicated by senescence of leaves and haulms. The days were counted from date of planting to maturity of the crop.

Growth parameters
Plant height (cm): refers to the height from the base to the apex of the plant. It was measured using a measuring tape at 50% flowering from the main stem originating directly from mother tubers to the apex of the plant by taking five sample plants from each plot.
Leaf area: It was determined by counting from five plants at 50% flowering stage.

The tuber yield and yield component of potato
Marketable tubers yield: These were recorded as the weight of marketable tubers that were free from diseases, insect pests, and greater than or equal to 25 g in weight (Lung'aho *et al.*, 2007). These were taken from 5 plants from net plot area at harvest.

Unmarketable tubers yield: These were recorded as the weight of unmarketable tubers that were affected by diseases, insect pests, and less than 25 g in weight (Lung'aho *et al.*, 2007). These were taken from 5 plants from net plot area at harvest used to record for marketable tubers yield.

Total tuber yield: This was recorded from the weight of total tuber per plot. The data was taken from plants in the net plot area at harvest.

Statistical analysis
Data on soil physicochemical properties, growth and yield components of potato were subjected to two way analysis of variance (ANOVA) (SAS, 2009). Significant differences between treatment means were separated using the Least Significance Difference test at 5% level of significance for the parameters showed significance difference between treatments.

RESULTS AND DICUSSION

Soil physical and chemical characteristics

The soil characteristic of the study area (Table 1) is as follows. The soil pH was very low (4.8). The extreme low soil pH is a constraint of plant growth since at this level, soil has lack of nutrient. It requires liming application to increase its pH, thus it is going to be suitable for plant to grow. Low pH values in naturally acidified mountains caused by soil organic acids were also reported by Pohlman and McColl (1988).

Table 1 Physico-chemical characteristics of soil of the experimental site before sowing

Soil physical property	Value	Rating
Sand (%)	25	Low
Clay (%)	45	High
Silt (%)	30	Moderate
Textural class	Clay	
Soil chemical property		
Soil pH $_{H2O}$	4.8	strongly acidic
OC (%)	1.47	
TN (%)	0.50	
Av. K cmol (+) kg-1	1.04	Low
C:N	2.49	Low
Av. P (mgkg-1)	13.75	Low
CEC cmol (+) kg-1	14.80	
Ex. Acidity (meq 100g-1)	5.72	
Ex. H^+ (meq 100g-1)	1.90	
Ex. Al3+ (meq 100g-1)	3.01	

Effect of lime and vermicompost on phenology and growth of potato:
Effect of lime and vermicompost on 75% day's to potato maturity:

Significant variation was obtained among the interactions effect of different levels of lime and vermicompost application on 75% day's to maturity. As indicated in table 1: minimum day's (109 days) and maximum day's (126 days) to maturity was recorded. Prolonged maturity in response to increasing rate of lime and VC may be ascribed to the availability of optimum nutrients contained in VC and lime contribution that may have led to prolonged maturity through enhanced leaf growth and photosynthetic activities, thereby increasing partition of assimilate to the storage organ. This means it in turn, might have led to increase in synthesis of photo assimilate, which was further utilized in building up of new cells, and prolonged maturity of garlic. Significantly early matured bulb was obtained from nil application. The early maturity was due to lack of enough nutrient supply that leads a crop to senescence. On the other hand, increased levels of lime and vermicompost extend senescence of potato due to increased available nutrients. Similarly, Abdissa *et al*., (2000) reported that the combined application of lime (4 tha^{-1}), VC (5 tha^{-1}), and chemical P (40 tha^{-1}) holds a lot of promise as an efficient alternative to amend soil acidity and increase soil nutrient availability.

The sustainable agriculture is threatened by widespread acidity in many parts of the tropical region, and applications of lime (Yamoah *et al*., 1996) to these soils have been reported to significantly improve soil fertility. Acidity affects the fertility of soils through nutrient deficiencies (P, Ca, and Mg) and the presence of phytotoxic nutrient such as soluble Al (Awad, *et al*., 1976). Liming is the best mechanism to overcome this challenge to increase nutrient availability that impart plant growth through facilitating plants to get optimum nutrients and reason for pronged maturity duration.

Table 2. Effect of lime and vermicompost on yield and yield components of potato

Factors		dependent variable	
Lime (tha^{-1})	Vermicompost (tha^{-1})	75% days maturity	Plant height
0	0	109.00i	42.33g
	2.5	112.00i	56.20ef
	5	114.67fg	68.33c
	7.5	116.33ef	75.13b
3.9	0	110i	51.60f
	2.5	113.00gh	64.07d
	5	118.33d	69.00c
	7.5	122.67b	79.07a
5	0	116.33ef	55.40ef
	2.5	117.00de	66.93cd
	5	120.33c	74.53b
	7.5	126.00a	82.13a
LSD (0.05)		1.89	3.83
CV (%)		0.69	3.49

Effect of lime and vermicompost on plant height of potato:
Interaction effect of lime and vermicompost showed significant difference on plant height. The plants supplemented with lime and vermicompost exhibited a significant response in plant height attributes. The maximum plant height (82.13 cm) was recorded with applied highest rate of lime (5 tha^{-1}) and vermicompost (7.5 tha^{-1}) while the minimum (42.33 cm) was recorded with nil application of lime and vermicompost (Table 1). The ability of humic substances (HS) found in mineral-organic materials is to stimulate growth and yield of numerous plants by encouraged nutrient and water uptake is well documented (Theunisen *et al*., 2010; Chen *et al*., 2004; Nardi *et al*., 2002). Fikru and Fikreyohannes (2019) reported that compared to control, garlic plant height was increased by 13.22% with the application rate of 7.5 t VC ha^{-1}. This increase in plant growth might be due to the effect of plant growth hormone and nutrients which are exerted by bio-enriched (Gomaa, 1995). Moreover, it could be attributed to the fact that VC contains a good range of additional essential micronutrient other than NPK fertilizers, required for healthy plant growth (Surindra, 2009). The observed positive effect of lime on potato growth was due to its effect in increasing the pH and therefore increasing availability of most nutrients to potato rather than its ability to ameliorate aluminium toxicity.

Effect of lime and vermicompost on leaf area of potato:
Interaction effect of lime and vermicompost did not show significant difference on leaf area. Leaf area was significantly influenced due to main effect both increased lime and vermicompost level (Table 2). The highest leaf area (185.82cm^2) was recorded from application of vermicompost 7.5 tha^{-1} and the minimum (128.22 cm^2) was found from the nil vermicompost (0 VC tha^{-1}) application. Increased leave area is due to humic substance found in vermicompost. Because of vermicompost contains essential nutrients in plant-available forms, enzymes, vitamins and plant growth hormones (Borah *et al*., 2007), leaf growth is increased. The highest leaf area (140.07cm^2) was recorded from application of 5 lime tha^{-1} and the minimum (178.13cm^2) was found from the nil lime (0 lime tha^{-1}) application in this finding. Different minerals responsible for development of chlorophyll like N, Ca, and Mg concentration increased with increasing lime rates. This may be associated with higher N2-fixation rate by N2-fixing bacteria and higher Ca and Mg uptake with increasing lime rates. For most crops other than alfalfa (*Medicago sativa*), nutritional

conditions for maximum potential plant growth are most appropriate at pH values in a low acidity range (Fageria, 2009).

Table 3. Effect of vermicompost on leaf area of potato

Factors	Treatment	Leaf area (cm^2)
Vermicompost (tha^{-1})	0	128.22d
	2.5	153.31c
	5	170.91b
	7.5	185.82a
LSD (0.05)		9.44
Lime (tha^{-1})	0	178.13c
	3.9	160.50b
	5	140.07a
LSD (0.05)		8.18
CV		6.05

Where, tha^{-1}: tone per hectare; LSD: Least Significance Difference; CV: Coefficient of Variation

Effect of lime and vermicompost on yield components and yield of potato

Effect of lime and vermicompost on marketable tuber yield of potato

A significant difference was found among combination of different levels of lime and vermicompost application on the marketable tuber yield of potato. The maximum marketable tuber yield (33.43 tha^{-1}) was recorded without applications of vermicompost while the minimum tuber yield (17.98 tha^{-1}) with nill application of lime and vermicompost. This is due to the ability of humic substances (HS) found in mineral-organic materials which stimulate growth of numerous plants part by encouraged nutrient and water uptake (Theunisen *et al.,* 2010; Chen *et al*., 2004; Nardi *et al*., 2002). These include release of organic P from decaying residues, blockage of P adsorption sites by organic molecules released from the residues, a rise in soil pH and complexation of soluble Al and Fe by organic molecules (Iyamuremye and Dick, 1996). The available P increases the size of potato as it considered as marketable tuber yield. Liming increases soil pH that makes other nutrients more available and prevents Al and Mn from being toxic to plant growth (Yoa *et al*., 2010). Liming also enhances root development and water and nutrient uptakes necessary for healthy plant growth (The *et al*., 2006; Van, 2007). This increases marketable tuber yield of potato.

Effect of vermin-compost on unmarketable tuber yield of potato

Significant variation was found among different levels of lime and vermicompost on marketable tuber yield. The minimum unmarketable tuber yield (1.03 tha^{-1}) was obtained through application of 5 lime tha^{-1} and 7.5 VC tha^{-1}, and the maximum unmarketable tuber yield (3.89 tha^{-1}) was obtained without application of lime and vermicompost. Stimulation of root growth (initiation and proliferation of root hair), increased root development to absorb nutrient and water that enhanced plant growth and development have been reported with the application of vermicompost, this is because of the presence of humic acids (Suh *et al*., 2014) that create suitable environment for crop production. This reduced negative impact happened to tuber yield of potato that increase unmarketable tuber yield. Therefore, unmarketable tuber yield of potato is decreased with increased levels of lime and vermicompost. On the other hand, without application of lime and vermicompost, soil acidity limits or reduces crop production primarily by impairing root growth as a result of the toxicity to roots of high concentrations of soluble aluminium (Al) (Tisdale *et al*., 1985) and reduces yields.

Effect of vermicompost on total tuber of potato yield

Significant variation was obtained among interaction of different levels of lime and vermicompost on total potato tuber yield. The lowest tuber yield (21.87 tha^{-1}) was recorded without application of vermicompost while the highest total tuber yield (34.46 tha^{-1}) was recorded at maximum level of vermicompost (7.5 tha^{-1}). According to the report of Joshi *et al.,* (2015) the increased in tuber yield was due to vermicompost have high porosity, aeration drainage and water-holding capacity which create good environment for tuber development and total yield. Similarly, Osvalde *et al*., (2016) reported that the potato leaf analyses suggest that peat and vermicompost preparations used in organic potato cultivation system enhanced P uptake that contribute for the tuber yield of potato. In acidic soils with high levels of exchangeable Al, organic matter (OM) in vermicompost plays a significant role in the reduction of P adsorption and increased P availability due to cumulative effects of several mechanisms (Opala *et al*., 2010). These include release of organic P from decaying residues, blockage of P adsorption sites by organic molecules released from the residues, a rise in soil pH and complexation of soluble Al and Fe by organic molecules (Iyamuremye and Dick, 1996). These contribute for the increment of potato yield and yield components. Lime reduces acidity of the soil and facilitates availability of nutrient from the soil and vermicompost. The productivity of crops in acid soils with Al toxicity and low soil availability of P may be improved by use of lime, fertilizers with liming effects, and/or organic materials (Ouma *et al*., 2013; Viterello *et al*., 2005).

Table 4. Interaction effect of lime and vermicompost marketable, unmarketable and total tuber yield of potato

Treatment		Marketable tuber yield(tha^{-1})	Unmarketable tuber yield(tha^{-1})	Total tuber yield (tha^{-1})
Lime (tha^{-1})	Vermicompost (tha^{-1})			
0	0	17.98h	3.89a	21.87f
	2.5	22.47g	3.67ab	26.13e
	5	26.93ef	3.44b	30.37cd
	7.5	29.21bcde	2.70c	31.91abc
3.6	0	24.86fg	3.73ab	28.59de
	2.5	27.03ef	3.43b	30.46cd
	5	28.96cde	3.04c	32.00abc
	7.5	31.24abc	2.06d	33.30ab
4.9	0	27.93de	3.53b	31.47bc
	2.5	29.7bcd	2.99c	32.68abc
	5	31.68ab	2.067d	33.75ab
	7.5	33.43a	1.03e	34.46a
LSD (0.05)		2.62	0.34	2.63
CV (%)		5.59	6.85	5.09

Where, tha^{-1}: tone per hectare; LSD: Least Significance Difference; CV: Coefficient of Variation

CONCLUSIONS

Increased levels of lime and vermicompost had significant ($p<0.05$) stimulating effect on phenology, growth and tuber yield of potato. Extended duration of maturity, maximum result of plant height, marketable tuber yield, total tuber yield and minimum result of unmarketable tuber yield were recorded due to application of maximum rate of lime and vermicompost while minimum result of these parameters were observed without its application. Leaf area did not show significant difference due to interaction effect rather than due to main effect of lime and vermicompost. This indicates that lime and VC adjust the soil acidity to the conditions suitable for potato production. Therefore, according to the findings of this research, the application of maximum rate of lime (5 tha^{-1}) and vermicomost (7.5 tha^{-1}) is recommended for production of potato at the study area. From this study, it is concluded that lime and vermicompost is good organic fertilizer to obtain good yield of potato tuber on acidic soil. Therefore, 5 tha^{-1} of lime and 7.5 tha^{-1} of vermicompost should be considered for potato production at the study area.

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