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A Review on the Potential Effects of Lime and Vermicompost on Soil Properties and Crop Production Improvements on Highly Acidic Soils

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Abstract

Soil is an important natural resource, providing a wide range of food, feed, fiber and timber production, as well as through earth system functions that support the delivery of other ecosystem services. The suitability of the soil for those productions is based on the quality of the soil's physical, chemical and biological properties. However, soil acidity significantly influences soil quality, soil properties its productivity. Acidic soils make elements such as aluminium more soluble and therefore toxic to plant roots; this limits plant growth by reducing capacity to absorb water and nutrients, in addition to greatly limiting biological activity and potentially exposing soils to a range of related physical degradation processes. It is associated with a decrease in the availability of nutrients (particularly phosphorus, calcium and magnesium) and an increase in the presence acidic cations (hydrogen H^+), aluminum and iron. Lime is suggested to enhance soil health status through improving soil physic-chemical properties and neutralize the acid produced in the soil. In addition to this, it reduces Al^{+3} and Mn^{+2}toxicity and increases both Phosphorous uptake in high Phosphorous fixing soil and plant rooting system. Organic fertilizer application also improve crop growth by supplying plant nutrients as well as improving soil physical, chemical, and biological properties. From various organic amendments, vermicompost is one of the stabilized, finely divided organic fertilizers with a low C:N ratio, high porosity, and high water-holding capacity, in which most nutrients are present in forms that are readily available for plants. Application of vermicompost showed marked improvements in the overall physical and biochemical properties, and at the same time, decreases exchangeable acidity which can support a release of plant nutrients in the acidic soils.

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soil, lime, vermicompost, acidity.

Introduction

The constraints of sustainable agriculture can be partly attributed to continuous cropping, soil acidity (Kiiya *et al.*, 2006) and inadequate soil fertility management (Berga, *et al.*, 2001). Soil acidity is a complex of numerous factors involving nutrient deficiencies and toxicities, low activities of beneficial microorganisms, and reduced plant root growth, which limits absorption of nutrients and water (Fageria and Baligar, 2008). Soil acidification is a natural process, which can either be accelerated by the activity of plants, animals and humans or can be hindered by sound management practices. (Bolan *et al.*, 2003). Acid soils make up approximately 30% of the world's total land area and more than 50% of the world's potentially arable lands, particularly in the tropics and subtropics (Kochian *et al.*, 2004). Crop management practices, removal of organic matter, continuous application of acid forming fertilizers and contact exchange between exchangeable hydrogen on root surfaces and the bases in exchangeable form on soils, microbial production of nitric and sulfuric acids can also contribute to soil acidity (Behera and Shukla, 2015; Fageria and Nascente, 2014). Use of inorganic fertilizers is recognized as an effective way for overcoming nitrogen and phosphorus deficiencies.

One of the most emphasized consequences of soil acidity is disorders related to phosphorus nutrition (Gaume *et al.,* 2001). Liming is the most dominant and most effective practice to control soil acidity (Fageria and Baligar, 2008; Goulding, 2016). Generally known that liming increase the availability of phosphorus and soil alkaline cations and reduces the availability of most heavy metals. (Rahman *et al.,* 2002; Zhang *et al.,* 2004) elaborated influence of liming on phosphorus availability in acid soils, stressing that a moderate pH increase leads to greater phosphorus availability, while too high doses can lead to its decreasing. It is a management practice to reduce the soil acidity and therefore one of the soil fertility management practices (AGRA.2009).Most plants grow well at soil pH range of 5.5 to 6.5 and liming is aimed to maintain the pH at this range. Liming increases soil pH, Ca concentration, cation exchange capacity (CEC) and base saturation, simultaneously lowering the Al concentration and increasing P availability (Jafer and Hailu, 2017). And also it is raises the soil pH by adding calcium & magnesium to soil and causes the aluminium and manganese to go out from the soil solution back in to precipitate then, solid (non-toxic) chemical forms.

Additionally, application of organic manures, which are generally added as a nutrient source, often improves soil physical conditions particularly in arable soils. It is highly recommended to use organic fertilizers in agricultural production to supply soils with plant nutrients and improve soil chemical, physical, and biological properties (Brady and Weil, 2001). Conventional fertilizers such as farmyard manure and compost are widely used for these purposes (Ferreras *et al.*, 2006; Herencia *et al.*, 2007). However, in recent years, vermicompost has been emerged as an alternative to conventional organic fertilizers due to its additional benefits. Vermicompost contains most nutrients in plant-available forms such as nitrates, phosphates, and exchangeable calcium and soluble potassium (Orozco *et al.*, 1996). There is accumulating scientific evidence that vermicomposts can influence the growth and productivity of plants significantly (Edward, 1998).

Effect of lime and vermicompost on some soil chemical properties of acidic soil

Increase of Soil pH and Decrease of Exchangeable Acidity

Soil reaction is expressed in terms of pH indicating whether the soil is acidic, alkaline or neutral. Soil pH measures the molar activity (concentration) of hydrogen ions in the soil solution (Moody and Cong, 2008).Soil pH it is an important consideration when producing any crop and should be the first soil consideration when attempting to grow a plant. Soil pH affects soil microbial activity and populations, soil chemical reactions, and nutrient availability; thus it is an important soil property to consider for maximum productivity. As soil acidification occurs, soil chemical and biological properties change and adversely affects a number of soil chemical properties, such as availability of macro and micronutrients, as solubility of soil chemical compounds is related to soil pH. Soil acidity is quantified on the basis of hydrogen (H^+) and aluminium (Al^{3+}) concentrations of soils (Fageria and Baligar, 2008). Understanding soil pH is essential for the proper soil management and optimum crop productivity. Soil pH is an excellent chemical indicator of soil quality. According to Adriano (2001), the pH can be viewed as the master variable of all the driving factors because it can affect the surface charge and subsequent adsorption of solutes by variable charge soil components, such as layer silicate clays, organic matter, and oxides of Fe and Al.

High soil exchangeable acidity and aluminum might be associated with the occurrence of lower soil pH. Reports also indicate that exchangeable acidity is a function of soil pH and presence compounds such as $Al(OH)^{3+}$ or $Al(OH)^{2+}$, and weak organic acid ions held at the colloidal surfaces of the soil (Hinrich *et al.*, 2001).Soil pH helps to identify the kinds of chemical reactions that are likely taking place in the soil. It affects nutrient availability and toxicity, microbial activity, and root growth. Most plants grow well at a pH range of 5.5 to 6.5 and liming and vermicompost is aimed to increase the pH to this range. Liming is a management practice to reduce the soil acidity and therefore one of the soil fertility management practices (AGRA.2009). When lime is added to acid soils that contain high $Al^{3+}$and H^+ concentrations, it dissociates into Ca^{2+} and OH^- ions. According to Fageria *et al.*,(2007). the rise in pH of soil is associated with the presence of basic cations (Ca^{2+}) and anions (CO_3^{-2}) in lime that are able to exchange H^+ from exchange sites to form $H_2O + CO_2$. Cations occupy the space left behind by H^+ on the exchange leading to the rise in pH.

The high amount of organic matter in vermicompost, its oxidation and degradation leads neutral pH increase micronutrients availability such as Fe, Mn, Zn and Cu in soil (Gallardo-Lara and Nogales, 1987). Increase in soil pH was accompanied by an increase in Available Ca and Mg; hence, in acidic it is an effective means of neutralizing the acidity of the soil as well as economically feasibility for small scale farmers to substitute lime. Tigist, (2017) reported that combined application of lime and vermicompost at the rates of 3.26 and 3.00 t $ha^{-1}$and 4.90 and 4.50 t ha^{-1} increased pH of the soil from 5.2 to 6.0 which is equivalent to change in the soil reaction from strongly acidic to moderately acidic. Even though, changes in soil pH values were the same for these rates of applications, exchangeable acidity and Al were decreased from 6.40 to 2.16 and from 3.04 to 0.96, respectively in plots treated with combined lime and vermicompost at the rate of 4.90 and 4.50 t ha^{-1}. According to Biruk *et al.*, (2017) reported that application of lime significantly increased the soil pH showing higher soil pH (5.95) at lime rate of 3 t ha^{-1}, which exceeded the control by 0.24 pH units and the soil before treatment application by 0.55 pH units. Abdissa *et al.*, (2018) reported that the highest lime rate (6 ton $CaCO_3 \cdot ha^{-1}$) significantly increased the pH from 4.80 to 6.01, reduced both the exchangeable acidity and Al from 2.4 to 0.17 $cmolc \cdot kg^{-1}$ and 1.70 to 0.33 $cmolc \cdot kg^{-1}$, respectively, and reduced acid saturation from 30% to 1.62%. (Abdissa *et al.*, 2018) indicated that combination of the highest level of vermicompost (7.5 $tons \cdot ha^{-1}$) with lime (4 $tons \cdot ha^{-1}$) increased pH from 4.80 to 6.05 and decreased exchangeable acidity and Al from 2.38 to 0.17 $cmolc \cdot kg^{-1}$ and 0.45 to 0.09 $cmolc \cdot kg^{-1}$, respectively. Ubi *et al.*, (2016)revealed that the soil reaction (pH) varied from 3.9 to 4.0 with no lime with a mean of 3.9, indicating that the soils are highly acidic. The values of pH is ranged between 6.0 to 6.6 in lime treated plots season with a mean of 6.3, indicating that lime treated soils were medium acidic to neutral. Adane, (2014) indicated that Soil pH increased significantly from 5.03 in the plots without lime to 6.72 at the lime rate of 3750 kg $CaCO_3$ ha^{-1}. Negese *et al.*, (2021) indicated that application of lime rates increased soil pH from 5.1 (control) to 5.7. The increases in soil pH over the control were 0.3, 0.3, 0.4 and 0.6 units for application of 25, 50, 75 and 100% of LR, respectively, when lime added to acid soils, it dissociates to yield Ca^{2+} and OH ions, Ca^{2+} replaces Al^{3+} and H^+ from the exchange sites. The Al^{3+} and H^+ ions react with hydroxyl ions forming Aluminum hydroxide (Al $(OH)_3$) and water, respectively. This causes decreasing in the activity of Al^{3+} and H+ ions and thereby, increasing pH of the soil solution. Similarly, Negese *et al.*, (2021) reported that application of vermicompost alone showed change in soil pH from 5.1 (control) to 5.5 by 0.3 - 0.4 units. Additionally, Negese *et al.*, (2021) the combination of lime with vermicompost at higher rates (75 and 100% LR with 2.5 and 5 t VC ha^{-1}) mostly increased the soil pH from 5.1 (strongly acidic) to 5.8 (moderately acidic. This raise in soil pH by the combined application of lime and vermicompost might be due to reduction in H^+ and Al^{3+} concentration in the soil solution by the neutralizing and buffering ability of lime and VC. (Khoi *et al.*, 2010)

Increase of Cation Exchange Capacity (CEC)

The removal of base cations, especially Ca and Mg, by leaching and erosion results in their replacement by acidic cations like H, Al and Fe on exchange sites and in the soil solution (Johnston, 2004). Acid soils are generally infertile with plant growth being limited by one or more commonly interacting factors which include, buildup of toxic levels of aluminium (Al) or manganese (Mn), effects on soil microbial activities and deficiencies of calcium (Ca), magnesium (Mg), potassium (K) and molybdenum (Mo) (Ligeyo and Gudu, 2005). In acid soils with pH < 5.5, the solubility of aluminium increases to toxic levels that severely restrict root systems and reduce plant growth (Marschner, 1995). In addition, phosphorus reacts with iron and aluminium in soil solution under acidic conditions to form insoluble phosphates hence reducing its availability to plants. Phosphorus deficiency often, therefore, occurs simultaneously with aluminium toxicity in these soils (Liao, *et al.*, 2006).

The productivity of acid soils is limited by the presence of toxic levels of aluminium (Al) and manganese (Mn) and deficiency of nutrients such as phosphorus (P), calcium (Ca), magnesium (Mg) and molybdenum (Mo) (Brady and Weil, 2014). Liming increases soil pH and therefore eliminates aluminium toxicity at pH > 5.5 by precipitating Al thus making it unavailable for plant uptake (Merino-Gergichevich, *et al.*, 2010). It also improves Ca supply and Mo availability and ensures optimal bacterial nitrogen fixation (Bambara and Ndakidemi, 2010). Vermicompost contains most nutrients in plant-available forms such as nitrates, phosphates, and exchangeable calcium and soluble potassium (Orozco *et al.*, 1996). Zeinab *et al.*, (2014) reported that vermicompost has large particulate surface area that provides sites for the microbial activity and retention of nutrients. Similarly, Wael *et al.,* (2011) declared that vermicompost can be used to increase the pH in acidic soils and reduce Al and Mn toxicity because of its alkalinity. Adane (2014) reported that liming had affected the CEC of the soil significantly. All lime levels resulted in a significant increase in CEC over the control plots. Accordingly, the highest (33.34 cmol (+) kg^{-1}) and the lowest (19.18 cmol (+) kg^{-1}) values of CEC were observed under the highest lime treated and the control plots, respectively

Increase phosphorous availability

Phosphorus (P) is one of the most abundant elements and is essential for plant growth as well as an important component in the developmental processes of agricultural crops (Zhuo *et al.,* 2009a; Withers *et al.,* 2008) Approximately two-thirds of inorganic Phosphorous and one third of organic Phosphorous are not available in soil, especially in soils of variable charges making it difficult for plants to absorb and use (Liu *et al.,* 2000; Lei *et al.,* 2004). In acidic soils, the Phosphorous is fixed by high-energy sorption surfaces such as oxides and hydroxides of Fe and Al by formation of insoluble Fe and Al phosphates by ligand exchange and precipitation reactions (Ohno and Amirbahman, 2010). The amount of plant available phosphorus can be increased if pH is raised (Kisinyo *et al.,* 2014a). The availability of Phosphorous is influenced by soil organic matter, pH, and exchangeable and soluble Al and Fe. Phosphorus is generally available to crops at soil pH of 6 to 7. When the soil pH is less than 6, Phosphorous deficiency increases in most crops. High concentrations of hydrogen in soil solution (low soil pH) may cause the release of soluble aluminum from soil minerals. Aluminum in soil solution binds with phosphorus (decreasing phosphorus availability to plants) and inhibits root growth and development (limiting nutrient uptake). Phosphorus reacts with Fe and Al oxides/hydroxides under acidic conditions to form insoluble phosphates, hence reducing P availability to plants (Kamprath, 1984).

The productivity of crops in acid soils with Al toxicity and low soil availability of Phosphorous may be improved by use of lime, fertilizers with liming effects, and/or organic materials (Ouma *et al.,* 2013). Lime is the most effective means of amending soil acidity (Kenyanjua *et al.,* 2002). Tigist (2017) reported that application of lime alone at the respective rates increased available phosphorous content of the soil by 31- 33% over the control plot. Liming of acidic soils could increase soil pH, which enhances the release phosphate ions fixed by Al and Fe ions into the soil solution (Chimdi *et al.,* 2012). Similarly, Achalu *et al.,* (2012) showed that deficiency of P could be corrected thought liming acid soil to increase the pH more than 6.

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+} ions in the soil solution. Hence, this leads to increased soil pH and available Phosphorous due to reduction in Phosphorous sorption (Kisinyo, 2011). Increasing soil pH liming makes other nutrients more available and prevents Al and Mn from being toxic to plant growth (Yao *et al.,* 2010). Liming also enhances root development and water and nutrient uptakes necessary for healthy plant growth (Calba *et al.,* 2006). Negese *et al.,* (2021) reported that application of lime alone increased available P of the soil from 5.61 to 12.17 mg kg-^{1}, which was about 53.9% increment over the control. Organic fertilizer application has been reported to improve crop growth by supplying plant nutrients as well as improving soil physical, chemical, and biological properties (Mengesha and Mekonnen, 2012). Vermicompost is one of the stabilized, finely divided organic fertilizers with a low C: N ratio, high porosity, and high water-holding capacity, in which most nutrients are present in forms that are readily available for plants (Arancon, *et al.,* 2004). Tigist (2017) application of vermicompost alone increased available Phosphorous contents of the soil treated with the respective levels by 4.5 - 17.7% over the control plot. Application of vermicompost showed marked improvements in the overall physical and biochemical properties, and at the same time, vermicompost decreases exchangeable acidity which can support a release of plant nutrients in the acidic soils (Abafita, 2016). Azarmi *et al.,* (2008) reported that Soils treated with vermicompost at the rate of 15 t ha^{-1} had significantly more Phosphorous as compared to control plots. This implied that the continuous inputs of P to the soil were probably from slow release from vermicompost and release of P was due largely to the activity of soil microorganisms (Arancon *et al.,* 2006). At the same time Azarmi *et al.,* (2008) indicated that in this experiment the more available P probably could have contributed to decrease of soil pH caused from application of vermicompost.

Negese *et al.,* (2021) reported that the highest available P (13.27 mg kg^{-1}) was obtained under the combined application of lime and VC at 75% LR with 2.5 t VC ha^{-1} which was about 72.34% increment over the control.

Fig.1 Effect of the doses of the calcium amendment on exchangeable acidity (Eliecer *et al.*, 2020)

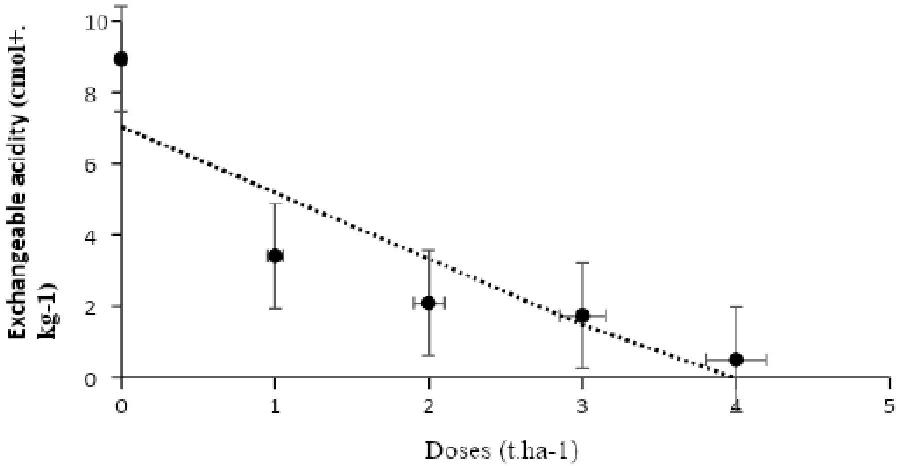


Fig.2 General qualitative representation of soil phosphorous availability as impacted by pH (price. *Australian soil fertility Manual, 2006*)

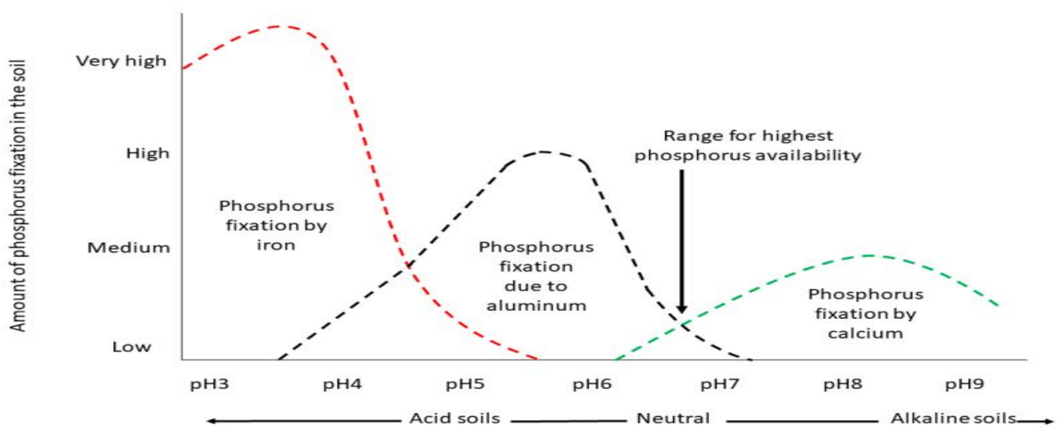
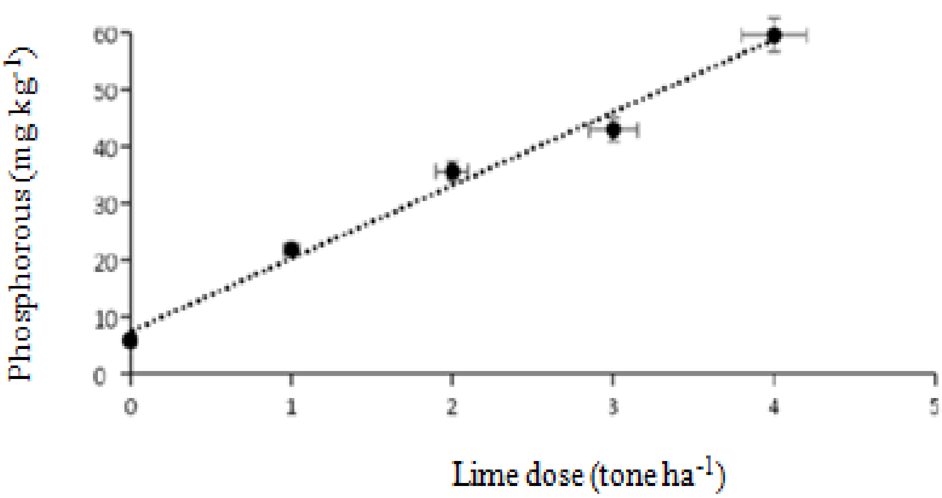


Fig.3 Effect of lime on the phosphorus content in the soil (Eliecer *et al.*, 2020)



Effects of liming and vermicompost on soil biological properties

Microorganisms are the key players in processes such as degradation of organic material, formation of soil organic matter, and nutrient cycles and that these processes are the ones determining soil quality and fertility. Among biological properties, activities of beneficial microorganisms are affected by adverse soil acidity and limits the activities of beneficial microorganisms, except fungi, which grow well over a wide range of soil pH (Brady and Weil. 2002). Liming acidic soils and use organic fertilizers improve soil chemical, physical, and biological properties and enhance the activities of beneficial microbes in the rhizosphere and hence improve root growth by the fixation of atmospheric nitrogen because neutral pH allows more optimal conditions for free-living N fixation (Brady and Weil, 2001). Liming has been shown to provide optimum conditions for a number of biological activities that include N_2 fixation, and mineralization of Nitrogen, Phosphorous and sulfur in soils. The enhanced mineralization of these nutrient ions is likely to cause an increase in their concentration in soil solution for plant uptake and for leaching (Arnold *et al.*, 1994).

The lime-induced increase in earthworm activity may influence the soil structure and macro porosity through the release of polysaccharide and the burrowing activity of earthworms (Springett and Syers, 1984). The application of vermicompost to soil is considered as a good management practice in any agricultural production system because of the stimulation of soil microbial growth and activity, subsequent mineralization of plant nutrients, and increased soil fertility and quality (Arancon *et al.*, 2006). Vermicompost is as an organic fertilizer include an active biological mixture of bacteria, enzymes, plant residue, manure and cyst (capsule) of earthworm can cause the continuum analysis of organic matter and improve microbial activity in planting bed. Abdissa *et al.*, (2018) indicated that Lime and vermicompost application either individually or in combination increased soil pH and organic matter content, which in turn enhances the microbial population. An increase in pH may decrease the stress on soil microbes and microbial activity and thus increases soil organic matter.

Effects of lime and vermicompost on crop productivity improvement

Due to its multiple positive effects on the physical, chemical and biological soil properties, lime and vermicompost contributes to increase of crop productivity and crop quality (Fageria and Baligar, 2008). Plant growth improvement in acid soil is not due to addition of basic cations (Ca, Mg), but it is due to increasing pH that reduces toxicity of phytotoxic levels of Al (Fageria and Beligar, 2008). Long term field trials proved that lime has an equalizing effect of annual/seasonal fluctuations regarding the availability of plant nutrients and thus the final crop yields. Better crop results were often obtained during the second year of lime were applied than the first year (Temesgen *et al.*, 2017). However, crop yields after pure lime application were mostly lower when compared to with mineral fertilization or phosphorus (Temesgen *et al.*, 2017), at least during the first years. This can be explained by the slow reaction of lime with soil, and might be attributed to solubility and downward movement of lime as the time progresses, and normal rainfall with uniform distribution through outgrowing season in second year as compared to first year. Follet *et al.*, (1981) reported that lime action is slow acting, of long duration and not conspicuous. (Weisz *et al.*, 2003; Fuentes *et al.*, 2006) also showed a statistical grain yield increase when excess acidity was neutralized over time. Beukes *et al.*, (2012) reported that Liming significantly affected P, K, Ca, Mg and Mn concentrations of maize leaves, as well as grain yield, but had no clear effect on leaf N, Cu, Fe and Zn. The increased uptake of the former nutrient elements indicates that liming improved the use efficiency of these elements by the maize crop. Tigist (2017) reported that the highest grain yield of soybean (1.95 t ha^{-1}) was obtained from plots received with 4.90 t ha^{-1} lime combined with vermicompost (3.00 t ha^{-1}) and the lowest (0.65 t ha^{-1}) was obtained from untreated (control) plot which is more than 195% yield difference.

Vermicompost (VC) and wood ash were reported to increase the pH of acid soils and improve soil fertility by supplying essential plant nutrients (Chaoui, 2003; Materechera, 2012). Along with this, Zeinab *et al.*, (2014) reported that vermicompost has large particulate surface area that provides sites for the microbial activity and retention of nutrients. Similarly, Wael *et al.*, (2011) declared that vermicompost can be used to increase the pH in acidic soils and reduce Al and Mn toxicity because of its alkalinity. It has been reported that application of vermicompost increases the supply of easily assimilated as well as micronutrients to plants besides mobilizing unavailable nutrients into available form (Zeinab *et al.*, 2014). Bekele *et al.*, (2018) reported that application of lime, vermicompost, and mineral P fertilizer had a significant ($P \leq 0.01$) effect on cob length. Accordingly, the highest mean cob length was recorded in plots that received the highest rates of Phosphorous and vermicompost in the limed plots, where the cob length was 2.5 times higher than that of the control. The increase in the cob length might be attributed to the reduction in acidity and increase in nutrient availability, whereas the reduction in cob length of the control might be due to unavailability of nutrients as a result of lower pH and P sorption. Similarly Bekele *et al.*, (2018) the highest mean above ground dry biomass yield (12.18 t ha^{-1}) was recorded in plots treated with the highest rates of vermicompost and mineral phosphorous along with lime, while the minimum (5.02 t ha^{-1}) was in the control with a difference of about 7.16 t ha^{-1}. This difference might be due to synergistic effects of lime, vermicompost, and mineral phosphorous.

High amount of rain fall that exceeds the soil holding capacity that leaches appreciable amounts of exchangeable bases from the soil surface, crop management practices, removal of organic matter and continuous application of inorganic fertilizer, acidic parent material, highly decomposition of organic material are among some of the factors that contribute to soil acidity, and removal of elements through harvest of high yielding crops in soils is most responsible for increased soil acidity, have adverse effects on the environment and can threaten human health as well as in food safety and quality. Limes and vermicompost are needed for highly acidic soil, particularly in phosphorus poor soils. Compared to inorganic fertilizer alone, combination of lime with vermicomost specifically phosphorus are considered an economic and environmentally-friendly alternative, and have longer-lasting effects. Liming and adding vermicompost can increase soil pH and nutrient availability and reduce the concentration of Alumunium. While the general effects of lime and vermicompost application on soils, have been well documented such as increasing soil pH, available phosphorus, cation exchange capacity, basic cations, microbial activity, organic carbon, total nitrogen, and decreasing leaching of nutrients, exchangeable alumunium and acidity.

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