AMELIORATION OF SUBSOIL ACIDITY AND ALUMINIUM TOXICITY IN LATERITIC SOILS UNDER BLACK PEPPER

By

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THESIS

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DECLARATION

I, **Thamarai Thuvasan K.** (2008-11-120) hereby declare that the thesis entitled **"Amelioration of subsoil acidity and aluminium toxicity in lateritic soils under black pepper"** is a bonafide record of research work done by me during the course of research and that it has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Amelioration of subsoil acidity and aluminium toxicity in lateritic soils under black pepper"** is a record of research work done independently by **Mr. Thamarai Thuvasan K.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Thamarai Thuvasan K.

Dedicated to

My Family,

My Department

and

My Beloveds

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Introduction

1. INTRODUCTION

Black pepper (***Piper nigrum* L.**), known as the king of spices, is an important spice crop of Kerala. The stout glabrous climbing herb is indigenous to the Malabar coast of Kerala preferring a humid tropical climate. It is mostly cultivated on the acid soils of Kerala, which have a pH of 5.0 to 6.2 are generally having low level of plant nutrients, low cation exchange capacity (CEC) with weak retention capacity of bases applied as fertilizers or as amendments. The soils are low in P status and have high P fixing capacity because of the abundance of Fe and Al, are deficient in S, and the N loss through leaching is substantial in high rainfall areas. The high exchangeable aluminium in soil can become toxic to plants.

These soils are mostly lateritic characterized by a subsurface layer containing high amount of exchangeable Aluminium. This layer offers a chemical barrier for root growth and the conventionally applied liming materials do not control this acidity. In the surface applied liming material Ca, is present as $CaCO_3$ and its effect will be confined to the top layer of soil. Soluble forms of Ca like phosphogypsum are a viable alternative for this (Alva and Sumner, 1990; Hovland, 2000).

Phosphogypsum, a by-product from phosphoric acid plant, was found to be effective in correcting the soil acidity in laterite soil by reducing the exchangeable acidity especially the exchangeable Al content (Sumner, 1970; Reeve and Sumner, 1972). Since Ca in phosphogypsum is soluble and mobile, it can correct subsoil acidity also even when applied to the surface (Deepa, 2008; Alcordo and Recheigl, 1993).

The studies done using phosphogypsum have shown encouraging results in many crops (Jacob, 1992; Jeena, 2003; Deepa, 2008). However, phospho gypsum is a material with acidic pH and its application in acidic soil does not encourage a favourable pH for the soil. In many cases, this material is recommended to be applied along with $CaCO_3$.

Fly ash is another industrial by-product formed where solid fuel is used in furnaces. M/s Synthates Chemicals, Cochin use chilli and black pepper spent material to charge the furnace and the ash obtained is a better material compared to coal fly ash. (There is an annual estimated production of 1000 tonnes of such type of ash material in many rice factories, and solvent extraction plants).

Increase in pH and better results in many crops were observed with the application of fly ash by several workers (Adams *et al*., 1972; Jastrow *et al*., 1979; Taylor and Schumann, 1988). Indian fly ash does not have heavy metal and radio nuclide contamination to a hazardous level and also there is no significant uptake by plants (CFRI, Dhanbad, 1999; RRL, Bhopal, 1999). But the material is strongly alkaline and cannot be used for direct soil application on standing crops.

With this background an investigation was carried out to evaluate the suitability of phospho gypsum and its blends with fly ash in combination with vermicompost on controlling sub soil acidity in lateritic soils of pepper garden. The whole investigation was carried out as three experiments, an incubation and pot culture study at College of Horticulture, Vellanikkara and a field experiment at Pepper Research Station Panniyur.

In order to standardise the blending ratio of PG and FA, these two materials were blended and suitable blends were selected based on pH.

The investigation was carried out with following objectives,

1. To assess the extent of subsoil aluminium concentration in a typical lateritic soil with black pepper cultivation

2. To assess the performance of phosphogypsum blended with fly ash and vermicompost for its suitability in regulating exchangeable Al, Fe and Mn concentration in lateritic soil

3. To evaluate the performance of promising blends on growth of pepper vines in field

4. To monitor the nutrient status and yield attributes of pepper vines where the ameliorants were applied on the surface.

Review of Literature

2. REVIEW OF LITERATURE

Soil acidity is one of the major problems for agricultural production in many parts of the world (Kamprath, 1984). It controls the solubility and precipitation of chemical compounds of some essential plant nutrients. Soil acidity is harmful for plant growth due to several nutritional disorders as well as the immediate toxicity of soluble Al, Mn, and H^+ (Haynes and Mokolobate, 2001).

Soil acidity is common in humid tropical regions where precipitation is high enough to leach appreciable quantities of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) from the surface layers of soils. Exchangeable hydrogen and exchangeable aluminium are responsible for soil acidity. Other factors like organic matter, clay minerals, compounds of iron, manganese, sulphur, nitrogen and acid rains are also influencing the soil acidity.

Previously, many scientists worked the problem of soil acidity, with respect to plough layer and amelioration by conventional liming and ploughing procedure. But now, more emphasis is given towards the subsoil acidity as effect of conventional liming is confined to the top soil layers alone.

2.1 Nature of soil acidity in lateritic soil

Soil acidity is of three kinds, namely a) active acidity, b) exchangeable acidity and c) reserve acidity. The active acidity may be defined as the acidity developed due to concentration of hydrogen (H^+) and aluminium (Al^{3+}) ions in the soil solution. Whereas, the exchangeable acidity can be defined as the acidity developed due to adsorbed hydrogen (H^+) and aluminium (Al^{3+}) ions on soil colloids.

However, this exchangeable aluminium and hydrogen concentration is meagre in moderately acid soils. In strongly acidic soils, the concentration of exchangeable aluminium and hydrogen ions contribute more towards exchangeable acidity. Aluminium hydroxy ions, hydrogen and aluminium ions present in non-exchangeable form with organic matter and clays account for the reserve or potential acidity. It contributes to titrable or total acidity.

In highly weathered lateritic soils, an appreciable fraction of the permanent negative charge is contributed by aluminium and hydrogen ions and this fraction is generally known as exchangeable acidity. Initially, soil acidity was thought to be caused by exchangeable hydrogen because it could be leached out of acid soils by neutral salts, but titration curves of clay suspension suggested that acid clays behave like weak acids and that hydrogen ions adsorbed on clays when exchanged by neutral salts immediately dissolves hydrated aluminia in the soil which cause Al^{3+} to appear in the extract (Coulter, 1969)

Results of studies conducted by Coleman and Thomas (1967) and Mc-Cart and Kamprath (1965) clarified that in highly weathered acid soils, exchangeable aluminium was the predominant cation contributing to soil acidity rather than other ions.

Pavan (1983) reported that the cation exchange capacity of acid soils of Brazil has a very large pH dependent charge. Aluminium was the dominant cation in the exchange complex and only a small proportion of the exchange capacity was balanced by basic metals.

Studies by Kaminiski and Bohnen (1976) revealed that exchangeable aluminium and organic matter levels showed the greatest effect on soil acidity. While studying the inter-relationships between the nature of soil acidity, exchangeable aluminium and per cent aluminium saturation, the authors considered soil acidity as a poorly defined parameter and recommended that per cent aluminium saturation calculated on the basis of effective cation exchange capacity could be taken as a useful measure of soil acidity.

Duchanfour and Souchier (1980) observed that Al^{3+} is more harmful to plants than H^+ in acid soils. But a negative relationship was obtained by Manrique (1986) between Al saturation and pH in 1M KCl in Ultisols. According to Sarkar *et al.* (1989) and Jose *et* *al.* (1998) in Kerala, more than 60 per cent of soils are of lateritic type with pH values less than 5.5. Soil acidity and other allied problems are major chemical drawbacks for crop production in these soils.

But Sharma *et al.* (1990) reported that, in red soils of Trivandrum, the exchangeable acidity contributes about 6 per cent and pH dependent acidity contributes 60 per cent of total acidity. However exchangeable aluminum altogether contributes more than 90 per cent. These factors are considered as the major source of exchangeable acidity in these soils. According to Nambiar and Meelu (1996) soil acidity in lateritic soil is increasing over the years due to long-term use of acid forming fertilizers.

Values of total potential acidity, total acidity, pH dependant acidity, hydrolytic, and exchangeable acidity ranged from 1.5 to 11.25, 0.93 to 4.75, 1.41 to 10.35, 0.89 to 3.85, and 0.04 to 1.03 Cmol P^+ kg^{-1}, respectively, in red and lateritic soil of West Bengal (Chand and Mandal, 2000).

Similarly, Dolui and Sarkar (2001) recorded that in the red soil profiles of Orissa, exchangeable acidity contributed to 9 to 19 per cent of total acidity whereas, pH dependent acidity constituted around 81 per cent of total potential acidity. But, in the red soils of West Bengal, the mean values of exchangeable and pH dependant acidity were 12.4 and 87.6 per cent of total potential acidity (Rahman and Karak, 2001).

2.2 Sub soil acidity

Subsoil acidity has been recognized as an important yield-limiting factor on a wide variety of soils throughout the world (Adams and Moore, 1983; McKenzie and Nyborg, 1984; and Farina and Channon, 1988).

Subsoil acidity has decreased the yield of lucerne (*Medicago sativa*) grown on the yellow podzolic soils of the Yass valley in eastern Australia (Simpson *et al.,* 1979) and wheat (*Triticum aestivum*), lucerne (*Medicago sativa*) and rape (*Brassica napus*) grown on the granitic soils in the southern tablelands of New South Wales (Pinkerton and Simpson, 1986).

In Western Australia, wheat yields on the yellow earth soils in the eastern wheatbelt can be severely restricted by subsoil acidity (Porter and Wilson, 1984). From a Hoagland solution culture experiment, Deepa (2008) reported that there is a subsoil acidity barrier in the soil due to exchangeable aluminium and hydrogen and that this zone needs special attention.

2.3 Form of aluminium in soil as influenced by pH

Next to oxygen and silica, aluminium is found to be the most abundant element in the earth's crust. In the form of Al_2O_3, it ranges up to 20 to 60 per cent in highly weathered soils and laterites (Jackson, 1973). The higher percentage of Al_2O_3 is generally associated with a high percentage of gibbsite, as in bauxite ore.

Moore and Patrick (1991) observed that jurbanite $Al(SO_4)OH.5H_2O$ governs Al^{3+} activity under low pH and amorphous $Al(OH)_3$ at high pH. Most of the pH dependent CEC sites are contributed by organic matter which complex with aluminium.

Chand and Mandal (2000) reported that buffering nature of soils under these severely acid conditions is attributed to acid hydrolysis of alumino silicate clays and dissolved Al^{3+} activity appears to be directly related to pH and as pH rises, aluminium is precipitated as hydroxide or basic sulphate.

The primary mechanisms of Al toxicity are inherently difficult to evaluate because primary effects of Al toxicity can occur during the first minutes or hours of exposure to Al, but later on they can become masked after longer periods of exposure (Rengel, 1992).

2.3.1 Soil Acidity due to aluminium and effect on crops

Pavar and Marshall (1934) suggested that the measurement of exchangeable Al as the better criteria of soil acidity rather than hydrogen ion concentration. Aluminium toxicity and calcium deficiency are important constraints for normal crop growth in acid soil. This leads to poor root penetration and proliferation in acid soils (Pearson, 1966).

The initial and most obvious symptom of Al toxicity is the inhibition of root growth. Injured roots are characteristically stubby with reduced growth of the main axis and inhibited lateral root formation (Foy, 1988). Root growth inhibition occurs through impedance of both cell elongation and cell division (Kochian, 1995). Since root growth is restricted, plant water uptake is reduced. As a result, nutrient and/or water stresses are common in plants suffering from Al toxicity (Foy, 1984).

Evans and Kamprath (1970) proposed that liming in the soil increased the growth of corn when the aluminium saturation was greater than 70 per cent and the concentration of soil solution Al was greater than 0.4 me/litre. Soybeans responded to liming when the Al saturation was greater than 30 per cent and soil solution Al concentration was 0.2 me/litre. On the other hand, Mc-Lean (1970) reported that liming had only very low favourable effect on phosphate availability to plants in highly weathered semitropical and tropical soils because of the presence of more of reactive surface area composed of Al and Fe hydroxides or hydroxy-Al-hydroxy-Fe ions for fixing soil phosphorus.

Sanchez (1976) treated the soil acidity as a poorly defined parameter and recommended the liming of acid soils to pH range of 5.5 to 6.0 for favourable response. This would in turn bring out the precipitation of exchangeable Al as $Al(OH)_3$. But Martini *et al.* (1977) suggested different lime rates to bring soil pH from 4.8 to 5.7 and to reduce exchangeable Al to 1.5 me/100 gm soil as a sustainable measure of increasing the crop yield than raising of soil pH towards neutral. However soil acidity is considered as a major growth limiting factor in crop production and the deleterious effect is due to high aluminium (Al) toxicity (Foy, 1983).

Aniol (1996) found that generally, shoot and root response depended on the concentration of Al in the soil solution, age of plants and the type of cultivar. Higher concentrations of aluminium drastically retarded shoot and root growth and mainly older plants showed higher Al tolerance than young ones during occasions. There was a relationship between sensitivity of the plants to Al and ability to increase solution pH.

Similarly, Marziah (1991) reported that aluminium drastically reduced the cell growth of peanuts. Application of 200 micromolar Al on peanut culture recorded relatively 90 per cent more growth for more than two weeks than those untreated plants. However, cultures treated with 400 micromolar Al showed low response in terms of growth, throughout the experiment. Maximum effects of aluminium toxicity could occur during the initial six days of culture.

But results of experiment conducted on tobacco plants by Yamamoto *et al.* (1994) revealed that cell growth was inhibited even at a minimum dose of 1×10^{11} Al atoms per cell at the logarithmic growth phase. Cells at stationary phase offered resistance to Al and from these it is very clear that the uptake of Al depends on the active growth of cells.

Similarly Fageria (1982) concluded that aluminium toxicity affects the shoot growth of non leguminous plants like rice and gleditsia. Whereas, Neogy *et al.* (2002) noted that the toxic concentration of aluminium sulphate in solution cultures caused more nutrient deficiency, poor crop yield, reduction in leaf area and dry weight of mungbean.

Keser *et al.* (1975) reported that 4, 8 and 12 mg L^{-1} Al nutrient solutions caused curving of the primary root of sugarbeat and root cap breakage. Also lateral roots emerged as small outgrowths on the primary root axis but their development was abnormal. Ermolayev *et al*. (2003) reported normal lateral roots with numerous root hairs in transgenic soybean seedlings tolerant to aluminium grown in modified Hoagland solution

2.4 Effect of Aluminium toxicity on crop roots

Aluminum in acidic subsoil restricts root development, increasing the susceptibility of crop plants to drought. Hutchinson (1983) found that aluminium ions were potentially toxic to plant roots. The primary symptom of aluminium toxicity in higher plants is inhibition of root growth due to auto removal of root cap (Ryan *et al.*, 1993).

Abraham (1984) reported that in rice, aluminium concentration in the range of 20 to 40 ppm in the nutrient solution decreased root elongation and caused reduction in the number of productive tillers, yield of grain and straw, as well as shortening and branching of roots with a resultant reduction in the uptake of nutrients and also led to a higher uptake of iron in rice. The site of aluminium toxicity is root apex and aluminium injured roots have been found to be stubby and brown (Ryan *et al.*, 1993).

Pavan *et al.* (1982) reported that low content of calcium and aluminum toxicity affect root growth and absorption of water and nutrients by plants, ultimately causing reduction in crop yields.

The roots of aluminium treated wheat seedlings exhibited typical symptoms of aluminium toxicity like stunting, brittleness and browning of the tips. Sensitive cultivars showed more reduction in root length than resistant types (Kymberly *et al.*, 1994).

Deepa (2008) reported that 5 mg L^{-1} concentration of Al in Hoagland solution promote the growth of morphologically normal lateral roots with numerous root hairs from the newly emerged roots in pepper variety Panniyur 1. She also observed that pepper plant root growth was better at an aluminium concentration between 0 and 5, while at 10 mg L^{-1} there was decline.

2.5 Acidity reclamation in lateritic soil

The problem of overcoming the acidity in lateritic soils through liming had received attention from a very early period. In order to increase the productivity of acid soils, liming is considered as the first step since it directly neutralizes the acidity and indirectly increases the availability of nitrogen by enhancing the decomposition of organic matter, making available the nutrient elements to the crop and decreasing the toxic elements *viz.,* Al, Fe, and Mn.

Liming is one of the most important management options in laterite soil where soil acidity poses the major challenge for successful crop production. Liming, though a relatively costly remedial treatment, is the most effective solution for correcting the problem of soil acidity (Ukrainetz, 1984).

According to Moralli *et al. (*1971), liming decreased the exchangeable and titrable acidity and also brought up the pH to a depth of 100 cm in oxisols. This also promoted the migration of Ca and Mg towards different directions in the soil system.

Experiment on continuous soil liming for five years conducted by Raji *et al*. (1982) revealed that neutralization of soil acidity below the plough layer was insignificant. This ameliorated the soil acidity to a favourable limit and substantially augmented Ca + Mg status and lime potential in soil. Similarly, Maria *et al. (*1985) reported that liming increased the pH values insignificantly. The nitrogen status of plants was improved by lime application.

Cahn *et al.* (1993) applied lime on the surface soil, leading to leaching of Ca from 0 to 30 cm depth, but only limited amounts accumulated in the subsoil. Base saturation below 45 cm was less than 50 per cent at the end of the experiment irrespective of lime treatment. But Farina *et al*. (2000) predicted that even the highest application rate of lime had only minimal effects on acidity below the depth of incorporation.

When gypsum was added to the surface soil, level of extractable calcium increased in the subsoil, but there was no change in subsoil pH. During the reclammation of highly acidic soil, only less chance existed of obtaining significant effects of the surface treatment on the untreated subsoil. A sufficient root zone would have to be achieved by incorporating the liming agent up to the desired rooting depth (Willert and Stehouwer, 2003).

2.5.1 Lime and slaked lime as an ameliorant

Awan (1964) reported highly significant yield increment of sorghum, corn, beans, cowpea and green manure, when acid soil (pH 5.5) was limed to raise the pH to 6.5. He also added that exchangeable Al and Mn content of humid tropical soils were sharply increased by fertilization alone but decreased by liming. Ross *et al. (*1964) substantiated that liming would not appreciably affect the amount of exchangeable Mg and K or extractable P in soils.

Varghese and Money (1965) showed that the acidic pH of red and laterite soils of Vellayani could be raised by ameliorating with calcium and magnesium compounds. Black *et al.* (1965) also explained that liming improved the soil aggregation, maximum water holding capacity and the hydraulic conductivity of the soil, and also exchangeable cations and per cent base saturation was almost doubled due to addition of lime @ 17.90 t ha^{-1}. Liming significantly decreased the exchange acidity as well as pH dependent acidity. The available nitrogen, phosphorus and potassium were also increased significantly with higher doses of lime.

Helyar and Anderson (1974) demonstrated that calcium carbonate application increased exchangeable Ca and decreased exchangeable Al and Mn but had only little effect on the exchangeable levels of other cations. Calcium carbonate application reduced all cations except Ca. Rojas and Adams (1980) observed that the K:Ca and K:Mg ratios decreased with increased lime application while the Ca+Mg:K ratio increased.

Haynes and Ludecke (1981) explained that liming resulted in an increase in exchangeable Ca and per cent base saturation with concomitant decreases in levels of exchangeable Al, Fe and Mn. Increasing lime rates significantly reduced concentrations of Mg, K and Na in saturation paste extracts but had no effect on exchangeable Mg, K and Na levels. With increasing lime additions available P increased.

Availabilty of P and Ca was promoted by lime application @ 2.5 t ha^{-1} with subsequently higher yield of barley and maize in a strongly acid soil of pH of 4.3 (Prasad *et al.,* 1984). Liming is one of the most important management options in laterite soil where soil acidity is considered to be a major challenge for successful crop production. Enright (1984) reported that the application of lime @ 2 t ha^{-1} in laterite soil increased the soil pH by two units by decreasing exchangeable aluminium content.

Field lime trials conducted by Edmeades *et al.* (1985) and Grove *et al.* (1981) showed that liming reduced exchangeable Mg. This was increased with increasing rate of lime and with time after lime application. Blaszcyk *et al. (*1986) proposed that liming at the rate of 18.4 t ha^{-1} significantly increased calcium, magnesium and potassium concentration in the top soil.

Similarly, Bishnoi *et al. (*1987) proposed that liming reduced extractable and exchangeable Fe, Al and Mn in acid soils. Gama (1987) reported that application of calcium carbonate resulted in the release of non-exchangeable potassium and slight magnesium fixation in acid soils. Exchangeable aluminium was reduced to very low levels. It is suggested that this may improve the adsorption of Mg from soil solution.

Amelioration of acid soils by common liming materials such as calcium oxide, calcium carbonate, calcium hydroxide are limited only to the depth of incorporation, due to their low mobility and solubility (Brown and Munsell, 1938; Pearson *et al*. 1973 and Recheigl *et al*. 1985).

Deepa (2008) reported that $CaCo_3$ is more effective than Phospho Gypsum (PG) in decreasing the exchangable aluminium concentration due to its effect on maintaining high pH, but it is confined to the site of application due to insoluble Ca. However PG did not bring any significant decrease in exchangable Al and pH of soil due to free phosphoric acid. Hence the need of applying PG mixed with $CaCo_3$ to obtain most beneficial effect.

Abraham (1984) reported that lime @ 1200 kg ha^{-1} in kari (acid peat) soil raised the pH from 3.8 to 5.7. Similar reports were also given by Lin *et al*. (1988) and Broadbent *et al.* (1989). Neutralisation of active acidity by different calcium sources such as CaO, $Ca(OH)_2$ and $CaCO_3$ brought about increase in pH where as phosphogypsum did not cause such a reaction (Jeena, 2003).

Nakayama *et al.* (1987) found that liming increased nitrogen, phosphorus, potassium, calcium and magnesium contents of the soil. Studies conducted by Bertic *et al* (1988) revealed that by the application of hydrated lime at the rate of 20 t ha^{-1}, the Fe content in soil decreased from 34.1 ppm to 14.1 ppm, titrable acidity from 16.0 to 1.6 me/100gm soil and exchangeable acidity from 3.0 to 0.1 me/100gm soil. The pH in KCl increased from 4.03 to 6.42.

In soybean, nutrient solution culture experiment conducted by Noble et al., (1996) revealed that increasing Al in solution significantly reduced the concentration of ions like Ca, Mg, P and Mn in the shoots. Similarly, incubation studies conducted on acid soils of Sikkim by Patiram and Rai (1988) showed that CEC, pH, potential buffering capacity and labile K increased after lime application while exchangeable aluminium and activity ratio of potassium decreased.

Gupta *et al.* (1989) confirmed that availability of calcium, soil pH, CEC and lime potential of soil increased with liming whereas, availability of potassium, iron and aluminium, aluminium saturation and free energy were decreased. Bailey and Stevens (1989) reported that on most soils, lime responses appeared due to either enhanced soil nitrogen mineralization or to the reclammation of aluminium toxicity. But, according to Cahn *et al*. (1993) substantial amounts of Ca were leached from lime from the top soil to 30 cm depth during the experimental period, but only limited amounts accumulated in the subsoil.

Base saturation below 45 cm depth was less than 50 per cent at the end of the experiment regardless of lime treatment. Roots of maize were concentrated from 0 to 30 cm depth in both limed plots and unlimed plots. Balatti *et al.* (1991) concluded that liming increased the Ca levels in the soil which induced normal distribution of nodules on the tap root and lateral root by Rhizobium in soybean.

Results of field studies conducted by scientists like Rheinheimer *et al.* (2000), Gascho & Parker (2001), Conyers *et a*l. (2003), Pires *et al.* (2003) and Tang *et al.* (2003) showed that the movement of lime to different depths varied according to time and rate of liming, lime forms, soil type, weather conditions, addition of acidic fertilizers, and cropping systems.

In a soil column experiment to study the effects of slaked lime [$Ca(OH)_2$] and gypsum [$CaSO_4.2H_2O$] on soil acidity, soil solution chemistry and nutrient leaching in an acid soil, results showed that application of sufficient slaked lime to initially increase the pH of the topsoil by one unit caused an increase in pH 5 cm deeper than the layer of application as a result of bicarbonate leaching (Sun *et al*., 2000). With leaching of Ca from slaked lime or gypsum from the topsoil to the subsoil, there was a decrease in exchangeable Al in the subsoil.

Mora *et al.* (2002) reported that combined application of limestone, dolomite and gypsum raised the pH and decreased aluminium saturation from 20 per cent to less than 1 per cent in acid soil. This was also supported by Staley (2002), Caires *et al.* (2002), Whalen *et al.* (2002), Nkana and Tonye (2003) and Tang *et al.* (2003). Similarly, Pires *et al*. (2003) concluded that repeated application of lime into planting furrows and surface application, raised the soil pH and decreased exchangeable aluminium in acid soil.

2.5.2 Influence of liming on Nutrient uptake

Koshy (1960) and Nair (1970) recorded low potassium content in plants grown with high level of liming. However the phosphorus and magnesium content were unaffected. Bhor *et al.* (1970) obtained significant effect on the uptake of phosphorus and manganese, and the uptake of calcium was directly proportional to the lime content of the soil in paddy and jowar plants.

Kuruvila (1974) explained that the application of lime alone or in combination with MnO_2 or nitrate results in reduction in the nitrogen and phosphorus content of straw. Similarly, Mandal (1976) reported that liming had been found to depress the uptake of iron, manganese, copper and zinc in soybean.

A notable increase in the uptake of N, P, K, Ca and Mg with increased dose of lime by rice was obtained by Anilakumar (1980) and Kunishi (1982). Blasko (1983) explained that in order to ensure adequate uptake of phosphorus, the lime status of the soil should be maintained at an optimal level. Marykutty (1986) found that the total uptake of N, P, Ca and Mg by rice plant increased with lime application whereas uptake of K decreased with increase in levels of lime.

Baligar *et al.* (1985) reported that liming increased the calcium content in shoots of legumes and decreased the concentration of magnesium, potassium and zinc. Meena (1987) proposed that a reduction in exchangeable Al and per cent Al saturation values resulted in an increased uptake of N, P, Ca and Mg in cowpea. Similarly, Gupta *et al.* (1989) substantiated that liming would increase the uptake of phosphorus, calcium and potassium in plants.

2.5.3 Phosphogypsum as an ameliorant for soil acidity

Subsoil acidity is a major problem in tropical soils, which requires deeper incorporation of these liming materials. Mechanical incorporation of lime into deeper soil layers is of an expensive process and heavy application of lime leads to toxicity.

Hence, alternate liming materials with better mobility were tried for the correction of subsoil acidity. Phosphogypsum was found to be one such effective material for the correction of subsoil acidity (Sumner, 1970; Shainberg *et al.*1989 and Alcordo and Recheigl, 1993).

Phosphogypsum, a by-product from phosphoric acid plant was found to be effective in correcting the soil acidity in lateritic soil by reducing the exchangeable acidity especially the exchangeable Al content (Sumner, 1970; Reeve and Sumner, 1972).

Since Ca in phosphogypsum is soluble and mobile, it can correct subsoil acidity even when applied to surface (Alcordo and Recheigl, 1993; Deepa, 2008). During 1970's Sumner (1970) studied the suitability of phosphogypsum to correct soil acidity in lateritic soil. Thereafter, many research works have been conducted on its ability to control soil acidity in iron and aluminium rich soils.

Gypsum moves downward more rapidly than lime, increasing soil solution calcium ion activity up to a depth of 0.8m within 5 months of initial application (Mc-Cray *et al.*, 1991). An increase in soil pH to the extent of 0.8 units in dark red latosol after gypsum application was reported by many workers (Ritchey *et al.*, 1980; Keng and Uehara, 1974; Hue *et al.*1985; and Bolan *et al.* 1992).

Application of gypsum and lime: gypsum combination at 25:75 % in groundnut grown in acid soil improved the yield more than the sole application of lime (Aniol, 1996). Similarly, Alva and Sumner (1989) found that application of phosphogypsum alleviated aluminium toxicity and increased soyabean root growth in nutrient solutions.

The detoxification of subsoil aluminium by the flouride content of phosphogypsum was reported by Alva *et al.* (1988). Jacob (1992) suggested that soil pH increased by 0.05 units by the application of lime and gypsum at the rate of three times exchangeable aluminium in red and lateritic soils of Kerala. According to Cameroon *et al*. (1986), decrease in pH was recorded after gypsum application in black soil to the extent of 0.5 to 0.9 units.

In highly weathered Palexerult soils also the decrease in pH was noticed by Arias and Fernandez (2001) whereas no change in pH due to phosphogypsum application was observed by many workers (Hammel *et al.* 1985; Oates and Caldwell, 1985; Sumner *et al*., 1986). Both phosphogypsum and mined gypsum can ameliorate aluminium toxicity in the subsoil horizon of highly weathered soil belonging to soil orders such as ultisol and oxisol (Martin *et al*., 1988) and also in soils such as non allophanic andosol (Saigusa *et al.*, 1996; Toma and Saigusa, 1997).

Alva and Sumner (1990) suggested that the ameliorating effect of mined gypsum or phosphogypsum is due to the supply of calcium and also due to the enhanced mobility of gypsum (Caldwell *et al*. 1990; Alcordo and Recheigl, 1993; Sumner, 1993; Moody *et al.* 1998 and Hoveland, 2000). Repeated application of phosphogypsum decreased the exchangeable aluminium (Alva *et al.*, 1990) and increased cation exchange capacity of acid soil (Alva *et al.*, 1991).

2.5.4 Ameliorating mechanism of phosphogypsum in soil acidity

Phosphogypsum could act as ameliorant for soil acidity in soils rich in Fe and Al. This is made possible through several mechanisms such as,

1) Self liming effect (ligand exchange of hydroxyl group by sulphate on the sesquioxide surface) (Shainberg *et al.*, 1989; Alva *et al*., 1990).

2) Precipitation of solid phases in the form of basic aluminium sulphates such as jurbanite (Hue *et al.*, 1985; Alva *et al.*, 1991).

3) Co-adsorption of SO_4^{2-} and Al^{3+}, which involves a preferential salt absorption of Al^{3+} over the Ca^{2+} on negative charges formed by specific adsorption of SO_4^{2-} (Sumner, 1993).

4) Formation of ion pair (Chaves *et al.*, 1991) involving formation of ion pairs such as $AlSO_4^+$ (Mc-Lay and Ritchie, 1993; Pavan *et al.*, 1982) and AlF^{2+} in the case of phosphogypsum (Cameron *et al.*, 1986) and

5) Increasing ionic strength of solution would reduce the activity of Al^{3+} in solution (Pavan and Bingham, 1982).

2.6 Removal of aluminium by plants

Once Al concentrations reached toxic levels in root tissues, root senescence would be an effective mechanism for removal of Al from the living biological tissues (Vogt *et al.*, 1987). Study conducted by Dennis *et al*., (1994) to examine aluminum exclusion by roots of two differentially tolerant soybean genotypes revealed more Al accumulation in all root regions in the Al sensitive genotypes. The genotypic difference in Al accumulation was particularly apparent at the root apex, adjacent to root cap and mucilage.

2.6.1 Genetics of acid tolerant plants

According to Aniol (1996) aluminium tolerance in wheat is a dominant character which could be explained by the hypothesis of two or three gene pairs, each gene affecting the same character, with complete dominance of each gene pair. Genes controlling aluminium tolerance in ditelosomic lines of Chinese spring wheat cultivar are located on the short arm of chromosome 5A and the long arms of chromosomes 2D and 4D.

2.6.2 Effect of calcium and magnesium

Edmeades *et al*., (1991) reported that both calcium (Ca) and magnesium (Mg) ameliorate aluminium (Al) toxicity in plants. The effects of both Ca and Mg are additive, but together could not completely eliminate the deleterious effect of aluminium. Magnesium ameliorated Al toxicity in the tolerant wheat genotypes. Calcium either had no effect, or at low Mg levels, exacerbated the effects of Al toxicity. Mg was much more effective than Ca in protecting roots against adsorbed/ precipitated Al and in excluding Al from roots and shoots (Keltjens and Dijkstra, 1991).

2.7 Effect of aluminium and boron

Root growth inhibition is an early symptom of Al toxicity and is subsequently followed by B deficiency. Incorporation of supplemental B prevented the Al inhibition of root growth. Boron concentrations may need to be increased under acidic (high Al) soil conditions, to promote the root penetration into these soil horizons, and this could be especially important during periods of drought stress (Aniol, 1996).

Lenoble *et al*., (1996) substantiated that Aluminium toxicity is an important factor for poor plant growth in acid soils. Symptoms of B deficiency and Al toxicity are very similar and generally associated with impaired membrane function and root growth. Protection was apparent at all levels of organization. They examined primary root and lateral root lengths; primary cell elongation, cell production rate, tissue organization and cell structure; primary root morphology and maturation.

2.8 Fly ash as an ameleorant for soil acidity

Vimleshkumari (2009) reported that addition of fly ash to soils results in altering the soil pH. Fly ash may either have a positive or negative effect on plant growth and yielding if not used in optimum doses.

According to Kalara *et al*. (2003), application of fly ash at 5 to 12 t/ ha/yr modified the soil physico-chemical properties viz., reduced the bulk density, increased the water holding capacity, improved the exchangeable calcium and magnesium status of the soil, which enhanced the wheat yield.

Meller (1999) found that increasing levels of coal fly ash resulted in significant increase in pH, the total contents of alkaline exchange cations, cation exchange capacity and the per cent base saturation. This was mainly attributed to the inherent properties of fly ash itself. Tiwari *et al.* (1992) reported that fly ash was effective for improving physicochemical properties of sodic soil, which in turn resulted in significant increase of yields for rice and wheat.

2.8.1 Effect on phosphorus solubility

The mixture of fly ash and phospho-gypsum reduced water-soluble phosphate in the surface soils by shifting water-soluble phosphate form and iron bound- P to calcium bound- P and aluminum bound-P during rice cultivation in acid soils. Mixtures of fly ash and phospho-gypsum should reduce P loss from rice paddy soils and increase soil fertility (Chang-Hoon-Lee *et al.,* 2003).

Similarly, Stout *et al.* (1998) reported that fly ash and phosphogypsum are sources of Ca, Al and Fe compounds that can form insoluble precipitates with P thereby reducing the P run off.

2.9 Effect of organic manures on subsoil acidity

Manures are very good amendments in reducing the Al toxicity. Results of Tang *et al.* (2003) revealed that poultry litter and feed lot manure increased the soil pH and reduced the extractable Al and increased wheat biomass.

In solution culture experiments, Suthipradit *et al.* (1990) found that addition of fulvic acid reduced the amount of monomeric Al present in solution and alleviated the toxic effect of Al on growth of soybean, cowpea, and green gram. The addition of organic residues to soils can increase soil pH (Hoyt and Turner, 1975; Hue, 1992; Noble et al., 1996) and precipitate soluble Al. Additionally, poultry litter and feedlot manure may raise pH via a liming effect because they contain large amounts of $CaCO_3$, which originates in the animal diet (Eghball, 1999; Moore and Edwards, 2005).

The addition of animal manures to acid soils decreased total Al or monomeric Al in soil solution and increased crop growth (Hue, 1992)

Wong and Swift (1995) reported that plant residue compost, urban waste compost, farmyard manure, and peat can be used to ameliorate soil acidity. Farmyard manure and a sedge peat resulted in increased soil pH and decreased aluminum (Al) saturation.

The increased soil pH was directly proportional to the protons consumption capacity of the organic materials. The organic matter addition decreased the solubility of soil aluminum and addition of brown coal and peat to soil resulted in changes in Al activity in the soil solution. The negative log of Al activity (pAl) was directly proportional to the soil solution pH.

According to Alter and Mitchell (1992) and Hue (1992) reaction of tropical acid soils with composts, manures and coal derived organic products results in increased soil pH, decreased Al saturation, and improved conditions for plant growth.

Wong and Swift (1995) suggested that the adsorption of Al by organic matter and the resulting dissolution of aluminum hydroxide due to under-saturation of the soil solution relative to the mineral phase contributed to increased soil pH and the resulting lowered Al activity in the soil solution.

2.9.1 Effect of vermicompost on subsoil acidity

Organic amendments like vermicomposts, manures, and peats contain major constituents like humic and fulvic acids with functional groups such as carboxyl groups that are able to consume protons and Al at their natural pH values (Wong, 1981; Stevenson and Vance, 1989).

According to Acevedo and Pire (2004), largest plant growth was found with highest rate of vermicompost, without any N fertilizer. With N fertilizer, intermediate rates of vermicompost were more efficient. Papaya seedlings (cv. Co 2) grown in the potting mixture treated with vermicompost showed early flowering (86.69 days) with minimum plant height (90.93 cm) and first bearing height (96.95 cm) (Rajamanickam *et al.*, 2008).

Ndegwa *et al.* (2000) suggested that on decomposition, vermicompost improves the soil structure and increases the cation exchange capacity. However, thermophilic composting is generally a more time-consuming process requiring frequent mixing with possible losses of nutrients especially nitrogen.

Muscolo *et al.* (1999) reported that vermicomposts are comprised of large amounts of humic substances which have some significant role in improvement of physical structure of the potting medium, increase in populations of beneficial microorganisms and enhanced availability of plant growth influencing substances produced by microorganisms. These were factors considered to have contributed to increased fruit yields (Aracnon *et al.,* 2006).

2.9.2 Proton consumption by ameliorating material

Wong *et al.* (1998) concluded that about 60% of the base cations were not involved with proton exchange at pH 4.0. This involves simply the transfer of protons from the acid soil to the organic material. Small additional proton consumption would occur at lower pH values.

A large proportion of the base cations presumably occurred as neutral inorganic salts and as structural constituents that were not involved in proton exchange. Acid amelioration would result simply from the transfer of protons from the acid soil to the organic material.

But according to Jarvis and Robson (1983), the excess cation charge is closely related with values of ash alkalinity. It is, therefore, assumed that the excess cation charge is complexed with organic anions and that microbial oxidation of the anions in the soil results in the formation of alkalinity (Noble *et al*., 1996). Mechanism of amelioration is the transfer of protons from the acid soil (lower pH) to the added organic material (higher pH than soil). This process explained accurately the final pH achieved in a number of acidic soils treated with a variety of humified organic materials (Wong *et al*., 1998).

Materials and Methods

3. MATERIALS AND METHODS

An investigation was carried out at College of Horticulture, Vellanikkara, Thrissur to study the ameliorating effect of phosphogypsum and its combination with fly ash and vermicompost on subsoil acidity and its effect on growth of black pepper vines (*Piper nigrum*) in lateritic soil.

The whole investigation was carried out as three experiments, an incubation and pot culture study at College of Horticulture, Vellanikkara and a field experiment at Pepper Research Station Panniyur. In order to standardise the blending ratio of PG and FA, these two materials were blended and suitable blends were selected based on pH.

The investigation was carried with different experiments in the following steps:

- Collection of soil samples, and analysis of physical and chemical properties.
- Preparation and standardisation of different blends of phosphogypsum and fly ash.
- Incubation experiment, to evaluate the ameliorating effect of different ameliorants selected on soil properties with special reference to exchangeable aluminium.
- Pot culture experiment to evaluate the suitability of the selected material for promoting the growth and uptake of nutrients.
- Evaluation of the materials on five year old pepper vines at Pepper Research Station, Panniyur, Kannur.

The experiment details with special reference to the materials used and methods adopted are discussed in this chapter.

3.1 Collection of Soil samples

Soil samples were collected randomly from unfertilized area of lateritic soil, from two locations, one from Pepper garden, College of Horticulture and another from Pepper Research Station, Panniyur. The air dried soil samples were ground and passed through 2 mm sieve and stored in air tight containers.

The samples were analysed for bulk density, particle density, porosity, texture, EC, pH, exchangeable Al and exchangeable Ca, organic carbon and available nutrients such as N, P, K, Ca, Mg, Fe, Cu, Mn and Zn on following standard procedures (Table 1). The data are presented in Table 2.

3.2 Bulk soil sample collection

Bulk soil samples were collected randomly from different locations of unfertilized area of pepper garden of College of Horticulture, Vellanikkara. Soil samples were pooled together and used for incubation study.

3.3 Collection of ameliorants

The ameliorant Phosphogypsum (PG), was obtained from Fertilizers and Chemicals Travancore Ltd. (FACT), vermicompost (VC) from College of Horticulture, Vellanikkara and fly ash from M/s Synthate, Cochin. All the three were analysed for Bulk density, pH, free acidity/ alkalinity, heavy metals (Al, Pb, Hg, Cd, As, Ni & Cr) and for other nutrients as per standard procedures (Table 3). The data are presented in table 4.

3.4 Preparation of PG and Fly ash blends

Phosphogypsum was blended with fly ash at different ratios and pH of the blends was determined. Blends which had the desired pH (7.2-9.3) were again

Table 1. Analytical methods followed in soil analysis

Sl. No	Parameter	Method	Reference
1	Bulk density	Undisturbed core sample	Black *et al.* (1965)
2	Particle density	Pycnometer method	Black *et al.* (1965)
3	Porosity	-	Black *et al.* (1965)
4	Texture analysis	International Pipette Method	Robinson (1922)
5	Electrical conductivity	Conductivity meter	Jackson (1958)
6	pH	pH meter	Jackson (1958)
7	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
8	Available N	Alkaline Permanganate Method	Subbaiah and Asija (1956)
9	Available P	Bray extraction and photoelectric colorimetry	Jackson (1958)
10	Available K	Flame photometry	Pratt (1965)
11	Available Ca	Atomic absorption Spectroscopy	Jackson (1958)
12	Available Mg	Atomic absorption Spectroscopy	Jackson (1958)
13	Available Fe	Atomic absorption Spectroscopy	Sims and Johnson 1991
14	Available Cu	Atomic absorption Spectroscopy	Emmel *et al.* (1977)
15	Available Mn	Atomic absorption Spectroscopy	Sims and Johnson (1991)
16	Available Zn	Atomic absorption Spectroscopy	Emmel *et al.* (1977)
17	Exchangeable Al	Atomic absorption Spectroscopy	Willis (1965)

Table 2. Physico-chemical properties of the soil

Sl. No.	Parameter	Vellanikkara Soil	Panniyur Soil
I	**Physical Properties**		
1	Bulk Density (g cm^{-3})	1.29	1.15
2	Particle Density (g cm^{-3})	2.17	1.97
3	Pore space (%)	59.45	50.25
II	**Mechanical Composition**		
1	Sand (%)	54.71	61.4
2	Silt (%)	16.53	14.7
3	Clay (%)	28.76	23.9
4	Texture	Sandy Clay Loam	Sandy Clay Loam
III	**Chemical Parameters**		
1.	pH	5.13	4.69
2.	Electrical Conductivity (ds m^{-1})	0.1	0.09
3.	Organic carbon (%)	1.72	1.9
4.	Available Nitrogen (kg ha^{-1})	448	604.8
5.	Available Phosphorus (kg ha^{-1})	6.92	17.24
6.	Available Potassium (kg ha^{-1})	56	64.21
7.	Available Calcium (kg ha^{-1})	670	374
8,	Available Magnesium (kg ha^{-1})	150	197
9.	Exchangeable Aluminium (mg kg^{-1})	232	103
10.	Available Iron (mg kg^{-1})	170	120
11.	Available Copper (mg kg^{-1})	14.1	12.1
12.	Available Manganese (mg kg^{-1})	496	715
13.	Available Zinc (mg kg^{-1})	2	6

Table 3. Analytical methods followed for plant and amendments analysis

S. No	Parameter	Method	Reference
1.	Total N	Modified Kjeldhal digestion method	Jackson (1958)
2.	Total P	Vanodo molybdate yellow colour method	Piper (1966)
3.	Total K & Na	Flame photometry	Jackson (1958)
4.	Total Ca, Mg, Cd and As	Atomic Absorption Spectroscopy	Issac and Kerber (1971)
5.	Total Fe, Mn, and Ni	Atomic Absorption Spectroscopy	Piper (1966)
6.	Total Cu, Zn and Cr	Atomic Absorption Spectroscopy	Emmel *et al*. (1977)
7.	Total Al and Hg	Atomic Absorption Spectroscopy	Jackson (1958)
8.	Total Pb	Atomic Absorption Spectroscopy	Page *et al*. (1970)
9.	Total Hg	Atomic Absorption Spectroscopy	Perkin-Elmer (1979)

blended with vermicompost at 1:1 ratio on weight basis. This was again analysed for bulk density, pH, free acidity / alkalinity and heavy metals (Al, Pb, Hg, Cd, As, Ni & Cr) content and other nutrients as per standard procedures (Table 3) and the data are shown in table 5.

Table 4. Chemical composition of amendments

S. No	Parameter	Amendments		
		FA	PG	VC
1.	pH	13	4.4	8.2
2.	Free Acidity (meq/100g)	-	1.2	-
3.	Free Alkalinity (meq/100g)	235	-	8.5
4.	Bulk density	0.5	1.0	0.5
Heavy Metals				
5.	Al (mg kg^{-1})	830	50	37
6.	Pb (mg kg^{-1})	34	10	0
7.	Hg (mg kg^{-1})	47	42	0
8.	Cd (mg kg^{-1})	5	1.1	0
9.	As (mg kg^{-1})	2.3	1.5	0
10.	Ni (mg kg^{-1})	1.5	1.2	0.3
11.	Cr (mg kg^{-1})	2.4	1.8	0.1
Nutrient Status				
12.	N (%)	0.31	0.21	0.98
13.	P (%)	0.91	0.45	0.4
14.	K (%)	6.16	0.01	0.22
15.	Na (%)	0.46	0.32	0.04
16.	Ca (%)	0.98	1.03	0.55
17.	Mg (%)	2.37	0.01	0.05
18.	Fe (mg kg^{-1})	0.21	0.03	0.14
19.	Cu (mg kg^{-1})	121	16	17
20.	Mn (mg kg^{-1})	250	10	90
21.	Zn (mg kg^{-1})	210	20	50

Table 5. **Chemical composition of Blends**

S. No	Property	PG: FA (10:1)	PG : FA (20:1)	PG :FA (30:1)	(PG :FA) :VC (10:1):1	(PG :FA) :VC (20:1):1	(PG :FA) :VC (30:1):1	PG: VC (1:1)
1.	pH	9.3	8.5	7.2	8.7	8	7.3	6.2
2.	Free Acidity (meq/100g)	-	-	-	-	-	-	0.4
3.	Free Alkalinity (meq /100g)	2	0.7	0.3	1.7	0.8	0.3	-
4.	Bulk Density	0.8	0.83	0.92	0.81	0.78	0.7	0.8
Heavy Metals								
5.	Al (mg kg^{-1})	95	112	134	90	92	94	42
6.	Pb (mg kg^{-1})	18	20	9	8	6	5	7
7.	Hg (mg kg^{-1})	42	41	39	18	16	17	9
8.	Cd (mg kg^{-1})	1.2	2.3	0.9	1.1	1.1	1.3	0.9
9.	As (mg kg^{-1})	1.3	1.8	1.2	0.9	0.9	1	0.9
10.	Ni (mg kg^{-1})	1.1	1.3	1.1	0.7	0.7	0.8	0.7
11.	Cr (mg kg^{-1})	1.4	1.6	1	0.8	0.5	0.6	0.4
Nutrient Status								
12.	N (%)	0.36	0.32	0.31	0.42	0.52	0.53	0.53
13.	P (%)	0.68	0.7	0.57	0.61	0.56	0.5	0.4
14.	K (%)	1.8	1.2	0.78	1.18	0.82	0.48	1.04
15.	Na (%)	0.12	0.1	0.08	0.08	0.06	0.06	0.48
16.	Ca (%)	0.97	0.99	1.01	0.98	1.00	1.07	1.02
17.	Mg (%)	0.28	0.13	0.09	0.17	0.12	0.09	0.04
18.	Fe (mg kg^{-1})	0.09	0.08	0.06	0.09	0.09	0.08	0.09
19.	Cu (mg kg^{-1})	22	15	14	18	17	16	14
20.	Mn (mg kg^{-1})	150	85	70	160	130	120	90
21.	Zn (mg kg^{-1})	40	30	20	40	30	30	30

3.5 Incubation Experiment

An incubation study was conducted to evaluate the efficacy of materials, like phosphogypsum and its blends with fly ash on controlling pH and regulating exchangeable nutrients *viz.,* Ca, Fe and Mn along with its ameliorating effects on exchangeable Al. For incubation study, 300 g of soil was taken and filled in separate glass bottles. Phosphogypsum and its combinations with fly ash were applied based on lime requirement (LR). The soil samples were mixed with the amendments. Water was added to a level of 50 per cent field capacity. This was incubated at laboratory temperature conditions for three months. The different treatments and details of the experiment are presented below.

Treatments – 5

T_1 = Phosphogypsum
T_2 = Phosphogypsum + Fly ash @ 10:1ratio
T_3 = Phosphogypsum + Fly ash @ 20:1ratio
T_4 = Phosphogypsum + Fly ash @ 30:1ratio
T_5 = Control

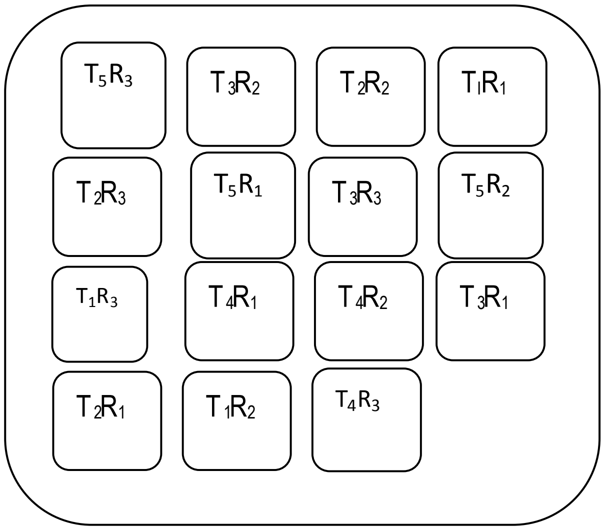
Replications – 3

Design: CRD

From the incubated soil, samples were drawn periodically and analyzed for pH, exchangeable, Ca, Fe and Mn at 15, 30, 45, 60, 75 and 90 days after incubation. Al was analysed only after 90 days of incubation.

The soil pH was measured in soil-water suspension (1: 2.5). The samples were extracted with 0.1N $BaCl_2$ (1:10) and analyzed for Al. To estimate Ca, the soil was extracted with 1N Ammonium acetate (1:5). The samples were extracted with 0.1 N HCl (1:10) for the analysis of available Fe and Mn. The concentration of the elements in the extracted solutions was measured using Perkin Elmer atomic absorption spectrophotometer. The layout of this experiment is shown in Fig.1a.

Fig.1a. Layout for Incubation study



3.6 Pot culture study

A pot culture study was conducted in soils collected from the Vellanikkara series, to study the effect of the ameliorants on the physical and chemical properties of soil. The effects of treatments on the growth of rooted pepper cuttings were also observed. Totally five kg of soil was taken and filled in separate pots. Phosphogypsum and its combinations with fly ash and vermicompost were applied on the surface based on lime requirement (LR). The lime requirement doses were two gram material per 100 g soil. The details of the experiment are presented below:

Treatments – 10

T_1 = Phosphogypsum

T_2 = Phosphogypsum + Fly ash @ (10:1)

T_3 = Phosphogypsum + Fly ash @ (20:1)

T_4 = Phosphogypsum + Fly ash @ (30:1)

T_5 = (Phosphogypsum + Fly ash) + Vermicompost @ (10:1):1

T_6 = (Phosphogypsum + Fly ash) + Vermicompost @ (20:1):1

T_7 = (Phosphogypsum + Fly ash) + Vermicompost @ (30:1):1

T_8 = Phosphogypsum + Vermicompost@ (1 :1)

T_9 = Vermicompost

T_{10} = Control

Replications – 3

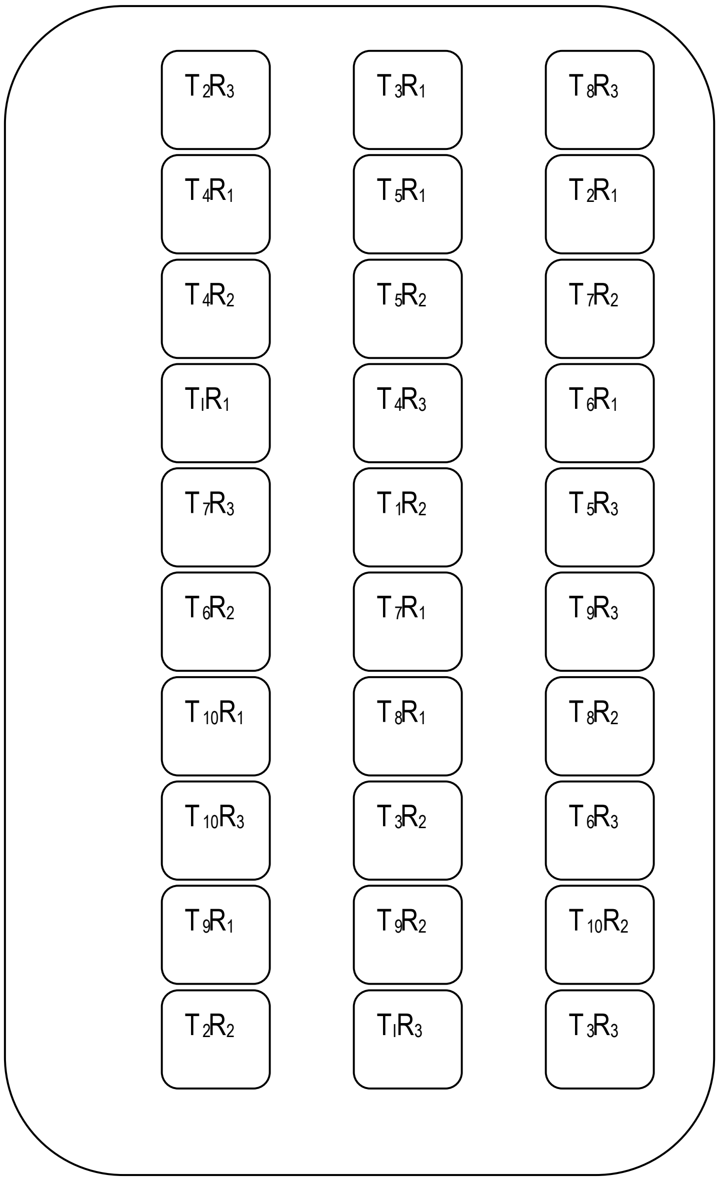
Design: CRD

3.6.1 Planting

After the application of amendments on the surface of soil, pots were irrigated and moisture was maintained at near field capacity, rooted cuttings of vines were planted in each pot. Fertilizers were applied as per Package of Practices recommendations.

Full dose of P and half the dose of N and K were applied as basal. Remaining N and K were applied at two months after planting. Benomyl was applied at the rate of 0.02 per cent on the plant for the control of foot rot disease and Dimethoate was sprayed @ 0.2 per cent to manage mealy bug damage. Copper oxychloride sprayings were given periodically for the control of foot rot. The layout of the pot culture experiment is shown in Fig. 1b.

Fig.1b Layout of the pot culture experiment



3.6.2 Biometric Observations

The following biometric observations were taken at monthly intervals for a period of six months. Shoot length was measured from the base of the stem to the tip of the youngest leaf using a meter scale and expressed in cm. Number of leaves per plant were also noted. Leaf area was worked out based on length and width of fully opened third leaf from the shoot tip (Jayasree, 1985).

3.6.3 Chemical analysis of plant samples

The fully matured young green leaves were drawn periodically at three months interval and analysed for different macro and micro nutrients *viz*, N, P, K, Ca, Mg, Fe, Cu, Mn and Zn by standard procedures (Table 3).

3.6.4 Chemical analysis of soil sample

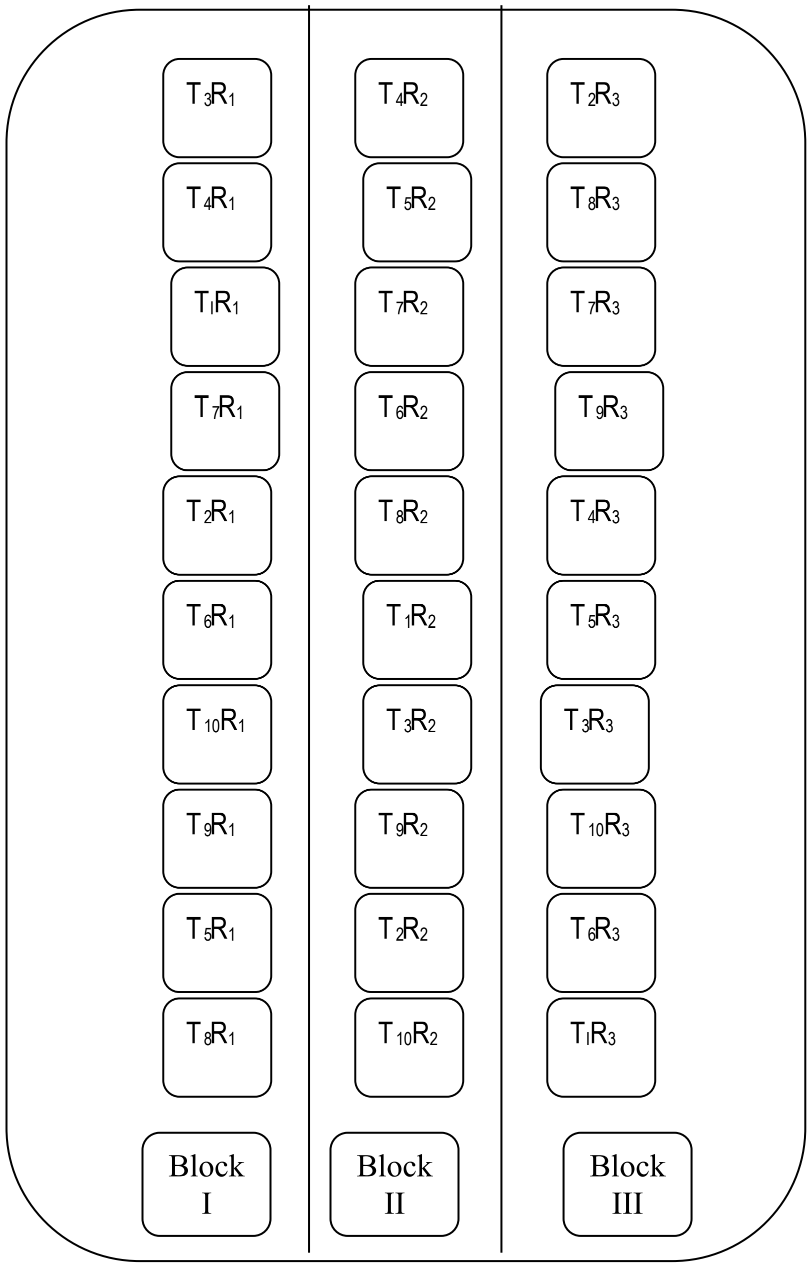
Soil samples were drawn at 15 cm depth at three and six months after planting and analysed for pH, exchangeable Ca, Fe, Mn and Al by standard procedures which have been shown in Table 1.

3.7 Field experiment

A field experiment was conducted to examine the effect of soil applied ameliorants on growth parameters of the existing plants at PRS Panniyur. The soil samples collected were measured for pH, content of exchangeable nutrients *viz.,* Ca, Fe Mn and Al.

Thirty pepper vines of the same age and of two meter height were selected and the area was divided into three blocks of ten plants each and treatments were applied. Amendments were applied based on lime requirement (LR). The details of the experiment and the layout of the field experiment and the layout of the field experiment (Fig. 1c) are presented below

Fig.1c Layout of the field experiment



Tretments – 10

T_1 = Phosphogypsum

T_2 = Phosphogypsum + Fly ash @ 10:1

T_3 = Phosphogypsum + Fly ash @ 20:1

T_4 = Phosphogypsum + Fly ash @ 30:1

T_5 =(Phosphogypsum+Fly ash)+Vermicompost @ (10:1):1

T_6 =(Phosphogypsum+ Fly ash)+Vermicompost @ (20:1):1

T_7 = (Phosphogypsum + Fly ash) +Vermicompost @ (30:1):1

T_8 = Phosphogypsum + Vermicompost @ (1:1)

T_9 = Vermicompost

T_{10} = Control

Replication- 3

Design- RBD

3.7.1 Biometric Observations

Biometric observations such as weight of spikes per plant, number of spikes for 100 g weight, number of berries per spike and length of spike were recorded at the time of harvest.

3.7.2 Chemical analysis of plant samples

The fully matured young green leaves were drawn periodically at three months interval and analysed for N, P, K, Ca, Mg, Fe, Cu, Mn and Zn by standard procedures (Table 3).

Plate 1. Incubation study at laboratory, SS & AC, COH, Vellanikkara

Plate 2. Pot culture study at COH, Vellanikkara.

Plate 3. Field study at PRS, Panniyur

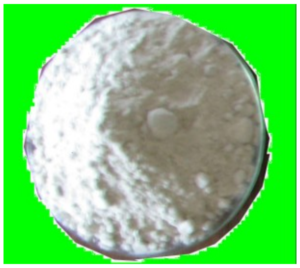


Plate 4.
Phospho Gypsum (T_1)

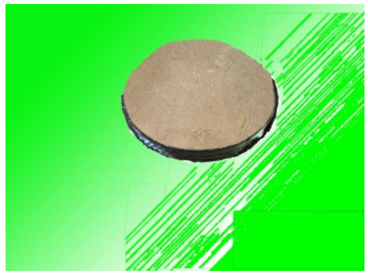


Plate 5.
Flv Ash

Plate 6.
Vermicompost (T_9)

Plate 7.
PG:FA at 10:1 ratio (T_2)

Plate 8.
PG:FA at 20:1 ratio (T_3)

Plate 9.
PG:FA at 30:1 ratio (T_4)

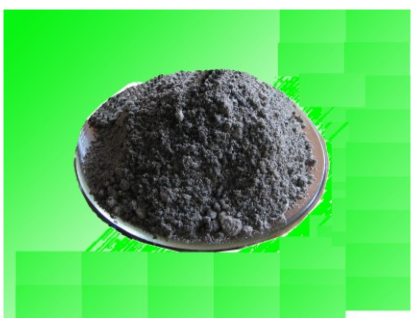


Plate 10.
T_2:VC at 1:1 ratio (T_5)

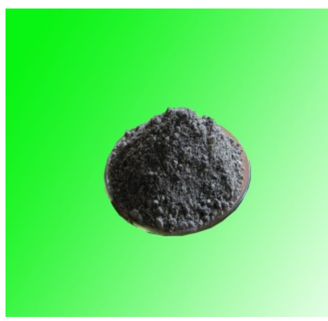


Plate 11.
T_3:VC at 1:1 ratio (T_6)

Plate 12.
T_4:VC at 1:1 ratio (T_7)

Plate 13
PG:VC at 1:1 ratio (T_8)

3.7.3 Chemical analysis of soil samples

The soil samples were drawn at a depth of fifteen cm from the surface three months and six months after application of ameliorants and analysed for pH, available Ca, Fe, Mn and Al by standard procedures (Table 1).

3.8 Statistical Analysis

The results of various parameters obtained by incubation study, pot culture study and field experiment were analysed statistically for the test of significance by standard procedures using MSTAT-C package.

Results

5. Results

The investigation was carried out to evaluate the efficacy of phosphogypsum and its blends with fly ash in controlling sub soil acidity. The experiment was carried out as incubation and pot culture studies at College of Horticulture, Vellanikkara and as field experiment at Pepper Research Station, Panniyur. Phosphogypsum (PG) was collected from FACT, Kochi and Fly ash (FA) was obtained from M/s Synthates Chemicals, Cochin. Vermicompost (VC) was obtained from the Vermicompost production unit at College of Horticulture, Vellanikkara. These materials were analysed and their pH and equivalent acidity / alkalinity was measured in 1:10 suspension with distilled water. The results of the analysis are given in table 6.

Table 6. pH and equivalent acidity / alkalinity of the ameliorants

Sl.No.	Parameter	PG	FA	VC
1.	pH	4.4	13	8.2
2.	Equivalent Acidity / Alkalinity (meq/100g)	1.2 (Acidity)	235 (Alkalinity)	8.5 (Alkalinity)

In order to have a desirable pH for the amendments, PG and FA were blended in different ratios and the pH of each combination was measured. The results are shown in table 7. It was seen that the blends at 10:1, 20:1 and 30:1 ratios of PG with FA were having desirable pH (7.2-9.3) for an ameliorant and these three blends were selected. Using these materials, an incubation experiment was conducted to evaluate their performance in reducing soil acidity.

4.1 Incubation experiment

An incubation experiment was conducted to evaluate the efficacy of PG and its blends with FA in reducing sub soil acidity. Soil samples were collected in bulk from Pepper garden, Vellanikkara, Thrissur, and were passed through a two mm sieve. Three hundred gram of this soil was mixed with six gram of ameliorants, which was equivalent to the recommended lime dose for the soil in terms of Ca content. The samples were kept at 50% field capacity and soil samples were drawn at 15 days interval upto 90 days and subjected to chemical analysis. The data were subjected to statistical analysis. Table 8 shows the effect of treatments of PG and its combinations with FA, after 15 days of incubation.

Table 7. pH of the Phosphogypsum – Fly-ash blends at different ratios

Sl. No.	Blended ratio (PG : FA)	Observed pH
1.	1:1	11.8
2.	1:1.5	12.2
3.	1:2	12.4
4.	1:2.5	12.7
5.	1.5:1	11.5
6.	2:1	11.4
7.	2.5:1	11.2
8.	5:1	10.6
9.	6:1	10.2
10.	8:1	9.8
11.	10:1	9.3
12.	20:1	8.5
13.	30:1	7.2
14.	40:1	6.9
15.	50:1	6.7

The analysis suggests that in all treatments that contain fly ash, the pH values were significantly higher than control and T_1. The lowest pH value of 4.5 was noticed in PG treated soil and the highest for T_2 where PG and FA were in 10:1 ratio. The Ca content of all the treatments was significantly higher then control. All the ameliorant treated samples had similar values. The Fe content on the other hand registered significantly lower values than control. With respect to Mn content, significant reduction was noticed for T_2 and all other treatments were on par. The results indicate that blending of FA helps to increase pH significantly.

Table 8. Effect of PG and FA combinations 15 and 30 days after incubation on nutrient contents and pH

15 days after incubation				
Treatment	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	pH
Phospho gypsum (T_1)	1063	1.8	98.9	4.5
PG :Fly Ash (10:1) (T_2)	907	1.7	73.1	5
PG :Fly Ash (20:1) (T_3)	1102	2.5	96.5	4.9
PG:Fly Ash (30:1) (T_4)	1064	1.5	91.2	4.8
Control (T_5)	299	170	496.3	4.7
CD (5%)	243	5	11.3	0.09
30 days after incubation				
Treatment	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	pH
Phosphogypsum (T_1)	1083	1.7	90.3	4.5
PG :Fly Ash (10:1) (T_2)	1087	1.9	53.4	4.8
PG :Fly Ash (20:1) (T_3)	1118	2.1	98.6	4.9
PG:Fly Ash (30:1) (T_4)	1150	1.7	84.2	4.8
Control (T_5)	299	182	504	4.7
CD (5%)	69	2.2	18.9	0.09

The results of the analysis done at 30 days after incubation are shown in table 8. A similar trend was seen at 30 days also where all fly ash blends were effective in increase of pH and T_2 was effective in decreasing Mn content. At 45, 60, 75 and 90 days after incubation (Tables 9 & 10) also, similar trend was noticed. All the treatments maintained a high Ca level throughout the experiment period, but only fly ash blended treatments showed significant effect on increasing pH and the treatment T_2 alone was effective in reducing Mn content. After 90 days incubation, the exchangeable Al content was also analysed (using 0.1 N $BaCl_2$ extract), and significant reduction in Al content was noticed for T_2 and T_3.

Table 9. Effect of PG and FA combinations 45, 60 and 75 days after incubation on nutrient contents and pH

45 days after incubation				
Treatment	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	pH
Phosphogypsum (T_1)	1125	1.8	107.5	4.1
PG :Fly Ash (10:1) (T_2)	1085	1.7	64.2	4.5
PG :Fly Ash (20:1) (T_3)	1075	2	102.7	4.6
PG:Fly Ash (30:1) (T_4)	1076	2	98.9	4.5
Control (T_5)	303	192	502	4.6
CD (5%)	196	3.3	23	0.1
60 days after incubation				
Treatment	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	pH
Phosphogypsum (T_1)	1094	2.1	101.1	4.3
PG :Fly Ash (10:1) (T_2)	1098	2.4	55	4.7
PG :Fly Ash (20:1) (T_3)	1127	1.7	97.2	4.8
PG:Fly Ash (30:1) (T_4)	1095	2.2	85	4.7
Control (T_5)	310	188	508	4.6
CD (5%)	57	3.4	19.8	0.18
75 days after incubation				
Treatment	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	pH
Phosphogypsum (T_1)	1070	1.5	89.5	4.4
PG :Fly Ash (10:1) (T_2)	1091	2	40.1	4.8
PG :Fly Ash (20:1) (T_3)	1063	2.7	105.4	4.9
PG:Fly Ash (30:1) (T_4)	1052	2	96.4	4.8
Control (T_5)	303	199	504	4.6
CD (5%)	25.7	3.8	35.6	0.18

Table 10. Effect of PG and FA combinations 90 days after incubation on nutrient contents and pH

Treatment	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	pH	Ca (mg kg^{-1})
Phosphogypsum (T_1)	1077	1.3	97.7	4.9	41.7
PG :Fly Ash (10:1) (T_2)	1097	1.1	43.7	5.2	13.3
PG :Fly Ash (20:1) (T_3)	1108	1.1	112.5	5.3	12.3
PG:Fly Ash (30:1) (T_4)	1080	1.1	100.3	5.2	54.3
Control (T_5)	303	199	304	4.5	235
CD (5%)	63.2	3.2	30.1	0.12	27.1

4.2 Effect of ameliorants on incubated soil over a 90 days period

In order to obtain the effect of the various treatments over different periods of incubations, pooled analysis of the data was done. The data on Ca, Fe and Mn contents and pH are shown in figures 2a, 2b, 2c and 2d respectively. Ca content was maintained at high level and Fe and Mn contents reduced in all the ameliorant treated samples. Increase in pH was observed in all the FA treated soils and PG alone resulted in low pH of soils. The treatment T_2 was effective in decreasing Mn content and maintaining high pH of soil. Unamended soils (control) showed extremely high values for Fe and Mn at all the stages.

4.3 Pot culture experiment

Based on the results of the incubation experiment, a pot culture study was conducted at the College of Horticulture, Vellanikkara. Ten treatments that contained PG, FA and / or vermicompost were applied along with a control. The details of results are as follows.

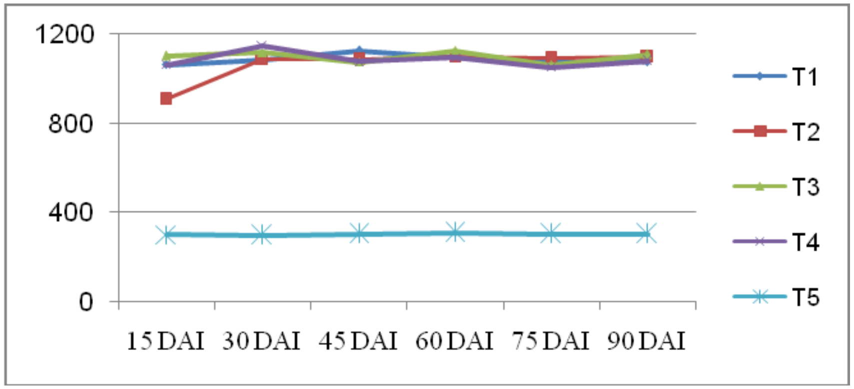


Fig. 2a. Soil Ca content (μg g^{-1}) of treatments over a period of 90 days

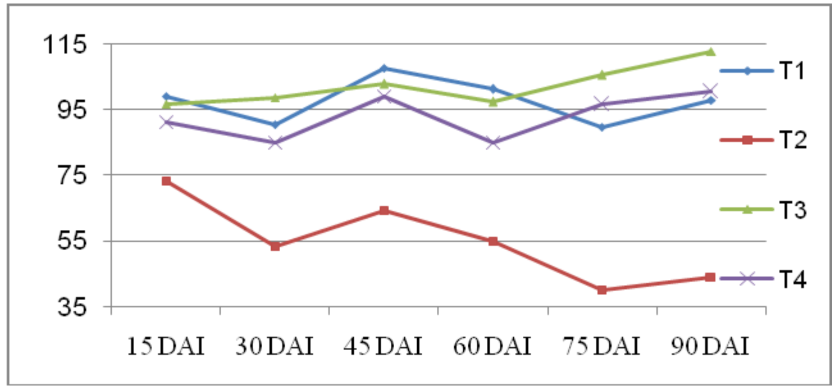


Fig. 2c. Soil Mn content (μg g^{-1}) of treatments over a period of 90 days

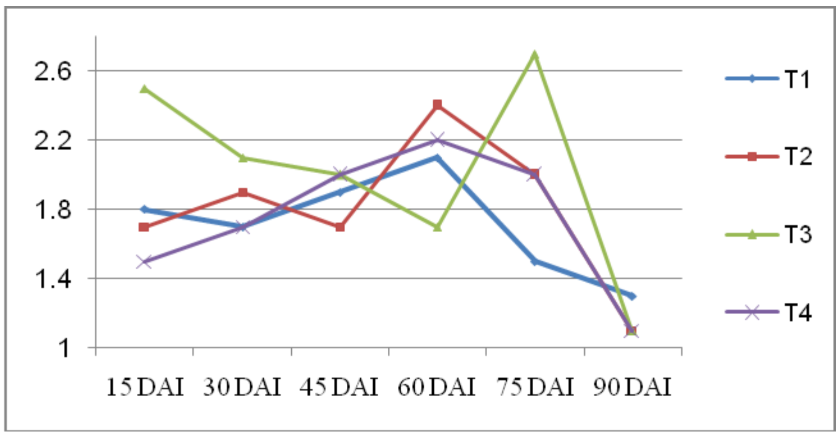


Fig. 2b. Soil Fe content (μg g^{-1}) of treatments over a period of 90 days

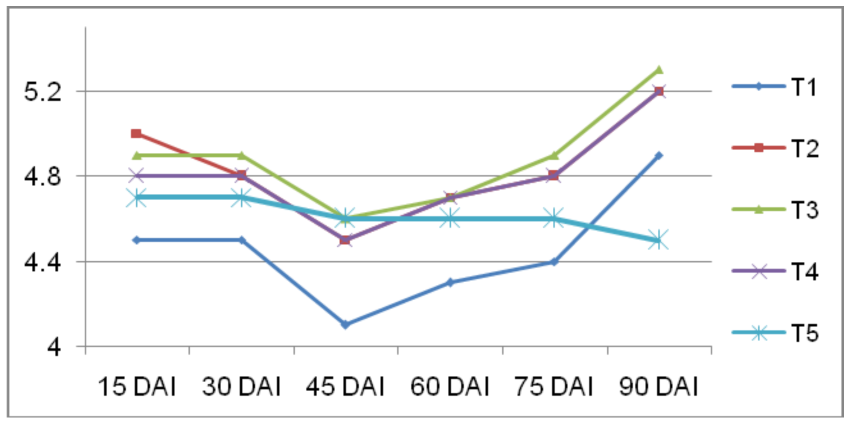


Fig. 2d. Soil pH of treatments over a period of 90 days

4.3.1 Number of leaves

In the pot culture experiment, the biometric observations of the plants were recorded at monthly intervals upto six months. At the time of planting the plants were at three leafe stage. The observations on the ten treatments were subjected to pooled analysis over the six month period and the results are given in table 11.

For all treatments there was a steady increase in leaf number. The rate of increase or the difference between treatments was not significant. But overall performance of the treatments was evaluated by taking average of the six months data and it is shown in a graph (Fig. 3a). All the ameliorant treated plants were superior to control, except T_2. The beneficial effect of blending ameliorants with vermicompost is shown in T_6, T_7 and T_8. Application of vermicompost alone and T_2 were at par with control.

Table 11. Effect of PG and its combinations with FA and VC on number of leaves of pepper vines over a six months period in pot culture experiment

Treatment	Months after planting					
	2	3	4	5	6	Mean
Phosphogypsum (T_1)	5	6	9	12	14	9
PG :Fly Ash (10:1) (T_2)	3	5	8	11	12	8
PG :Fly Ash (20:1) (T_3)	5	7	9	12	14	9
PG:Fly Ash (30:1) (T_4)	6	8	10	12	13	10
T2:Vermi Compost (1:1) (T_5)	4	6	8	11	14	9
T3:Vermi Compost (1:1) (T_6)	7	8	10	13	15	11
T4:Vermi Compost (1:1) (T_7)	7	8	10	13	14	11
PG:Vemi Compost (1:1) (T_8)	7	8	10	12	14	10
Vermicompost (T_9)	4	5	8	11	13	8
Control (T_{10})	3	5	7	9	11	7
Mean	5	6	9	11	13	

Treatment CD-1.6   Interval CD – 0.35   Treatment X Interval SE – 0.38.

4.3.2 Increase in shoot height

The increase in shoot length over the initial length was subjected to pooled analysis and it was noticed that the difference between treatments over the period was not significant. It seems that in all treatments the plant height increased steadily and the ameliorants blended with vermicompost recorded larger increases than other treatments.

The increase in shoot length after 6 months period was evaluated and the results presented in table 12 and Fig. 3b.

Table 12. Effect of PG and its combinations with FA and VC on increases in shoot height (cm) of pepper vines over a six months period in pot culture experiment

Treatment	Months after planting					
	2	3	4	5	6	Mean
Phosphogypsum (T_1)	25.9	27.6	31.3	37	40	32.6
PG :Fly Ash (10:1) (T_2)	26	27.6	30.1	35	39.5	31.6
PG :Fly Ash (20:1) (T_3)	27.7	29.4	32.4	36.9	39.7	33.2
PG:Fly Ash (30:1) (T_4)	30.3	31.9	36	39.8	42.9	36.2
T2:Vermi Compost (1:1) (T_5)	32	33	36	39	42	36.5
T3:Vermi Compost (1:1) (T_6)	32.6	34	37	40.2	43	37.4
T4:Vermi Compost (1:1) (T_7)	34.3	35.4	38.5	41.2	43	38.5
PG:Vemi Compost (1:1) (T_8)	28.2	29.2	32	35.8	37.4	32.5
Vermicompost (T_9)	27	28.4	32	35.6	37.6	32.1
Control (T_{10})	25.8	27.3	30.8	34.4	36.3	30.8
Mean	29	30.4	33.6	37.6	40.5	

4.3.3 Leaf area

The leaf area of the third leaf from the tip of the plants in different treatments was measured at monthly intervals upto six months and the data, after subjecting to pooled analysis are presented in table 13.

Table 13. Effect of PG and its combinations with FA and VC on leaf area (cm^2) of pepper vines over a period of six months in pot culture experiment

Treatment	Months after planting					
	2	3	4	5	6	Mean
Phosphogypsum (T_1)	71.9	73.8	73.7	74.4	68.3	72.4
PG :Fly Ash (10:1) (T_2)	67.9	66.1	66.4	66.8	53.6	64.2
PG :Fly Ash (20:1) (T_3)	54.1	63.2	63.3	63.4	60.0	60.8
PG:Fly Ash (30:1) (T_4)	58.3	64.1	63.6	62.0	66.8	63
T2:Vermi Compost (1:1) (T_5)	55.0	58.3	56.5	58.7	63.4	58.4
T3:Vermi Compost (1:1) (T_6)	62.0	64.5	64.4	64.5	60.5	63.2
T4:Vermi Compost (1:1) (T_7)	52.3	41.1	39.4	35.8	64.5	46.6
PG:Vemi Compost (1:1) (T_8)	71.9	68.4	68.3	68.3	43.2	64.0
Vermicompost (T_9)	48.9	52.4	53.6	53.6	58.5	53.4
Control (T_{10})	66.9	69.8	63.1	59.9	62.9	64.5
Mean	60.9	62.2	61.2	60.7	60.1	

Treatment CD- 7.4 Interval SE – 1.1 Treatment X Interval CD – 10

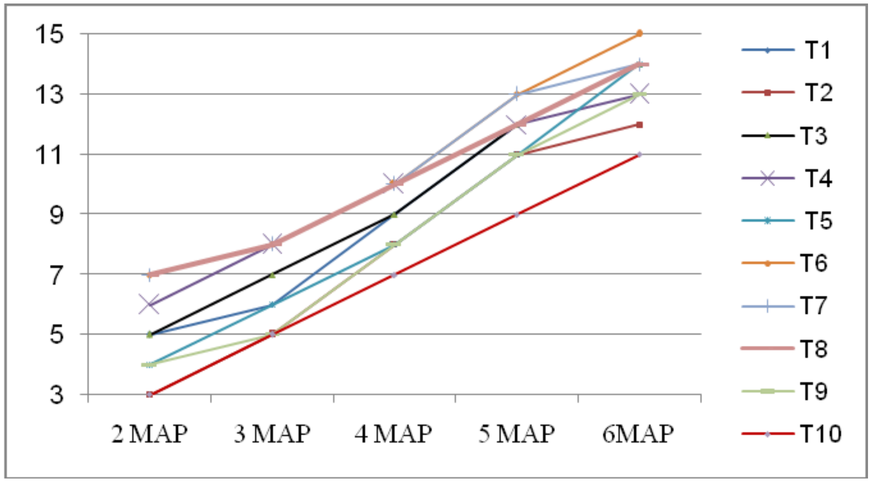


Fig. 3a. Number of leaves of pot cultured plants over a period of 6 months

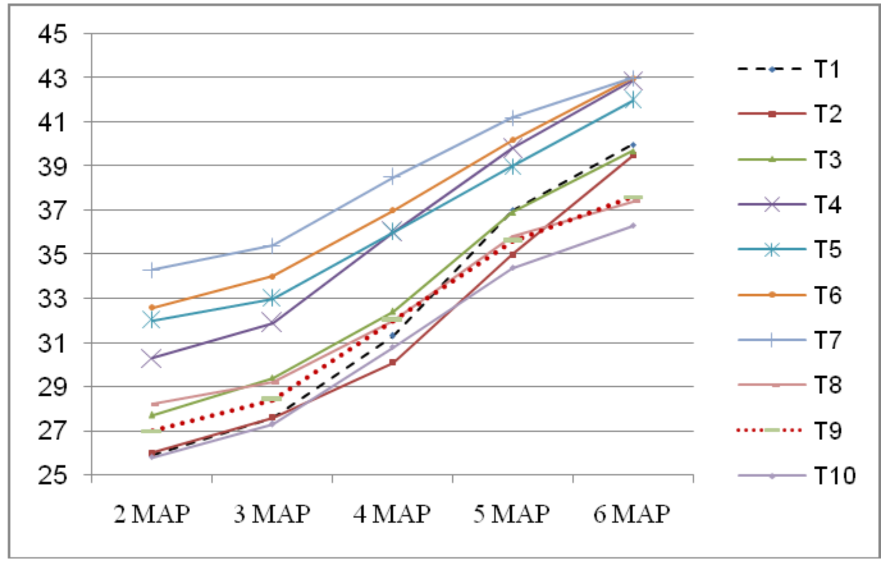


Fig. 3b. Increase in shoot height of pot cultured plants over a period of 6 months

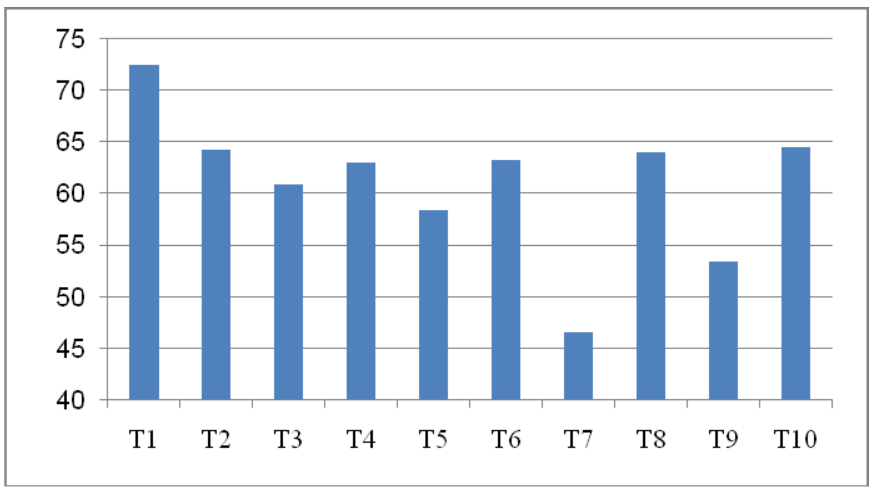


Fig. 3c. Average leaf area (cm) of pot cultured plants after 6 months

There were significant differences in leaf area for the different treatments over the various intervals of observations. But the data does not indicate any clear trend for any particular treatment or any particular period. The average over the six months interval was compared and only T_1, the PG treated plants showed significantly higher leaf area (72.4 cm^2) than the control and other treatments. In some treatments like T_7 and T_9, leaf area was significantly lower than control, the lowest value being recorded for T_7. This average data are presented in Fig. 3c.

4.4 Influence of ameliorants on nutrient status of pepper leaves and on chemical properties of soil

4.4.1 Nutrient status of pepper leaves (three months after planting)

The chemical analysis of leaf samples taken after three months was done and the data are presented in table 14. After a period of three months, leaf nitrogen content was higher in all the treatments that contained PG, when compared with control and T_9, the treatment with vermicompost alone. The highest content of 3% was noticed in T_6. All other PG containing treatments were on par. The treatment T_9 was on par with control.

Phosphorus content of leaves in all the treatments including vermicompost recorded lower values compared to control. Among the ameliorant treated plants, T_5 and vermicompost treated plants showed higher leaf P content. In the case of leaf K content, control as well as vermicompost treated plants showed significantly higher K value. The lowest K value was recorded in T_1 (1.5 %). The highest was recorded for vermicompost (3.8 %). The other treatments were almost at par.

Regarding Ca content of leaves, all the treatments were superior to control. The highest value was for T_8 followed by T_9 which were at par. The other treatments also varied significantly amongst the PG-FA-VC combinations, but all had significantly higher values when compared to control. The Mg content of leaves did not show any significant difference.

With respect to Fe content, all the PG containing treatments showed reduced Fe levels in leaves as compared to control and vermicompost. Blending of vermicompost with PG and PG-FA combinations slightly reduced Fe levels in leaves as compared to their application without vermicompost, but these differences were not significant

Table 14. Effect of PG and its combination with FA and VC on nutrient contents of pepper leaves three months after planting

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
PG (T_1)	2.4	0.28	1.5	2.0	550	620	66	140	40
PG :FA (10:1) (T_2)	2.4	0.31	1.9	2.4	540	900	93	113	38
PG :FA (20:1) (T_3)	2.4	0.26	2.4	1.7	520	673	40	93	53
PG:FA (30:1) (T_4)	2.4	0.29	2.1	2.5	540	600	33	100	46
T2:V C (1:1) (T_5)	2.2	0.34	2.4	2.4	510	900	40	113	38
T3:V C (1:1) (T_6)	3.0	0.30	1.9	1.9	500	853	33	73	27
T4:V C (1:1) (T_7)	2.5	0.32	2.8	1.9	530	860	40	93	29
PG:V C (1:1) (T_8)	2.4	0.25	1.9	3.0	550	840	33	106	32
VC (T_9)	1.8	0.33	3.8	2.6	550	1060	120	140	42
Control (T_{10})	1.9	0.37	3.3	1.3	510	1320	120	106	61
CD (5%)	0.27	0.12	0.97	0.5	NS	360	47	NS	NS
SE	-	-	-	-	13	-	-	15.63	10.06

In the case of copper, vermicompost and control were at par and all the treatments recorded significantly lower values except T_2. For the leaf nutrient concentration of Mg, Mn and Zn, there was no significant difference among the treatments.

4.4.2 Nutrient status of pepper leaves (six months after planting)

For leaf nitrogen content, the control and vermicompost treatments were on par and all the PG and PG – FA blended amendments showed significantly higher leaf N content compared to control and vermicompost treated pots after six months (Table.15). All the ameliorants were at par when they were applied alone or in combination with VC.

In the case of phosphorus, T_5 recorded highest concentration of 0.34%, followed by T_7 (0.31%) and control (0.29%), all other treatments having significantly lower values. T_5 and T_7 were superior to control. All other treatments had significantly lower values when compared with control.

Table 15. Effect of PG and its combinations with FA and VC on nutrient contents of pepper leaves six months after planting

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
PG (T_1)	2.2	0.25	2.7	3.1	500	604	8	342	32
PG :FA (10:1) (T_2)	2.3	0.27	3.4	2.8	500	1334	8	412	26
PG :FA (20:1) T_3)	2.2	0.25	2.4	2.3	600	1542	16	370	22
PG:FA (30:1) (T_4)	2.3	0.25	3.1	2.7	700	1048	10	582	25
T2:V C (1:1) (T_5)	2.2	0.34	2.9	2.8	900	932	12	516	23
T3:V C (1:1) (T_6)	2.5	0.26	3.7	2.5	700	907	18	468	27
T4:V C (1:1) (T_7)	2.5	0.31	3.1	2.9	900	726	10	494	33
PG:V C (1:1) (T_8)	2.3	0.20	2.2	2.3	500	750	10	654	28
VC (T_9)	1.8	0.25	3.3	2.0	1100	976	8	536	26
Control (T_{10})	1.9	0.29	2.5	2.8	520	1338	14	996	27
CD (5%)	0.26	0.01	0.12	0.03	28	13.9	4	5.7	5

For potassium content, the treatments T_8 had significantly lower value and T_3 was at par with control. All others registered higher values and among these T_6 registered the highest value of 3.7 %. When the Ca contents were compared, it was noticed that the lowest value was recorded for vermicompost and all others including control was superior. The highest value was for T_1 (3.1%). The data on Mg content of the leaves revealed that application of the ameliorants did not significantly affect the Mg content.

When the effect of the treatments on Fe contents were compared, it was seen that in all treatments that contained vermicompost the leaf Fe level was significantly lower to control. Still lower level (604 mg kg^{-1}) was noticed in PG treatment (T_1). When PG was blended with FA, the leaf Fe content increased and for T_2, it was at par with control while T_3 was higher and T_4 was lower than control. All these treatments had values significantly higher than their corresponding VC mixed combinations i.e., T_5, T_6, T_7 and T_8.

With respect to copper content of leaves, T_1, T_2 and T_9 were significantly lower to control. T_6 was superior and all others were at par. There was no distinct pattern for any ameliorant in general. All the treatments including VC differed significantly, some were higher and some were lower.

In the case of Mn contents in leaves, treatments varied significantly, and reduced the leaf concentration of this toxic element to a substantial level. The lowest was noticed for T_1 (342 mg kg^{-1}). Among the ameliorant treatments all differed significantly among themselves. For Zn, all the treatments were at par with control except T_7.

4.4.3 Comparative effect of ameliorants on nutrient status of pepper leaves over a period of six months

The chemical analysis data of the leaf samples collected at third month and sixth month were subjected to pooled analysis to examine the effects of the treatments at the two stages. The contents of N, P, K, Ca, Fe, and Mn are presented in Fig. 4a to 4f.

In the case of Nitrogen there was no significant difference between the pairs of values for the two intervals in any of the treatments. In all treatments except vermicompost and control, there was a declining trend though not at a significant level. While comparing the leaf P values, it was noticed that in control, the P content declined significantly at the sixth. Between treatments there were significant differences.

The pooled data on K status of the leaf, shown in Fig. 4c., indicate a significant decline in control. In all other treatments except vermicompost, the values increased and significant increases were noticed in T_1, T_4 and T_6. In all other cases the values of each pair were at par. The decline in the VC treatment also was not significant.

The Ca contents of T_1, T_2, T_3, T_5, T_6 and T_7 compared to that of control showed significant increase from third month to sixth month. But for control, it was from a low value of 1.3 % to a comparable high value, 2.8 %. In the ameliorant treated plants, from Ca content further increased and maintained the higher level. For T_4 though it increased, the rise was not significant. In T_8 and T_9 it declined significantly from an already very high value. Among the treatments after six months period only T_1 had significantly superior level than control.

Mg content of control as well as VC treatments increased significantly like in most of the ameliorant treated ones except T_1, T_2 and T_8. Here T_1 and T_2 are the combination without any FA. The overall superiority for Mg level was for control, followed by VC after six months.

While comparing the effects on leaf Fe, values remained similar in all pairs except T_1, T_2, T_3 and T_4. However the significantly lower values of third month could be maintained in sixth also only by VC containing ameliorant blends and in VC alone treatments. In all other ameliorant blends, the leaf Fe at sixth month period was higher than their third month level.

But in PG alone treatment, the lower value sustained. Copper content significantly declined in all treatments whereas Mn content increased in all treatments to a substantial level from third month to sixth month.

4.4.4 Influence of ameliorants on chemical properties of soil three months after planting

Table 16. shows that results of the analysis of the soil samples collected from the pots after three months. There was a significant difference for the various parameters examined *viz*., pH, exchangeable Ca, Fe and Mn. For pH, the phosphogypsum treated pots showed significantly lower pH values when compared to control. The vermicompost mixed with ameliorants treatments registered lower pH values when compared with the treatments which were not mixed with vermicompost, but the differences were not significant. In the treatment T_3 the increase in pH was significantly higher to all other treatments and was superior to others.

The Ca content of the soil after three months indicated that the control and vermicompost treatments were at par, suggesting that vermicompost does not provide any exchangeable Ca at this period. But all the ameliorant treated pots recorded higher Ca compared to control and vermicompost. The vermicompost mixed ameliorants also recorded significantly higher Ca levels, compared to control and vermicompost except T_5.

Table 16. Effect of PG and its combinations with FA and VC on nutrient contents and pH of soil three months after planting in pot culture studies

Treatment	pH	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Al (mg kg^{-1})
PG (T_1)	5.6	855	61	151	34.2
PG :FA (10:1) (T_2)	6.1	850	71	148	37.4
PG :FA (20:1) T_3)	6.4	865	75	162	23.7
PG:FA (30:1) (T_4)	6.2	850	69	166	51.1
T2:V C (1:1) (T_5)	6.1	830	55	157	50.3
T3:V C (1:1) (T_6)	6.0	862	91	233	65.6
T4:V C (1:1) (T_7)	6.0	854	92	245	69.8
PG:V C (1:1) (T_8)	5.9	852	97	275	78.4
VC (T_9)	5.7	763	96	255	56.5
Control (T_{10})	5.8	784	88	247	46.9
CD (5%)	0.3	54	12.2	42.6	0.71

The data on exchangeable Fe suggests that significant reduction in Fe concentration was noticed only for the treatments where PG-FA ameliorants were applied. Mixing of vermicompost in these materials did not reduce the exchangeable Fe except in T_5, i.e. the blend of 10:1 PG-FA with vermicompost; this particular treatment recorded the lowest Fe content of 55 mg kg^{-1} and the PG treated soil alone was at par with this. When the exchangeable Mn concentrations were evaluated it was seen that the pattern was similar to that of Fe, but here the lowest value was 151 mg kg^{-1} for PG treatment. All the PG-FA blends were on par and for the vermicompost mixed treatments, T_2 + vermicompost alone showed lower values. All other vermicompost containing treatments gave higher Mn values which were on par with control.

4.4.5 Effect of ameliorants on chemical properties of soil six months after planting

Table 17. shows results of soil analysis of the pot culture experiment done six months after the start of the experiment. After a period of six months, there was no significant difference in pH and exchangeable Fe.

Table 17. Effect of PG and its combinations with FA and VC on nutrient contents and pH of soil six months after planting in pot culture studies

Treatment	pH	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Al (mg kg^{-1})
PG (T_1)	5.5	801	200	423	52
PG :FA (10:1) (T_2)	5.7	708	159	553	73
PG :FA (20:1) T_3)	5.9	845	156	434	33
PG:FA (30:1) (T_4)	5.7	803	156	648	33
T2:V C (1:1) (T_5)	5.7	733	153	530	37
T3:V C (1:1) (T_6)	5.7	734	146	671	49
T4:V C (1:1) (T_7)	5.7	749	149	582	58
PG:V C (1:1) (T_8)	5.5	733	152	740	56
VC (T_9)	5.6	614	150	527	98
Control (T_{10})	5.4	628	165	527	108
CD (0.05%)	NS	90	NS	149.1	7.6
SE	0.1	-	16.3	-	-

All the treatments containing PG and its blends recorded significantly higher Ca levels except T_2. The vermicompost treatment and control were at par. It was also seen that mixing of vermicompost resulted in a decrease of Ca content, but was not significant. In the case of Mn, some treatments recorded higher Mn contents than control. The effect of the treatments in reducing exchangeable Al was very prominent in all the treatments. All treatments recorded lower values when compared to control. The lowest value was noticed in T_3 and T_4 where PG was blended with FA at 20:1 and 30:1 ratios respectively.

Mixing vermicompost in the PG-FA blend increased exchangeable Al content significantly over compared to treatments where these blends were applied alone. Among the vermicompost mixed treatments, T_5 showed significantly lower Al value, compared to other vermicompost containing treatments.

The graph (Fig. 5e.) shows the effect of different treatments on the exchangeable Al content of the soil after six month

4.4.6 Effect of ameliorants on chemical properties of soil over a period of six months

The soil sample analysis data of the experiment at three month and six months interval were pooled and analysed to compare treatment differences in the two periods. The results are presented in Fig. 5a to 5e.

Over the period from third month to sixth month pH significantly decreased in all treatments including control. At three months the PG-FA treatments maintained a pH of six or above and after a period of another three months they all declined significantly and reduced to a level of 5.7. The extent of decrease was most prominent in control (0.6) but in others it was less.

The exchangeable Ca content also showed very significant decrease in all treatments. Fe content increased in all cases, and the most prominent increase was in T_1 where it was over three times, whereas in all others it was around 2 times or less. Mn content also increased in a similar manner, but here the increase was much more in all treatments.

Exchangeable Al increased in T_1 and T_2 substantially but remained without much change in most of the vermicompost mixed ameliorants. In T_4 it decreased from 51.1 to 33.3. The increase was noticed in control as well as vermicompost mixed treatments. In most treatments with vermicompost, the Al concentrations remained without much change or reduction.

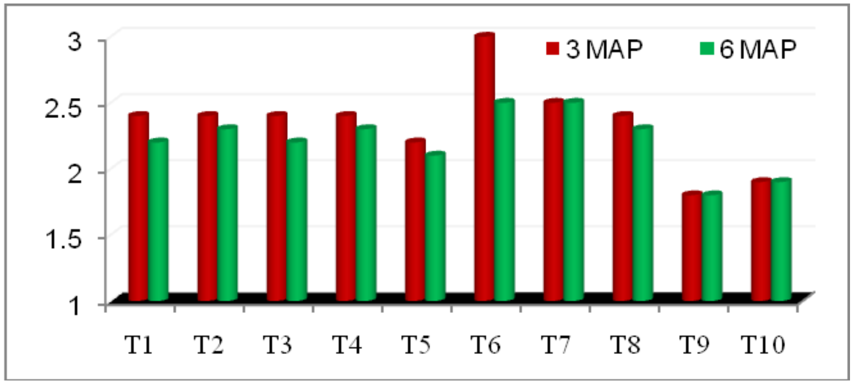


Fig. 4a. N content (%) of pot cultured plants at 3 months and 6 months after planting

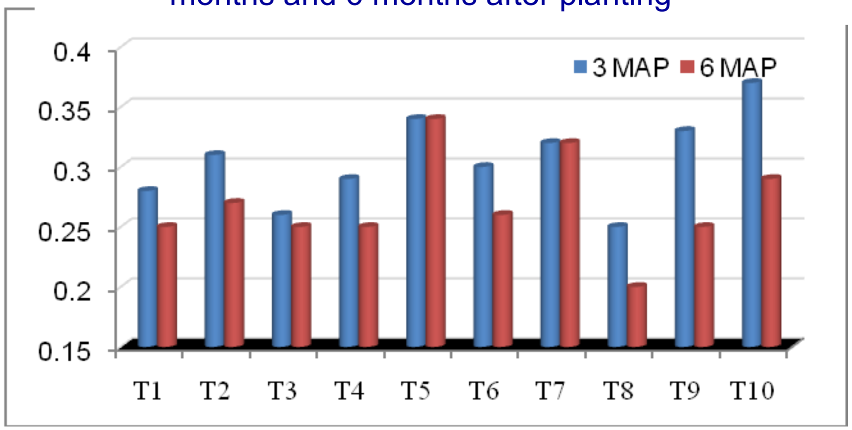


Fig. 4b. P content (%) of pot cultured plants at 3 months and 6 months after planting

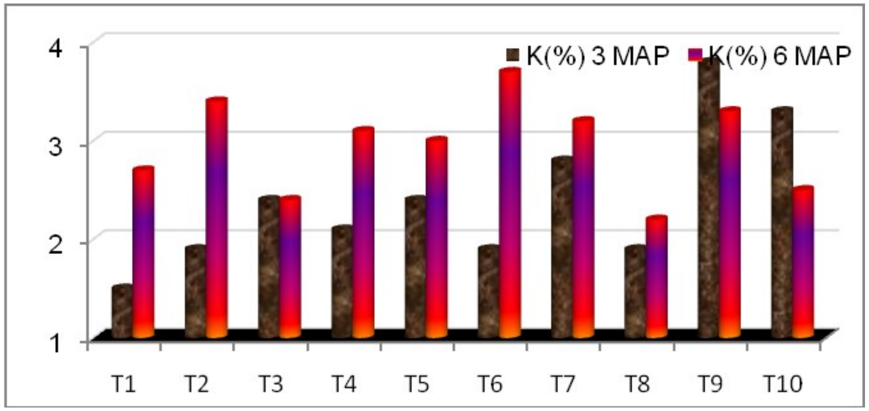


Fig. 4c. K content (%) of pot cultured plants at 3 months and 6 months after planting

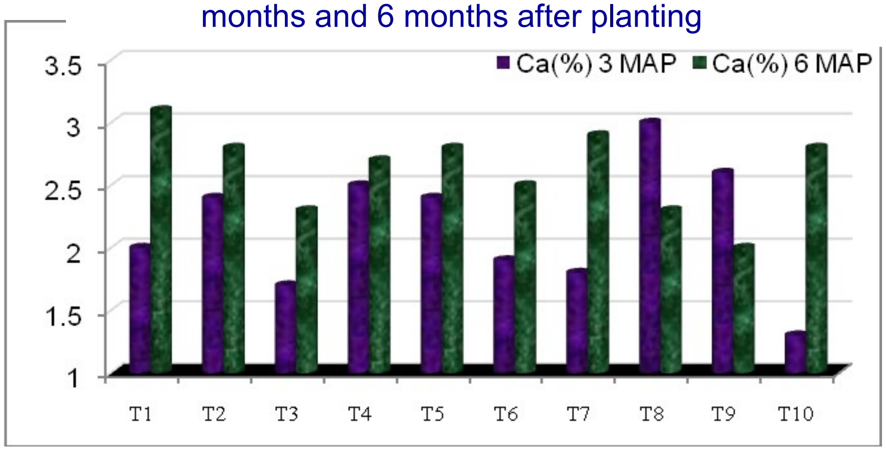


Fig. 4d. Ca content (%) of pot cultured plants at 3 months and 6 months after planting

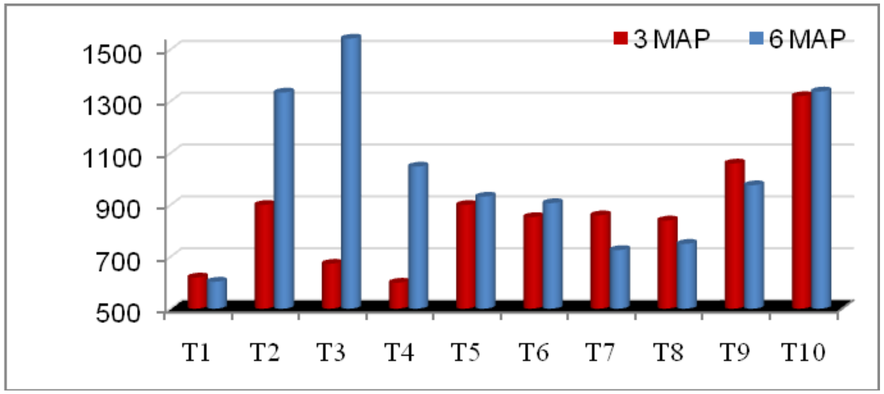


Fig. 4e. Fe content (μg g^{-1}) of pot cultured plants at 3 months and 6 months after planting

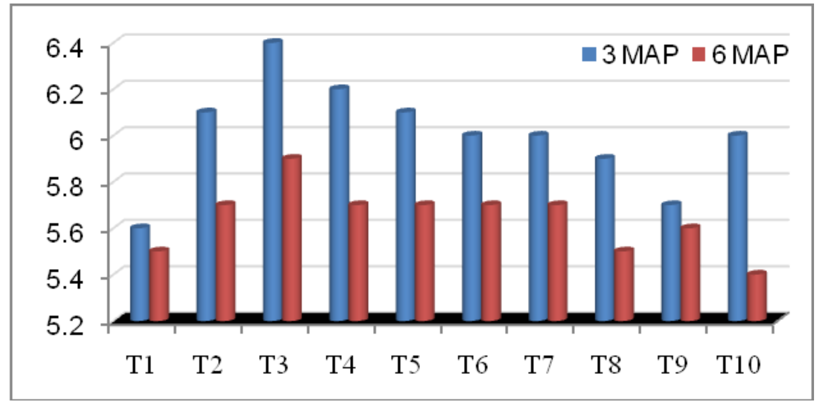


Fig. 5a. Soil pH of pot culture experiment at 3 months and 6 months interval

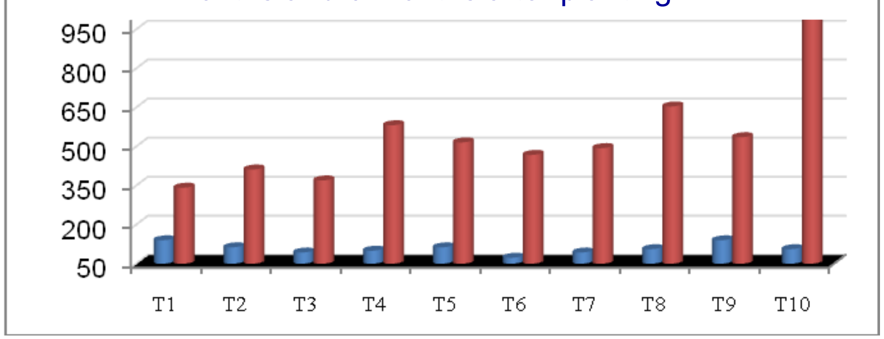


Fig. 4f. Mn content (μg g^{-1}) of pot cultured plants at 3 months and 6 months after planting

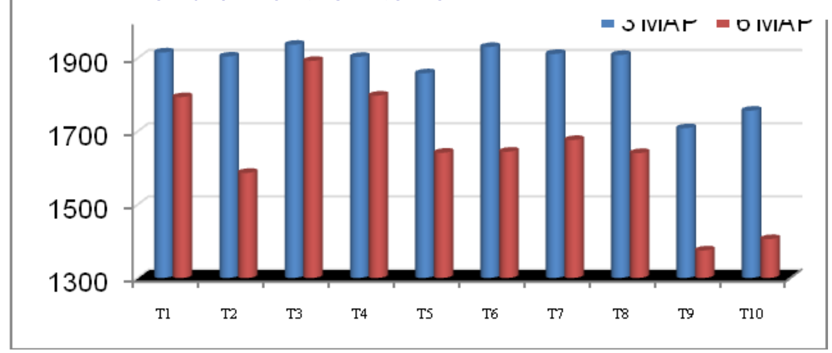


Fig. 5b. Soil Ca content (μg g^{-1}) of pot culture experiment at 3 months and 6 months interval

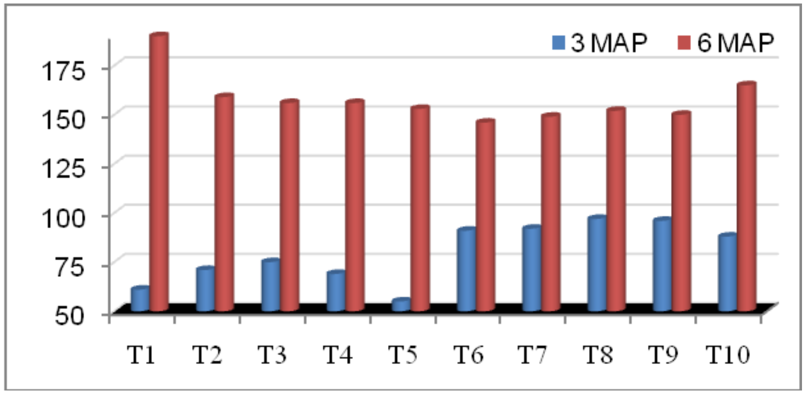


Fig. 5c. Soil Fe content (µg g^{-1}) of pot culture experiment at 3 months and 6 months interval

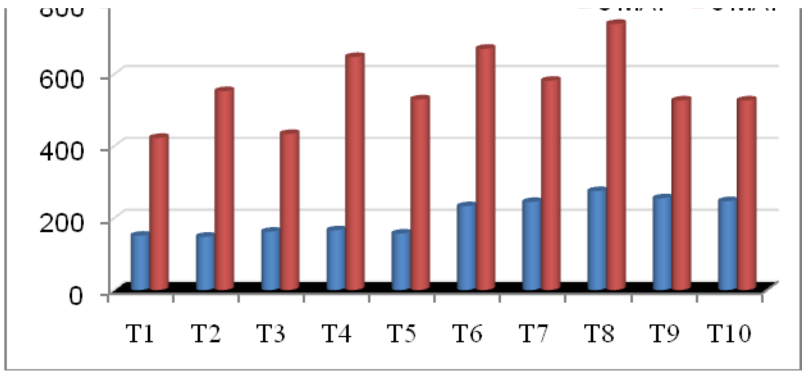


Fig. 5d. Soil Mn content (µg g^{-1}) of pot culture experiment at 3 months and 6 months interval

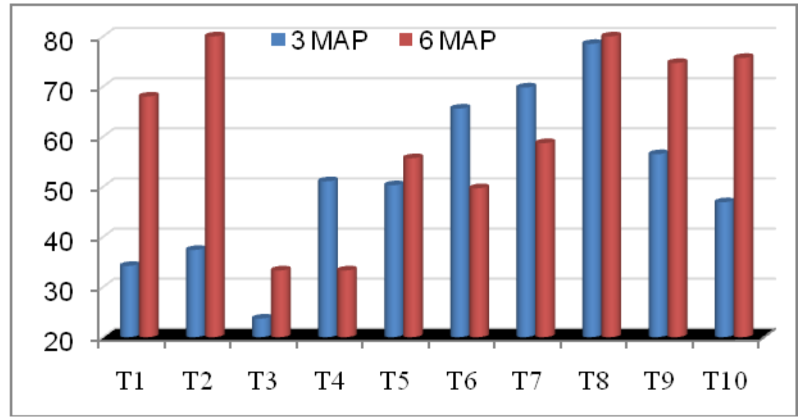


Fig. 5e. Soil Al content (µg g^{-1}) of pot culture experiment at 3 months and 6 months interval

4.5 Field experiment

4.5.1 Nutrient Status of Pepper Leaves (three months and six months after treatment application)

From the field experiment plants, leaf samples were collected initially and three months and six months after treatment application and were subjected to chemical analysis and the data after statistical analysis are presented in tables 18, 19 & 20.

Table 18. Nutrient Status of Pepper Leaves before Treatment Application

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
PG (T_1)	1.6	0.10	1.5	0.74	0.02	240	10.7	462	26
PG :FA (10:1) (T_2)	1.3	0.11	1.6	0.70	0.01	140	4.7	240	14
PG :FA (20:1) (T_3)	2.3	0.13	1.5	0.78	0.02	193	10.0	322	23
PG:FA (30:1) (T_4)	2.0	0.12	1.5	1.30	0.02	197	8.7	448	20
T2:V C (1:1) (T_5)	1.7	0.09	1.4	1.20	0.02	192	8.0	495	20
T3:V C (1:1) (T_6)	1.7	0.11	1.7	1.00	0.01	256	8.0	441	22
T4:V C (1:1) (T_7)	1.5	0.10	1.3	1.20	0.01	252	8.0	437	29
PG:V C (1:1) (T_8)	2.2	0.12	1.6	1.30	0.02	172	7.3	388	29
VC (T_9)	1.7	0.10	1.3	1.30	0.01	196	4.0	500	21
Control (T_{10})	1.9	0.10	1.2	1.35	0.01	288	4.7	608	19

At three month stage, with respect to N and P, all treatments showed superiority, but not to significant level. A similar pattern was noticed for other elements also. At this stage Ca contents of the leaves showed some increase in some treatments and K contents showed decrease. All other treatments remained at par.

Table 19. Effect of PG and its combinations with FA and VC on nutrient contents of pepper leaves three months after treatment application

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
PG (T_1)	2.1	0.16	1.9	1.2	0.02	302	510	332	27
PG :FA (10:1) (T_2)	2.1	0.14	1.6	1.1	0.02	205	367	298	20
PG :FA (20:1) (T_3)	2.4	0.12	1.2	1.0	0.02	141	358	215	15
PG:FA (30:1) (T_4)	1.9	0.08	1.8	1.8	0.02	288	500	269	31
T2:V C (1:1) (T_5)	2.3	0.20	1.9	2.0	0.04	252	812	534	60
T3:V C (1:1) (T_6)	2.2	0.20	1.0	1.0	0.01	155	366	360	24
T4:V C (1:1) (T_7)	2.3	0.14	0.8	1.2	0.02	188	472	339	43
PG:V C (1:1) (T_8)	2.0	0.12	1.7	1.9	0.03	262	661	456	40
VC (T_9)	2.2	0.13	1.8	1.5	0.02	276	474	342	16
Control (T_{10})	1.9	0.13	1.4	1.5	0.03	268	727	562	12
SE	0.19	0.02	0.32	0.31	0.01	49.89	126.71	95.86	13.66

4.5.2 Comparative Nutrient Status of Pepper Leaves over a Period of 6 Months

The data on leaf chemical analysis of the experimental plants done at initial stage, three months after and six months after treatment application were subjected to pooled analysis to examine the influence of the treatments over the period. The data on N, P, K, Ca, Fe, and Mn are presented in Fig. 6a to 6f.

For leaf nitrogen level over the two intervals, there were no significant difference in values for any of the treatments or with control though there was a slight increase over the initial level during 3^{rd} month and then it decreased. A similar trend was observed for phosphorus content also.

When the K concentration was examined it was noticed that between initial and third month nutrient level there was increase in some treatments and decrease in others but not to a significant level. However at sixth month, in some treatments like T_1, T_2 and T_3, the K level decreased significantly to lower values when compared with initial values. It can also be noticed that these treatments were ameliorants not blended with VC.

Table 20. Effect of PG and its combinations with FA and VC on nutrient contents of pepper leaves six months after treatment application

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
PG (T_1)	1.9	0.13	1.1	0.7	0.03	146	486	360	18
PG :FA (10:1) (T_2)	1.9	0.16	1.0	1.4	0.03	206	600	420	22
PG :FA (20:1) (T_3)	1.8	0.14	0.5	1.1	0.03	333	533	453	26
PG:FA (30:1) (T_4)	1.9	0.14	0.9	1.2	0.03	240	193	386	25
T2:V C (1:1) (T_5)	1.8	0.10	0.7	1.1	0.03	126	266	346	24
T3:V C (1:1) (T_6)	2.1	0.12	1.3	1.2	0.03	106	466	466	32
T4:V C (1:1) (T_7)	2.0	0.22	1.9	1.7	0.03	113	460	606	29
PG:V C (1:1) (T_8)	1.7	0.16	1.8	2.3	0.04	126	733	600	50
VC (T_9)	2.1	0.11	1.4	2.2	0.04	113	620	646	25
Control (T_{10})	2.0	0.14	1.3	1.4	0.02	120	846	566	26
CD (5%)	NS	NS	0.32	0.74	NS	NS	NS	NS	NS
SE	0.14	0.02	-	-	0.003	65.6	129.43	79.27	6.7

In the case of Ca content as in the case of N, the differences were not significant but the initial level was either maintained or the increase noticed at three month period was sustaining up to six months. Almost similar results were noticed for Mg also. For these nutrients the FA containing treatments in general showed significantly lower Mg levels than control and VC treated plots.

Fig. 6e. illustrates the comparison of Fe contents. There were no significant difference between initial and final Fe levels in treatments, most of the treatments had lower values but in some case the differences were not significant. However the general observation was that in all the vermicompost containing treatments and control there was a gradual decrease, but in treatments without vermicompost it increased or decreased initially, then increased. Zn content of leaves at the different stages of sampling varied significantly for some of the treatments and in most cases it was around 20 mg kg^{-1}, the sufficiency range.

4.5.3 Influence of Ameliorants on Chemical Properties of Soil (Three Months and Six months After Treatment application)

From the treatment applied plots of the field experiment laid out at PRS, Panniyur, soil samples were collected from a depth of 15 cm at three and six months interval. These samples were subjected to chemical analysis and the data were subjected to statistical analysis by conducting ANOVA for RBD and the results of soil analysis after three months and six months are presented in tables 21 and 22, respectively.

At three months after treatment application, all the parameters measured showed significant effects for the treatments. Vermicompost (T_9) and T_5 (combination of VC with PG-FA) recorded significantly higher pH and all other treatments were at par with control. With respect to Ca content, except T_1 all were superior to control.

The Fe content was higher in all PG and PG-FA treatments and when these treatments were blended with VC, the level at 15 cm depth was at par with control. With respect to the Mn concentration, all were at par with control, and lower values were noticed for PG and its blends with FA, VC mixing enhanced the Mn content.

Table 21. Effect of PG and its combinations with FA and VC on nutrient contents and pH of soil three months after treatment application

Treatment	pH	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Al (mg kg^{-1})
PG (T_1)	5.6	760	24	96	61.0
PG :FA (10:1) (T_2)	5.6	823	24	114	62.8
PG :FA (20:1) T_3)	5.5	861	22	109	56.3
PG:FA (30:1) (T_4)	5.7	896	22	97	51.0
T2:V C (1:1) (T_5)	6.2	877	18	117	39.0
T3:V C (1:1) (T_6)	5.6	867	11	135	64.9
T4:V C (1:1) (T_7)	5.5	907	15	174	54.0
PG:V C (1:1) (T_8)	5.9	914	17	182	60.5
VC (T_9)	6.3	861	14	166	76.5
Control (T_{10})	5.7	779	68	222	114
CD (5%)	0.46	62	9.03	42	0.54

Table 22. Effect of PG and its combinations with FA and VC on nutrient contents and pH of soil six months after treatment application

Treatment	pH	Ca (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Al (mg kg^{-1})
PG (T_1)	5.6	859	15	75	106
PG :FA (10:1) (T_2)	5.7	865	14	98	88
PG :FA (20:1) T_3)	5.5	868	16	81	62
PG:FA (30:1) (T_4)	5.8	872	12	82	74
T2:V C (1:1) (T_5)	5.8	861	22	89	84
T3:V C (1:1) (T_6)	5.6	889	16	231	87
T4:V C (1:1) (T_7)	5.6	853	17	245	88
PG:V C (1:1) (T_8)	5.9	870	10	210	85
VC (T_9)	5.9	838	20	254	133
Control (T_{10})	5.7	817	72	227	144
CD (5%)	0.25	NS	NS	38	NS
SE	-	17.7	3.1	-	23.6

Al content registered a significant decline compared to control in all the treatments. The lowest value of 39 mg kg^{-1} was recorded for T_5. The exchangeable Al content of the soil did not show any significant difference between the treatments. The result of the soil analysis at six months after treatment application did not show any significant difference for treatments except for Mn content. Here all the treatments and PG and its blends with FA registered low Mn values.

4.5.4 Comparative effect of ameliorants on chemical properties of panniyur field soil over a Period of 6 Months

The soil analysis data at three months and six months were pooled together and compared. The results are illustrated in Fig, 7a to 7e. The effect on pH is shown in Fig. 7a. In most of the PG containing treatments the soil showed lower pH value than control. Between the pairs of values significant difference was noticed only in very few cases.

Calcium content showed significant decrease or increase in a random manner. In control it increased and in vermicompost treated soil it decreased. The concentration of Fe in T_{10} and T_9 increased significantly at six months period. In PG and PG-FA blends applied pots, Fe decreased significantly, However in vermicompost treated ones it remain same or increased from the lower values except for PG-VC combination. Manganese also in general showed a similar pattern with few exceptions as in T_5.

The exchangeable Al was analysed and data shown in Fig. 7e. In control it remained similar and for all other treatments, the sixth month sample recorded substantially higher values; the rate of increase was not uniform, the highest increase was noticed for the treatment where vermicompost alone was applied.

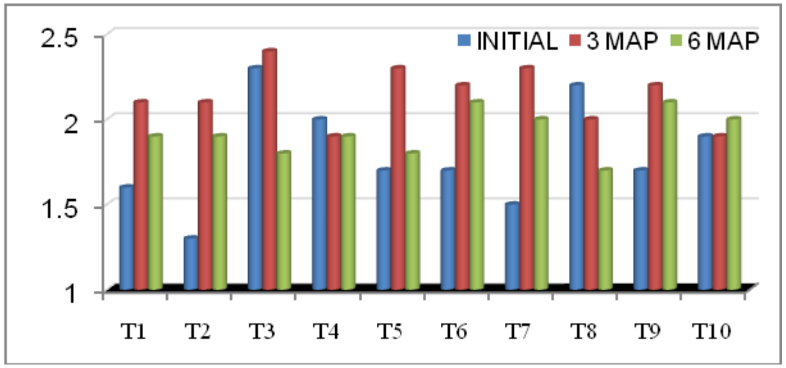


Fig. 6a. N content (%) of leaf samples of field vines at initial, 3rd and 6th month

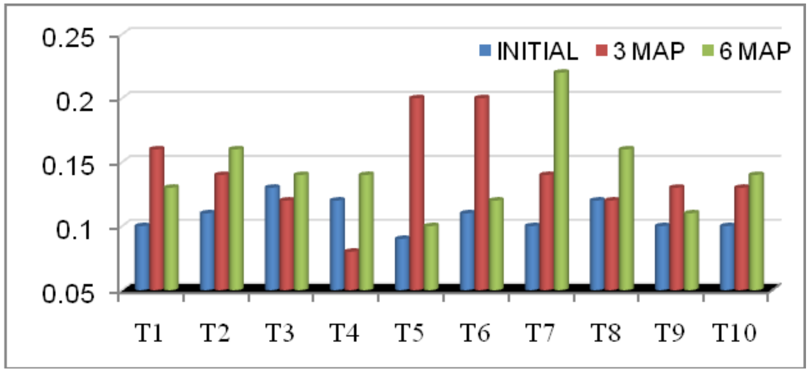


Fig. 6b. P content (%) of leaf samples of field vines at initial, 3rd and 6th month

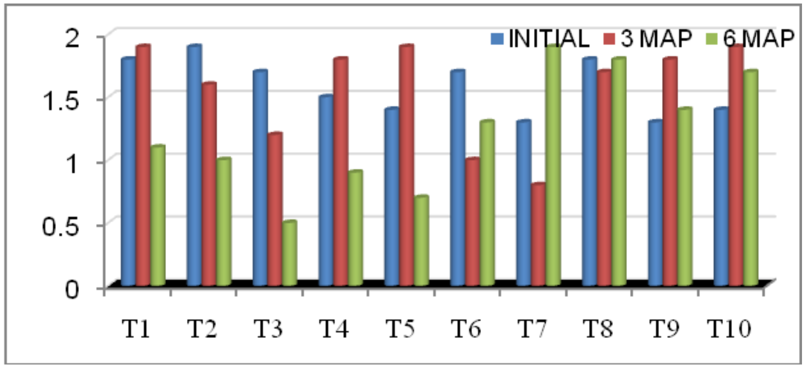


Fig. 6c. K content (%) of leaf samples of field vines at initial, 3rd and 6th month

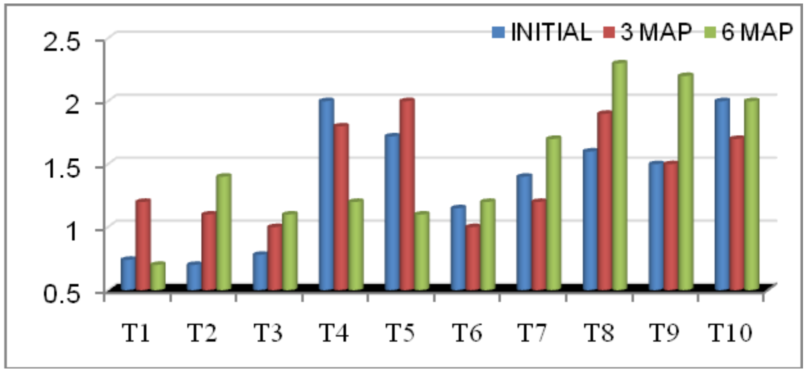


Fig. 6d. Ca content (%) of leaf samples of field vines at initial, 3rd and 6th month

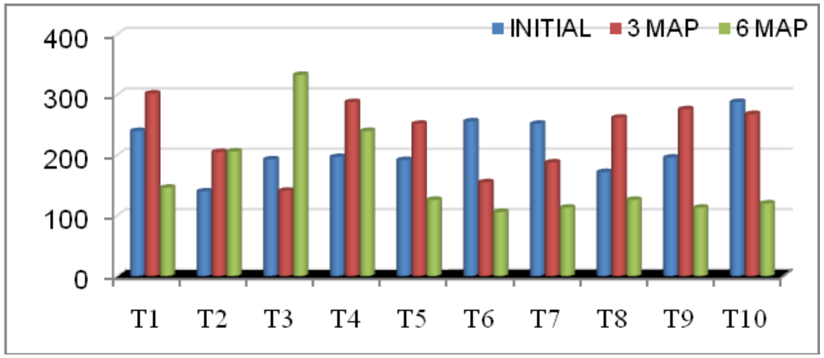


Fig. 6e. Fe content (μg g^{-1}) of leaf samples of field vines at initial, 3rd and 6th month

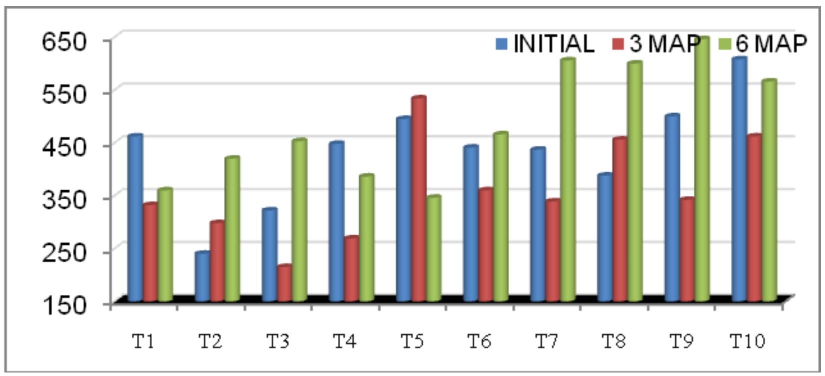


Fig. 6f. Mn content (μg g^{-1}) of leaf samples of field vines at initial, 3rd and 6th month

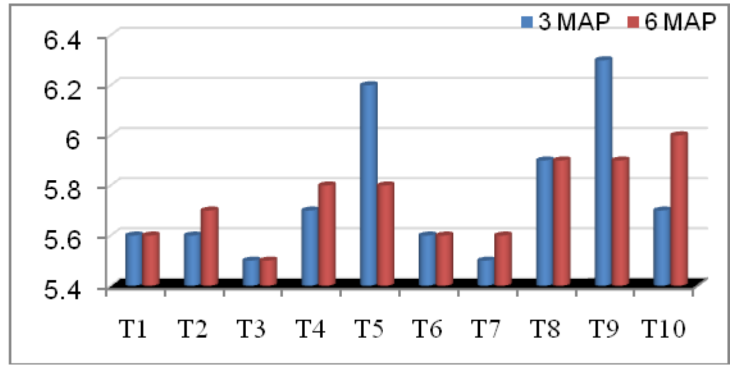


Fig. 7a. Soil pH of field samples at 3rd and 6th month

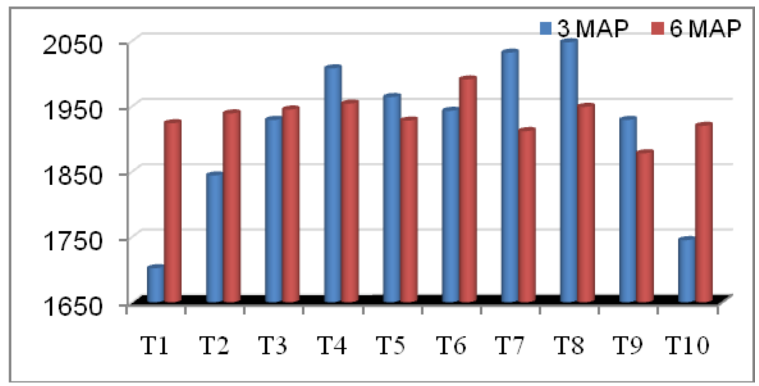


Fig. 7b. Soil Ca (μg g^{-1}) content of field samples at 3rd and 6th month

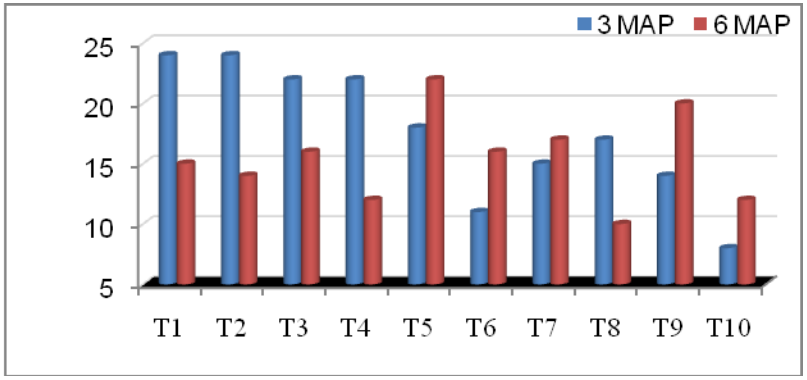


Fig. 7c. Soil Fe (μg g^{-1}) content of field samples at 3rd and 6th month

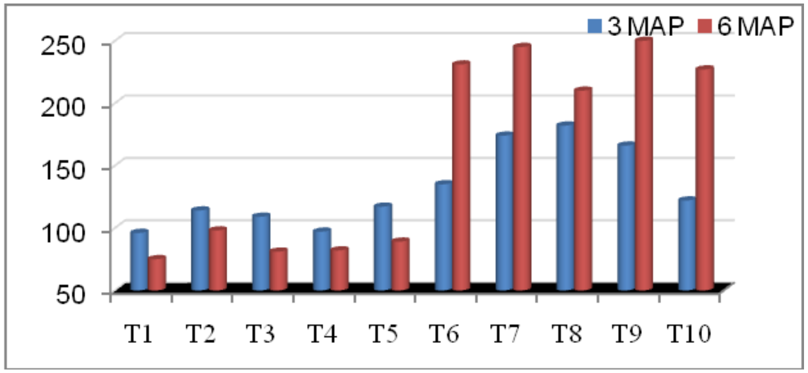


Fig. 7d. Soil Mn (μg g^{-1}) content of field samples at 3rd and 6th month

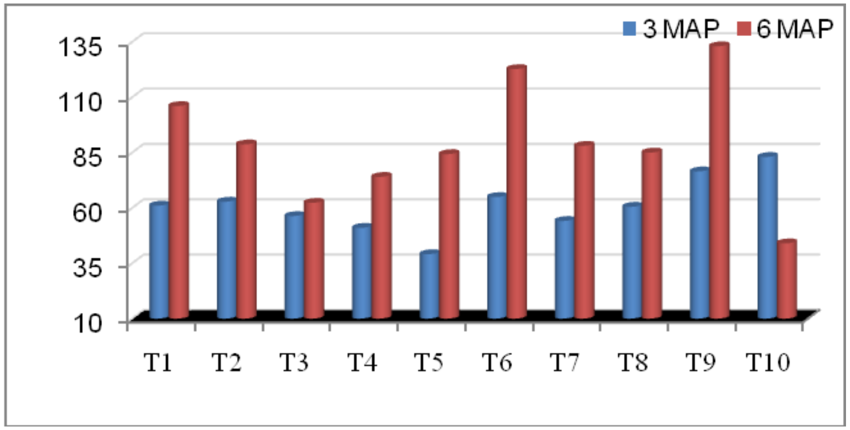


Fig. 7e. Soil Al (μg g^{-1}) content of field samples at 3rd and 6th month

4.6 Effect of Ameliorants on Yield Parameters of Field Pepper Vines

The harvest of the pepper spikes were done eight months after the treatments application. Average length of spike, number of berries per spike, weight of spikes per plant and number of spikes per 100g of spikes were recorded.

The data after subjecting to statistical analysis are presented in table 23. The yield response was lower than control in some treatments. Vermicompost (T_9), PG-FA (20:1) (T_3) and the blend of 30:1 with vermicompost (T_7) gave significantly higher yield. For T_4 the yield was lower. When the number of berries per spike was evaluated, again T_3 showed superiority.

Table 23. Effect of PG and its combinations with FA and VC on yield attributes of pepper

Treatment	Weight of spike / plt (g)	No of spikes needed for 100g	Number of berries /spike	Average length of spike (cm)
PG (T_1)	540	18	78	13.7
PG :FA (10:1) (T_2)	381	22	71	14.1
PG :FA (20:1) (T_3)	1735	13	111	15.2
PG:FA (30:1) (T_4)	138	19	42	9.5
T2:V C (1:1) (T_5)	580	16	88	15.7
T3:V C (1:1) (T_6)	800	12	101	14.6
T4:V C (1:1) (T_7)	1586	17	95	12.8
PG:V C (1:1) (T_8)	328	14	72	12.3
VC (T_9)	1321	14	95	14.1
Control (T_{10})	848	16	84	13.1
CD (5%)	498.9	NS	25.2	3.2
SE	-	3.3	-	-

The number of spikes needed for 100g was also measured and T_6 and T_3 recorded overall low value, indicating better weight of berries. These observations suggest the higher yield level of T_3 treatment among others.

4.7 Chemical Analysis of Harvested Berry Samples

The berry samples of each treatment were subjected to chemical analysis and the results are presented in table 24.

For nitrogen contents there was no significant difference. Highest P content was noticed in T_1 and lowest values were recorded for T_4 and T_5, and others were at par. For K content highest value was for PG-VC (T_8) and except T_2 and T_4 all were superior to control. Highest Ca content was for T_2 and T_3. In the case of Fe only T_3 and T_4 showed values significantly lower to control. For Cu, Mn and Zn, there were no significant differences.

Table 24. Effect of PG and its combinations with FA and VC on nutrient contents of pepper berries

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
PG (T_1)	1.4	0.25	1.5	0.25	0.02	102	90	80	13
PG :FA (10:1) (T_2)	1.3	0.21	1.3	0.35	0.03	110	108	122	16
PG :FA (20:1) (T_3)	1.4	0.22	1.2	0.31	0.02	80	92	77	14
PG:FA (30:1) (T_4)	1.5	0.16	0.7	0.2	0.02	51	40	79	13
T2:V C (1:1) (T_5)	1.5	0.16	0.9	0.2	0.02	120	74	74	24
T3:V C (1:1) (T_6)	1.6	0.2	1.5	0.26	0.03	230	101	128	25
T4:V C (1:1) (T_7)	1.5	0.21	1.5	0.31	0.03	164	112	130	24
PG:V C (1:1) (T_8)	1.6	0.21	1.6	0.28	0.03	214	118	131	28
VC (T_9)	1.4	0.18	1.4	0.15	0.02	129	88	105	14
Control (T_{10})	1.3	0.19	1	0.2	0.02	185	101	128	14
CD (5%)	NS	0.03	0.36	0.12	NS	84.8	NS	NS	NS
SE	0.19	-	-	-	0.003	-	15	17.17	4.37

4.8 Observation on Drought Tolerance

As an indirect evaluation of sub soil root proliferation and better moisture uptake, from the month of February onwards the plants were observed for their drought tolerance, and the leaf shedding nature. In the ameliorant treated plots, the plants remained fresh, while the control and vermicompost treated plants showed leaf yellowing and shedding. Because of the early summer showers, these observations could not be carried further, by taking leaf counts at peak summer.

Discussion

5. Discussion

Results of the investigations carried out to study the ameliorating effect of PG and PG-FA blends with respect to Al toxicity in black pepper are discussed here. The investigation comprised of analysis and standardization of PG and FA, conduct of incubation study, pot culture and field experiments.

5.1 Standardization of Ameliorants

The phosphogypsum sample had a pH of 4.4 and 100 g of the material had an equivalent acidity of 1.2 meq. This was mainly due to the free phosphoric acid present in the material and also due to the hydrolysis of sparingly soluble $CaSO_4$.

Sumner (1970) in his extensive review had mentioned about the acidic pH and had suggested blending of $CaCO_3$ to increase the pH. Though PG is widely recommended for ameliorating sodic soils where soil pH is alkaline, its scope in acid soil is very much limited. However the soluble Ca^{2+} and SO_4^{2-} present are advantageous and it is recommended for subsoil acidity amelioration (Sumner, 1993)

However Fly ash material had a very high alkaline pH of 13 and an equivalent alkalinity of 235 meq/ 100g material. This was mainly due to the presence of oxides of Ca, Mg, Na and K as indicated in Table 3. Meller (1999) attributed this alkalinity as an inherent property of the Fly ash. Owing to its high pH, the material as such is unsuitable for direct application to standing crops, though it has been widely used as an ameliorant prior to sowing.

Kalara (2003) has reported its beneficial effect on wheat crop. But its use in plantation crops of perennial nature like black pepper, is not popular. The high alkalinity of this material offered a good choice as a blending material with PG. The two ameliorants were thus blended at various proportions and the blends 10:1, 20:1 and 30:1 were found to be ideal with respect to pH for acid soils. At these proportions, equivalent acidity of the PG is neutralized by the equivalent alkalinity of the FA and the resultant pH will justify the use of blends in acid soils. More over the sulfur content of PG is another advantage, especially in soils of highly leached lateritic nature where sulfur deficiency is prevalent.

Based on the evaluation of blends, desired proportions of 10:1, 20:1 and 30:1 were selected and were evaluated further. The evaluation was done at three stages. The preliminary trial was to evaluate the blends for their suitability to maintain soluble Ca levels when applied to soil.

Subsequent to this a pot culture experiment and a field experiment were also carried out where in the selected blends were mixed with vermicompost. The beneficial effects of organic complexes and organic acids in reducing exchangeable Al have been well documented by many workers (Hoyt and Turner 1975; Hue 1992; Noble *et al*., 1996).

5.2 Incubation Experiment

In this experiment soil samples were incubated with ameliorants added at liming rates with respect to Ca. The samples were maintained at 50 per cent field capacity and analysed at 15 days intervals up to 90 days. The results of soil analysis after 15 days suggested that in all treatments that contained Fly ash the soil pH values increased significantly, whereas in soil treated with PG alone, pH was lowest.

The beneficial effect of FA in increasing pH has been reported by Meller (1999). The beneficial effect on PG-FA blends in increasing soil fertility for rice paddy has been reported by Chang-Hoon-Lee *et al* (2006).

They had indicated high amount of soluble Ca in soil subsequent to the application. In the present experiment also after 15 days interval, all the treated soil contained significantly high Ca. The Fe and Mn contents on the other hand were low, possibly due to increase in pH, coupled with high exchangeable Ca levels.

The analysis of samples taken after a period of 30 days also suggested similar trend. Here Fly ash containing treatments were more effective in increasing the pH, which is in conformity with the findings of Meller (1999). This trend was continuing up to 90 days period and highlights the benefit of Fly ash in bringing about increase in pH. The exchangeable Al content at 90 days was significantly reduced by all ameliorants. The effect of the treatments on increasing pH and reducing Exchangeable Al is shown in Fig. 8a.

The Fig. 8a. highlights the beneficial effect of the blended material in ameliorating the exchangeable Al toxicity. The beneficial effect of the blend may be due to the combined effect of increasing pH along with providing high amount of exchangeable Ca. In treatment with PG alone, the beneficial effect of high pH is not obtained.

These results point to the better ameliorating effect of PG-FA blends. Thus in a lateritic soil the PG-FA blends very effectively increased the pH and reduced the exchangeable Al and the effect was sustained for the three months period of the study.

5.3 Pot Culture Experiment

In pot culture experiment conducted at College of Horticulture, Vellanikkara, the treatment combinations of PG and PG-FA blends with and without vermicompost were compared with absolute control. There were ten treatments, and biometric observations of the black pepper vines were recorded for six months.

5.3.1 Leaf Number

The results on comparing the treatments with respect to leaf number did not show any significant difference. However the overall performance averaged over 6 months period indicated superiority for the ameliorants. In a similar experiment to study the influence of PG on root growth of pepper vines to deep soil layers (Deepa, 2008), better growth of vines were noticed in the PG treated pots.

5.3.2 Increase in Shoot Height

The increase in shoot height measured for the various treatments at various intervals was not significant and in all plants there was steady increase in shoot length (Fig. 8b).

But the ameliorant blends with VC showed some superiority indicating the beneficial effect of vermicompost. The beneficial effect of organic acids in reducing monomeric Al species has been suggested by many workers (Hue, 1992). More over it is reportedthat vermicompost ensures better soil micro flora and regulated supply of nutrients (Radhakrishnan, 2009). Thus mixing of Vermicompost with PG-FA blends gives more benefit. The data on leaf area measurements did not show any clear differences.

5.4 Influence of treatments on nutrient status of pepper leaves and soil of pot culture experiment

5.4.1 Nutrient Status of pot cultured pepper leaves over a period of six months

Leaf samples from the pepper vines grown in pots with the ten treatments were collected and their chemical analyses done at three months period and at six months period. At three months period in all the treatments that contained PG, leaf nitrogen was higher than control. Application of vermicompost alone also does not show any enhanced leaf nitrogen. Same trend was noticed after six months also.

This suggests the better nutrient uptake capacity of treatments where PG-FA blends were applied, possibly due to reduced deleterious effect of exchangeable Al in soil. High concentration of exchangeable Al in soil severely affects the root growth without showing any visible leaf symptoms. In such conditions the growth of the plants will be affected even if nutrients are present in soil (Pearson, 1966).

The enhanced root proliferation in plants receiving PG would have resulted in better uptake of N resulting in better growth performance. In pots receiving vermicompost alone the exchangeable Al concentration may still be high enough to hamper the root growth of plants. The root inhibition by exchangeable Al in black pepper has been reported by Deepa (2008).

The beneficial roles of the treatments are also indicated by lower levels of Fe and Mn. The Zn concentration of the PG containing treatments was higher. In soil Zn is not mobile and its higher uptake indicates better root exploration of the soil. This also points to the enhanced root growth in PG containing treatments.

Ameliorant treated vines registered lower level of K after three months of treatment but again after six months the level was increased. So K uptake was depressed temporarily immediately after application of ameliorants but in case of VC treated vines, this trend was not seen. Lateritic soils are generally deficient in K (Sarkar *et al.*, 1989) the report of Martens *et al*. (1970) is in contrast to results.

In the fly ash sample used for the present investigation the K content was only 6 per cent and more over it was used only in a very limited rate, at 10:1 or a lower ratio compared to PG.

Another reason could be the more soluble Ca and Mg present in the PG-FA blends and this could suppress the absorption of K slightly. However the results indicated that at six month the K content increased in all ameliorant treated pots. This showed that the depressive effect of Ca on K uptake is temporary.

The content of Cu also showed higher value but this cannot be taken as any indication as the plants were sprayed periodically with Copper Oxy Chloride / Bordeaux mixture to control foot rot disease. The beneficial role of soluble Ca forms in reducing toxic level of Fe and Al has been reported by Deepa (2008).

The results indicated that in all the PG treated pots the leaf P content registered significantly lower values. A similar observation was made by Chang Hoon Lee *et al*. (2006) in rice where PG-FA blends were applied. They attributed the low phosphorus as the reduced water soluble P content in the treated soil, which was due to the increased Fe-P and Ca-P contents. They have also reported the overall loss of P from soil.

The pooled analysis of data for three months period and six months period indicated that in the ameliorant treated pots the beneficial effect was either maintained, or declined slightly. The Ca content in PG applied plots were having higher value at six months, indicating the better availability. The ability of PG to maintain soluble Ca has been reported by Hoveland (2000) and Deepa (2008).

The beneficial effect of VC along with the PG-FA blends could be seen in maintaining the reduced level of leaf Fe content in third month as well as at sixth month. The presence of humic substances in vermicompost and its beneficial effect has been reported by many workers (Wong, 1981; Stevenson and Vance, 1989).

The chelating effects of humic substances present in vermicompost possibly provide an added advantage over the beneficial effect of Ca. The results of the soil analysis conducted at third month and sixth month after the start of the experiment indicated the better ameliorating effect of PG and its blends.

With respect to available Ca content, all the PG containing treatments had higher values. The ameliorating effect of Ca and Mg has been reported by Edmeades *et al* (1991). The beneficial effect of Fly ash in increasing the alkaline cations has been indicated by Meller (1999).

The K status of the leaves as depicted in Fig.4c showed decline at sixth month where as the values increased in all treatments containing ameliorants. In VC treated pots though there was decline it was not significant. Martens *et al*. (1970) reported that amendment of K deficient soil with Fly ash increases plant uptake of K.

While comparing the Fe content of leaves, there is an indication that in vermicompost mixed treatments the Fe contents were lower than the treatments with PG-FA blends. The Fig. 8c depicts the trend. From the graph it is clearly indicated that PG-FA with VC recorded the lowest Fe as compared to PG-FA or VC. This suggests the better ameliorating effect of PG-FA with VC where the benefits of soluble Ca, from PG, increase in pH due to FA and complexing effect of organic substances of VC could be derived combinedly.

The effect of these materials in decreasing Fe has been reported by Krug (1986) and Renken *et al*. (2006). These findings indicate that the ameliorant blended with organic material offers a better choice in reducing toxic levels of elements.

5.4.2 Chemical properties of pot culture soil over a period of six months

The soil analysis after six months indicated higher Ca in PG-FA blends, with VC as well as without VC. The VC mixing slightly reduced Ca but not significantly. Plank *et al.* (1974) has reported high Ca content in the displaced soil solution subsequent to Fly ash application.

The chelating effect of organic substances would have enhanced the uptake of Ca and this would have resulted in the marginal decline. Kumari and Usha Kumari (2002) have reported superior uptake of Ca along with other nutrients by cowpea when treated with vermicompost.

The beneficial effect of VC for better uptake of nutrients can be attributed to improved physio-chemical properties of soil or due to better microbiological action of beneficial organisms in soil as reported by Radhakrishnan (2009).

The effect of treatments in reducing the exchangeable Al content indicated that over the period of 6 months, the concentration of Al remained lower without much change. In control it increased. The result again points to the beneficial effect of PG-FA blends along with VC for their additive effects in reducing exchangeable Al, The beneficial effects of Fly ash-Pyrite blends has been reported by Tiwari *et al*. (1992), and the present results are in conformity with the findings.

Keefer *et al* (1988) reported reduction in exchangeable Al in treatments receiving fly ash, in an experiment on West Virginia soil. The prominent role of soluble Ca in reducing soil Al concentration has been highlighted by many workers (Caldwell *et al*. 1990; Alcordo and Recheigl, 1993; Sumner, 1993 and Moody *et al.* 1998.)

5.5 Influence of treatments on nutrient status of pepper leaves and soil of field experiment

The treatments imposed in pot experiment was repeated in the field experiment conducted at PRS, Panniyur. Leaf and soil samples were collected at three months and six months after treatment incorporation. Over and above biometric observations, yield attributes were also recorded after eight months when the vines came to bearing.

5.5.1 Nutrient Status of field pepper leaves over a period of six months

The chemical analysis of the leaf samples drawn at third month and sixth month after treatment application were done and the results interpreted. The chemical analysis data at third month indicated that all the treatments showed higher leaf N values than control. As in the case of pot experiment, better root growth and the subsequent enhanced uptake might be the reason for the superior leaf N levels in the ameliorant treated plants.

The only treatment in which the effect of increase of leaf N was absent was the PG-VC combination. Here there was no increase of soil pH as fly ash was not added and this could be a reason. The Ca content was increased and K content was decreased. Pooled analysis of the data over the two periods indicated that N and P contents were higher at three months period and declined at six months stage. This gives an indication that Al toxicity on roots would have been reduced and nutrient uptake improved in the ameliorant treated plants.

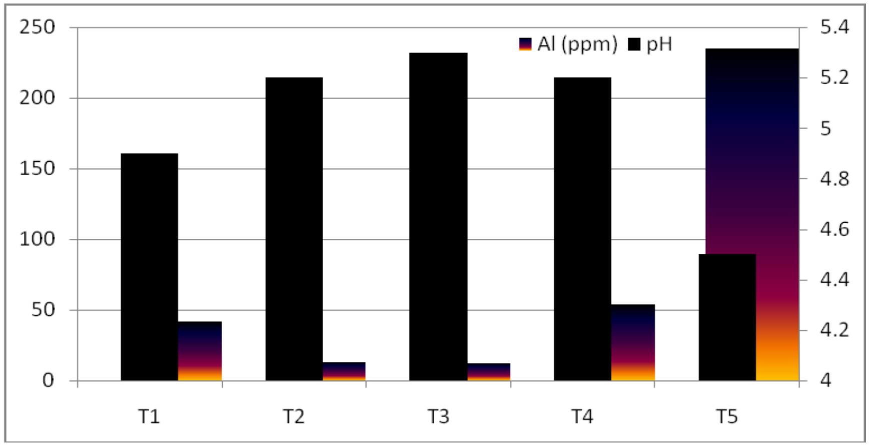


Fig. 8a. Beneficial effect of the blends on increase of pH and decrease of exchangeable Al (µg g^{-1}) 90 days after incubation

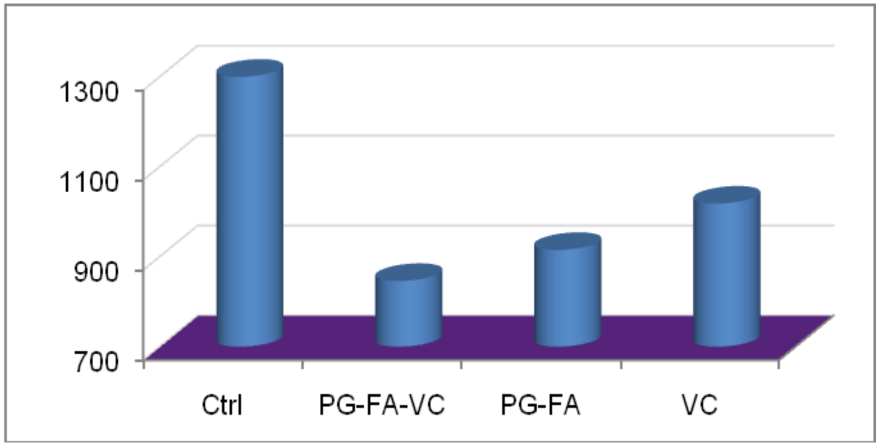


Fig. 8c. Beneficial effect of VC on decrease of exchangeable Fe (µg g^{-1}) six months after planting

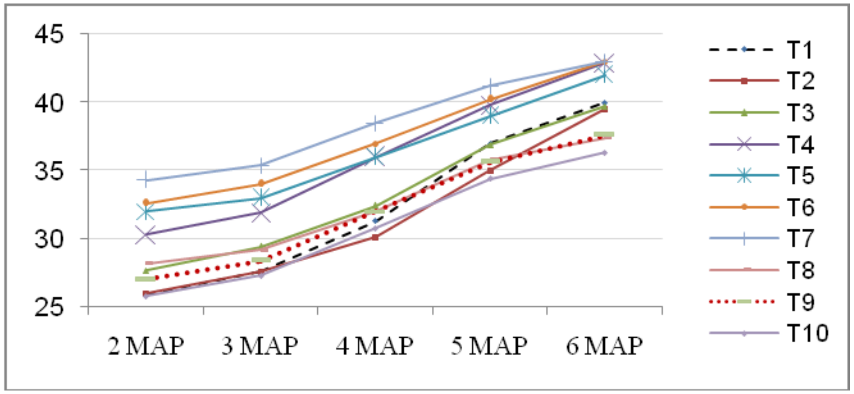


Fig. 8b. Steady increase in shoot height (cm) in pot cultured pepper vines over a period of six months

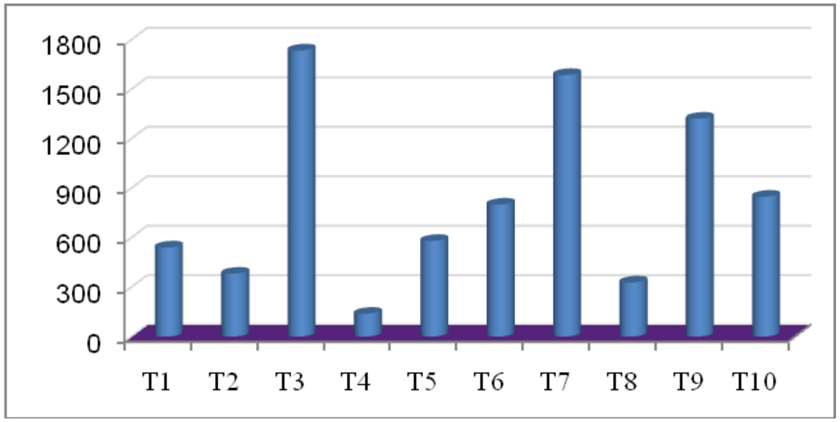


Fig. 8d. Effect of the treatments on yield (g/plant) of pepper vines

Pavan *et al*. (1982), Ryan *et al*. (1993) and Foy (1988) had reported the reduced uptake of water and nutrients due to Al toxicity. Potassium content was significantly reduced in PG alone and in PG-FA treated plants after six month period. Ca content was increased at three month which was sustained up to six month period but not to significant level by all treatments. Low of level of Mg was registered by PG, PG-FA and PG-FA-VC combinations applied plants than control and when VC alone was applied. Here again the high availability of Ca would have slightly suppressed the Mg uptake.

Low Fe level was recorded by VC treated plant and control but not significantly. For other treatments it either increased or decreased. For Mn content, most of the treatments have shown a decrease at third month and gradual increase after six months except for PG-VC treated plants. The presence of humic substances in VC and its chelating effect as reported by Wong, (1981) and Stevenson and Vance (1989) could be a reason for this. Sainz *et al*. (1998) reported the increased Ca, Mg, Cu and Zn in vermicompost treated soil. Also increased Ca content of tomato was registered by Premuzic *et al*. (1998).

5.5.2 Chemical properties of field soil over a period of six months

Soil samples were collected from a depth of 15 cm from the basins of treatment imposed plants and analyzed for the nutrient status and pH. VC applied and VC with PG-FA applied plants showed higher pH at three months stage, and then a gradual decline was noticed after sixth month stage. At sixth month stage VC alone and its combination with PG showed higher pH. So these results show that application of VC effectively increase the pH and sustain it, when compared to application of amendments alone. Application of slightly alkaline compost to an acidic soil increased the pH and they more effectively resisted pH change.

Transfer of protons from acid soil to organic material is the mechanism of amelioration (Wong *et al*., 1998). Moreover cations are complexes with organic anions and microbial oxidation of the anions in the soil resulted in the formation of alkalinity (Noble *et al*., 1996). PG-FA and PG-FA-VC combinations registered lower level of Al compared to PG, VC and PG-VC treatments.

But all the treatments are showed reduced level of Al as compared to control. Wong and Swift (1995) reported the increase soil pH and resulting lowered Al activity by organic matter application. Also addition of organic residues to soil is resulted in high pH and precipitation of soluble Al as recorded by many researchers (Hoyt and Turner, 1975; Hue 1992; Noble *et al*., 1996).

These results also point to the fact that organic materials are good in sustaining the beneficial effects derived by the ameliorants. In lateritic soils of acid nature, blending of PG with FA offers a potential solution and incorporating vermicompost rich in organic complexing agents further enhances the superiority of the material.

5.6 Influence of treatments on yield attributes of pepper vines in field experiment

Pepper spikes were harvested at eight months after treatment application. Biometric parameters like average length of spikes, number of berries per spike, weight of spikes per vine and number of spikes needed for 100g were recorded. The harvested berries were also subjected to chemical analysis.

Regarding yield responses, some treatments registered lower yield than control. Treatment T_9 (VC alone), T_3 (PG-FA at 20:1 ratio) and PG-FA blends at 30:1 with VC recorded significantly higher yield among the treated vines. T_3 recorded superiority in all yield parameters among the treatments. This may have been related to the increase of N and P contents in plants.

These results likewise were inversely related to the concentration of Al, Fe and Mn in both crop and soil. Similar result was obtained by Keefer *et al* (1988) in alfalfa and corn plants in green house condition. The application of fly ash with PG increased the yield effectively (Fig. 8d). Yield increases by application of VC were reported by Aracnon *et al*. (2004), Martens (1971) and Aracnon *et al*. (2006).

5.7 Influence of treatments on Nutrient Status of berries at the time of harvest

Chemical analysis of berries showed that P and Ca contents were increased, while Fe and Mn concentrations were reduced by application of PG and its blends with fly ash and content of K was increased by application of PG with vermicompost. Application of PG-FA-VC increased the N content but not significantly. Increases of N and K in plant tissues by application of VC were recorded by Sainz *et al*. (1998) and increased uptake of P and Ca by application of PG and FA was reported by Keefer *et al*. (1988) and Page *et al*. (1979).

Summary

6. SUMMARY

A study entitled "Amelioration of sub soil acidity and Aluminium toxicity in lateritic soils under black pepper" was carried out to investigate the extent of sub soil acidity and toxicity of Al present in lateritic soil and to evaluate the performance of Phosphogypsum (PG) blended with Fly ash (FA) and Vermi compost (VC) for its suitability in regulating pH, exchangeable Al, Fe and Mn concentration and also to evaluate the performance of promising blends on growth of pepper vines.

Phosphogypsum, a by-product from phosphoric acid plant was found to be effective in correcting the soil acidity in lateritic soil by reducing the exchangeable acidity especially the exchangeable Al content (Sumner, 1970; Reeve and Sumner, 1972). Since Ca in phosphogypsum is soluble and mobile, it can correct subsoil acidity even when applied to surface (Deepa, 2008; Alcordo and Recheigl, 1993).

Calcium rich coal combustion fly ash and other fly ash materials can be used as an amendment to neutralize soil acidity owing to oxides of Na, K and Ca content. But due to its high alkaline pH (12 - 13), its direct application on standing crop cannot be recommended. So this study was conducted blending the FA with PG. These blends were further evaluated by mixing it with vermicompost.

This study was conducted as three experiments. The first was as an incubation study, done in laboratory of the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Vellanikkara. A pot culture experiment at College of Horticulture, Vellanikkara was conducted at the second stage, and simultaneously a field experiment was conducted at Pepper Research Station, Panniyur.

Incubation study was conducted with five treatments. For this study, 300 g soil was incubated with PG and its blends with FA at 10:1, 20:1 and 30:1. The ameliorants were applied at rates equivalent to the lime requirement of soil with respect to Ca requirement. This study was conducted over a period of ninety days and soil samples were collected at fifteen days interval and examined for their pH and exchangeable cations such as Ca, Fe, Mn and Al.

Analysis of incubated soil samples revealed that amendment treated soils showed higher pH and mean exchangeable Ca content with reduced toxicity level of Fe, Mn and Al. Phosphogypsum did not show any improvement in increase of pH but it was effective in increasing Ca content initially. Among the PG-FA blends, the two blended at ratio of 10:1 showed significant superiority in reducing of Mn toxicity and 20:1 ratio blends maintained high pH throughout the period of ninety days. After 90 days, exchangeable Al was also analysed. The results indicated that all amendments treated soils showed reduction in Al toxicity and 20:1 ratio of PG-FA recorded superiority.

Based on the incubation study, pot culture experiment was done at the second stage, with ten treatments. The first four treatments were as such taken from the incubation experiment. The next four were combinations of these four treatments with VC at 1:1 ratio. Ninth treatment was VC alone and tenth was control.

Pot culture experiment was done with five kg of soil and the amendments and blends including vermicompost were surface applied. Ameliorants were applied based on the lime requirement. Pepper vines at three leaves stage were then planted and growth parameters observed. Biometric observations such as number of leaves, increase in shoot height and leaf area were recorded monthly upto a period of 6 months.

Analysed data of leaf number over a period of six months showed a steady increase in leaf number in all ameliorant treated plants and they were superior to control. Amendments blended with VC increased the leaf number. In case of increases in shoot height also, similar trend was observed and PG-FA-VC combination was superior. Regarding leaf area, PG applied plants showed higher effective width and length of leaves than others.

Leaf samples were collected at three months and at six months and analysed for nutrients. The data showed that VC and combination of PG-FA-VC treated plants registered higher contents of N, P and K among the treatments over a period of six months. However, P and K contents were lower than control at third month, and then increased at sixth month. Ca content increased significantly in all ameliorant treated plants but a reduction in Mg was observed.

Phosphogypsum and VC showed their effective beneficial role in reduction of Fe toxicity and they also sustained the low level of Fe upto a period of six months.

In the case of Mn content which was initially low, high concentration was reported at sixth month. Uptake of copper was enhanced by PG-FA-VC and similar trend was observed in Zn uptake also.

Soil samples were also collected three months interval upto a period of six months and the samples were subjected to chemical analysis to examine the chemical parameters such as pH, Ca, Fe, Mn and Al. The analysed data revealed that application of PG-FA increased the pH but its effectiveness was reduced at sixth month. Ca content was increased by all treatments but VC mixed combinations showed their superiority initially, but later, effectiveness decreased.

PG-FA and PG-FA-VC applied treatments registered lowest Fe and Mn contents but PG was superior in reduction of Mn toxicity. In the case of Al, same trend was noticed as that of Mn but PG-FA treated plants showed superiority in reduction of Al.

An field experiment was carried out at Pepper Research Station, Panniyur simultaneously with the pot culture experiment. This study was conducted with the same ten treatments. Five year old plants of two metre height were selected for the study. These plants were treated with the amendments based on the lime requirement of pepper vines. Both soil samples and plant samples were collected at three months intervals up to a period of six months and chemical analysis was done.

Leaf samples of the treated plants were collected from the field of Panniyur Research Station and were analysed for their nutrient contents. The results showed that all ameliorant treated plants registered significantly higher contents of N and P than control. Nitrogen content significantly increased after three months and declined at sixth month. A similar trend was observed in P content also. K content increased or decreased, but no clear trend was noticed. Initially PG registered highest concentration of K among the treatments but it was at par with control. After six months some improvement was observed in that PG-FA-VC blended at (30:1):1 and PG-VC blend at 1:1 ratio applied plants showed significant increases in K levels.

In the case of Ca content, FA treated plants showed reduction in Ca content but PG-VC and VC applied plants showed higher content of Ca in leaves. Mg also showed a similar trend and here vermicompost containing treatments showed beneficial effect. This could be possible by chelating the Ca and Mg with organic complexes and their subsequent steady release to plants. Most of the treatments reduced the Fe toxicity to a great level than control. VC treated plants showed highest efficiency in reduction of Fe content followed by VC blended ameliorants.

Soil samples were collected at three months interval up to six months after treatment application. Sampling was done at 15 cm depth from the surface to evaluate the subsoil pH and nutrient status such as that of exchangeable Ca, Fe, Mn and Al. Chemical analysis showed that PG and PG-FA treated plants registered significantly lower pH than control. But vermicompost treated plants showed increase of pH which was sustained up to six months.

In case of Ca content, PG treated soil registered low Ca level at three months but after six months it seemed to increase. VC treated plants showed higher level of Ca at third month stage than at sixth month. PG-FA and PG-VC-FA applied plants showed significantly higher Ca than others at three months and PG-FA-VC treated plants sustained high Ca level up to six months. Regarding Fe and Mn, their toxicity was rapidly reduced in ameliorant treated plants. VC alone and its blend with PG-FA combination showed better results by reducing Fe toxicity at third month but after six months PG-VC and PG-FA combinations showed more effective reduction of Fe toxicity than other treatments.

The same trend was observed in Mn content after six months. PG and PG-FA combinations treated plants registered reduction in Mn content over a period of 6 months. PG recorded effective reduction of exchangeable Mn content at third month and it sustained its effect over a period of six months as compared to PG-FA treated plants and any other ameliorant applied plants. Regarding Al content, PG-FA combination showed rapid reduction in exchangeable Al content over a period of six months.

Pepper berries were harvested eight months after treatment application and yield characters such as weight of whole harvested spikes per plant, number of spikes required for 100 g of spikes, number of berries per spike and average length of spikes were recorded and analysed statistically.

PG-FA blended at 20:1 ratio registered higher yield than any other treatment. This treatment showed superiority in all other yield parameters also. It registered less number of spikes required for 100 g of spikes and also more number of berries in single spike and highest average length of spike. PG-FA combination and its blends with VC also recorded less number of spikes required to make up 100 g of spikes.

Harvested berries were subjected to chemical analysis and the results showed that PG-VC at 1:1 followed by PG-FA-VC registered higher N content than others. P content seemed to increase significantly with PG application among the treated plants. PG-VC at 1:1 ratio showed highest K content and PG-FA at 10:1 and 20:1 ratios registered highest Ca content. Lowest Fe and Mn contents were recorded with PG-FA application and Cu uptake was enhanced by application of PG-VC combination blended at 1:1 ratio. A similar trend was observed in Zn uptake also.

Future line of works

1. PG is also a good source of SO_4. In the future trials the beneficial role of S, applied through PG has to be evaluated.
2. The enhanced root performance has to be measured by suitable techniques.
3. Beneficial effect of S on soil micro flora also has to be studied
4. Effect of heavy metals and radio nuclides in PG and fly ash has to be monitored.

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* Original not seen

Appendices

APPENDIX I

Pooled analysed mean value for incubated soil over a period of 90 days after incubation

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI
Ca (mg kg^{-1})						
T_1	1063	1083	1125	1094	1070	1077
T_2	907	1087	1085	1098	1091	1097
T_3	1102	1118	1075	1127	1063	1108
T_4	1064	1150	1076	1095	1052	1080
T_5	299	299	303	310	303	303
CD (0.05)	243	69	196	57	26	63
Fe (mg kg^{-1})						
T_1	1.8	1.7	1.9	2.1	1.5	1.3
T_2	1.7	1.9	1.7	2.4	2	1.1
T_3	2.5	2.1	2	1.7	2.7	1.1
T_4	1.5	1.7	2	2.2	2	1.1
T_5	170	182	192	188	199	199
CD (0.05)	11.3	2.2	3.3	3.4	3.8	3.2
Mn (mg kg^{-1})						
T_1	98.9	90.3	107.5	101.1	89.5	97.7
T_2	73.1	53.4	64.2	55	40.1	43.8
T_3	96.5	98.6	102.7	97.2	105.4	112.5
T_4	91.2	85	98.9	85	96.4	100.3
T_5	496.3	504	502	508	504	304
CD (0.05)	11.3	18.9	23	19.8	35.6	0.12
pH						
T_1	4.5	4.5	4.1	4.3	4.4	4.9
T_2	5	4.8	4.5	4.7	4.8	5.2
T_3	4.9	4.9	4.6	4.7	4.9	5.3
T_4	4.8	4.8	4.5	4.7	4.8	5.2
T_5	4.7	4.7	4.6	4.6	4.6	4.5
CD (0.05)	0.09	0.09	0.1	0.18	0.18	0.12

APPENDIX II

Pooled analysed mean value for pot cultured leaves samples over a period of six months

Treatments	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean
	N (%)			P (%)			K (%)			Ca (%)			Mg (%)		
T_1	2.4	2.2	2.3	0.28	0.25	0.265	1.5	2.7	2.1	2	3.1	2.55	0.055	0.05	0.0525
T_2	2.4	2.3	2.35	0.31	0.27	0.29	1.9	3.4	2.65	2.4	2.8	2.6	0.054	0.05	0.052
T_3	2.4	2.2	2.3	0.26	0.25	0.255	2.4	2.4	2.4	1.7	2.3	2	0.052	0.06	0.056
T_4	2.4	2.3	2.35	0.29	0.25	0.27	2.1	3.1	2.6	2.5	2.7	2.6	0.054	0.07	0.062
T_5	2.2	2.1	2.15	0.41	0.34	0.375	2.4	3	2.7	2.4	2.8	2.6	0.051	0.09	0.0705
T_6	3	2.5	2.75	0.3	0.26	0.28	1.9	3.7	2.8	1.9	2.5	2.2	0.05	0.07	0.06
T_7	2.5	2.5	2.5	0.32	0.32	0.32	2.8	3.2	3	1.8	2.9	2.35	0.053	0.09	0.0715
T_8	2.4	2.3	2.35	0.25	0.2	0.225	1.9	2.2	2.05	3	2.3	2.65	0.055	0.05	0.0525
T_9	1.8	1.8	1.8	0.33	0.25	0.29	3.8	3.3	3.55	2.6	2	2.3	0.055	0.11	0.0825
T_{10}	1.9	1.9	1.9	0.73	0.29	0.51	3.3	2.5	2.9	1.3	2.8	2.05	0.051	0.12	0.0855
Mean	2.34	2.21		0.348	0.268		2.4	2.95		2.16	2.62		0.053	0.076	
CD (0.05)	0.27	0.26		0.12	0.29		0.97	0.12		0.5	0.03		NS	NS	
SE	-	-		-	-		-	-		-	-		0.001	0.003	

Pooled analysed mean value for pot cultured leaves samples over a period of six months

Treatments	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean
	Fe (mg kg^{-1})			Cu (mg kg^{-1})			Mn (mg kg^{-1})			Zn (mg kg^{-1})		
T_1	620	604	612	66	8	37	140	342	241	40	32	36
T_2	900	1334	1117	93	8	50.5	113	412	262.5	38	26	32
T_3	673	1542	1107.5	40	16	28	93	370	231.5	53	22	37.5
T_4	600	1048	824	33	10	21.5	100	582	341	46	25	35.5
T_5	900	932	916	40	12	26	113	516	314.5	38	23	30.5
T_6	853	907	880	33	18	25.5	73	468	270.5	27	27	27
T_7	860	726	793	40	10	25	93	494	293.5	29	33	31
T_8	840	750	795	33	10	21.5	106	654	380	32	28	30
T_9	1060	976	1018	120	8	64	140	536	338	42	26	34
T_{10}	1320	1338	1329	120	14	67	106	996	551	61	27	44
Mean	862.6	1015.7		61.8	11.4		107.7	537		40.6	26.9	
CD (0.05)	360	13.9		47	4		NS	5.7		NS	5	
SE	-	-		-	-		15.6	-		10	-	

APPENDIX III

Pooled analysed mean value for pot culture soil samples over a period of six months

Treatments	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean
	pH			Ca (mg kg^{-1})			Fe (mg kg^{-1})			Mn (mg kg^{-1})		
T_1	5.6	5.5	5.55	855	801	828	61	200	130.5	151	423	287
T_2	6.1	5.7	5.9	850	708	779	71	159	115	148	553	350.5
T_3	6.4	5.9	6.15	865	845	855	75	156	115.5	162	434	298
T_4	6.2	5.7	5.95	850	803	826	69	156	112.5	166	648	407
T_5	6.1	5.7	5.9	830	733	781	55	153	104	157	530	343.5
T_6	6	5.7	5.85	862	734	798	91	146	118.5	233	671	452
T_7	6	5.7	5.85	854	749	801	92	149	120.5	245	582	413.5
T_8	5.9	5.5	5.7	852	733	792	97	152	124.5	275	740	507.5
T_9	5.7	5.6	5.65	763	614	689	96	150	123	255	527	391
T_{10}	6	5.4	5.7	784	628	706	88	165	126.5	247	527	387
Mean	6	5.64		836	627		79.5	158.6		203.9	563.5	
CD (0.05)	0.3	NS		54	90		12.2	NS		NS	149	
SE	-	0.1		-	-		-	16.3		42.6	-	

APPENDIX IV

Pooled analysed mean value for field leaves samples over a period of six months

Treatments	Initial	3 MAP	6 MAP	Mean	Initial	3 MAP	6 MAP	Mean	Initial	3 MAP	6 MAP	Mean
	N (%)				P (%)				K (%)			
T_1	1.6	2.1	1.9	1.87	0.1	0.16	0.13	0.13	1.8	1.9	1.1	1.60
T_2	1.3	2.1	1.9	1.77	0.11	0.14	0.16	0.14	1.9	1.6	1	1.50
T_3	2.3	2.4	1.8	2.17	0.13	0.12	0.14	0.13	1.7	1.2	0.5	1.13
T_4	2	1.9	1.9	1.93	0.12	0.08	0.14	0.11	1.5	1.8	0.9	1.40
T_5	1.7	2.3	1.8	1.93	0.09	0.2	0.1	0.13	1.4	1.9	0.7	1.33
T_6	1.7	2.2	2.1	2.00	0.11	0.2	0.12	0.14	1.7	1	1.3	1.33
T_7	1.5	2.3	2	1.93	0.1	0.14	0.22	0.15	1.3	0.8	1.9	1.33
T_8	2.2	2	1.7	1.97	0.12	0.12	0.16	0.13	1.8	1.7	1.8	1.77
T_9	1.7	2.2	2.1	2.00	0.1	0.13	0.11	0.11	1.3	1.8	1.4	1.50
T_{10}	1.9	1.9	2	1.93	0.1	0.13	0.14	0.12	1.4	1.9	1.7	1.67
Mean	1.79	2.14	1.92		0.108	0.142	0.142		1.58	1.56	1.23	
CD (0.05)		NS	NS			NS	NS			NS	0.32	
SE		0.19	0.14			0.02	0.02			0.32	-	

APPENDIX IV

Pooled analysed mean value for field leaves samples over a period of six months

Treatments	Initial	3 MAP	6 MAP	Mean	Initial	3 MAP	6 MAP	Mean
	Ca (%)				Mg (%)			
T_1	0.74	1.2	0.7	0.88	0.04	0.02	0.03	0.03
T_2	0.7	1.1	1.4	1.07	0.01	0.02	0.03	0.02
T_3	0.78	1	1.1	0.96	0.02	0.02	0.03	0.02
T_4	2	1.8	1.2	1.67	0.02	0.02	0.03	0.02
T_5	1.72	2	1.1	1.61	0.02	0.04	0.03	0.03
T_6	1.15	1	1.2	1.12	0.01	0.01	0.03	0.02
T_7	1.4	1.2	1.7	1.43	0.01	0.02	0.03	0.02
T_8	1.6	1.9	2.3	1.93	0.03	0.03	0.04	0.03
T_9	1.5	1.5	2.2	1.73	0.01	0.02	0.04	0.02
T_{10}	2	1.7	2	1.90	0.01	0.04	0.04	0.03
Mean	1.359	1.44	1.49		0.018	0.024	0.033	
CD (0.05)		NS	0.74			NS	NS	
SE		0.31	-			0.01	0.003	

APPENDIX IV

Pooled analysed mean value for field leaves samples over a period of six months

Treatments	Initial	3 MAP	6 MAP	Mean	Initial	3 MAP	6 MAP	Mean	Initial	3 MAP	6 MAP	Mean	Initial	3 MAP	6 MAP	Mean
	Fe (mg kg^{-1})				Cu (mg kg^{-1})				Mn (mg kg^{-1})				Zn (mg kg^{-1})			
T_1	240	302	146	229.33	10.7	510	486	335.57	462	332	360	384.67	26	27	18	23.67
T_2	140	205	206	183.67	4.7	367	600	323.90	240	298	420	319.33	14	20	22	18.67
T_3	193	141	333	222.33	10	358	533	300.33	322	215	453	330.00	23	15	26	21.33
T_4	197	288	240	241.67	8.7	500	193	233.90	448	269	386	367.67	20	31	25	25.33
T_5	192	252	126	190.00	8	812	266	362.00	495	534	346	458.33	20	60	24	34.67
T_6	256	155	106	172.33	8	366	466	280.00	441	360	466	422.33	22	24	32	26.00
T_7	252	188	113	184.33	8	472	460	313.33	437	339	606	460.67	29	43	29	33.67
T_8	172	262	126	186.67	7.3	661	733	467.10	388	456	600	481.33	29	40	50	39.67
T_9	196	276	113	195.00	4	474	620	366.00	500	342	646	496.00	21	16	25	20.67
T_{10}	288	268	120	225.33	4.7	727	846	525.90	608	462	566	545.33	19	12	26	19.00
Mean	212.6	233.7	162.9		7.41	524.7	520.3		434.1	360.7	484.9		22.3	28.8	27.7	
CD (0.05)		NS	NS			NS	NS			NS	NS			NS	NS	
SE		49.9	65.6			127	129			96	79			13.6	6.7	

APPENDIX V

Pooled analysed mean value for field soil samples over a period of six months

Treatments	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean	3 MAP	6 MAP	Mean
	pH			Ca (mg kg^{-1})			Fe (mg kg^{-1})			Mn (mg kg^{-1})		
T_1	5.6	5.6	5.6	760	859	809	24	15	19.5	96	75	85.5
T_2	5.6	5.7	5.65	823	865	844	24	14	19	114	98	106
T_3	5.5	5.5	5.5	861	868	864	22	16	19	109	81	95
T_4	5.7	5.8	5.75	896	872	884	22	12	17	97	82	89.5
T_5	6.2	5.8	6	877	861	868	18	22	20	117	89	103
T_6	5.6	5.6	5.6	867	889	877	11	16	13.5	135	231	183
T_7	5.5	5.6	5.55	907	853	880	15	17	16	174	245	209.5
T_8	5.9	5.9	5.9	914	870	892	17	10	13.5	182	210	196
T_9	6.3	5.9	6.1	861	838	849	14	20	17	166	254	210
T_{10}	5.7	6	5.85	779	817	816	8	12	10	122	227	174.5
Mean	5.76	5.74		854	863		17.5	15.4		131.2	159.2	
CD (0.05)	0.46	0.25		62	NS		9	NS		42	NS	
SE	-	-			77		-	3.1		-	23.6	

AMELIORATION OF SUBSOIL ACIDITY AND ALUMINIUM TOXICITY IN LATERITIC SOILS UNDER BLACK PEPPER

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ABSTRACT

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ABSTRACT

Sub soil acidity due to high level of exchangeable Al is a major root growth inhibiting chemical barrier in lateritic soils. Black pepper is extensively grown in such soils. Surface applied liming materials of conventional nature do not offer any solution to this and deep placement of liming materials is also not viable. Soluble Ca forms like phosphogypsum (PG) when applied on surface effectively get leached and reduce the Al^{3+} in bottom layers. But PG has an acidic pH and its direct application on standing crops produce initial undesirable effects.

Phosphogypsum, a by-product from phosphoric acid plant, was found to be effective in correcting the soil acidity in lateritic soil by reducing the exchangeable acidity especially the exchangeable Al content (Sumner, 1970; Reeve and Sumner, 1972). Since Ca in phosphogypsum is soluble and mobile, it can correct subsoil acidity, even when applied to surface (Deepa, 2008; Alcordo and Recheigl, 1993).

Fly ash (FA), a similar by-product of industrial units that use solid fuel in their furnaces, is good soil amendment (Renken *et al*., 2006). But owing to its high alkaline pH (12 - 13) its direct application on standing crops cannot be recommended. In the present investigation, PG and FA were first characterised for their properties and blended at different ratios and evaluated. The PG-FA blends of 10:1, 20:1 and 30:1 ratios had desirable properties and were further utilized for the study.

The whole investigation was carried out as three experiments. In the first stage an incubation experiment was done by combining PG with FA at three ratios *viz*., 10:1, 20:1 and 30:1 and applied to soil samples at rates equivalent to lime application dose with respect to Ca content. The samples were incubated at 50 per cent field capacity moisture level and samples were drawn at 15 days intervals upto 90 days and examined for various properties like pH, exchangeable Ca, Fe and Mn.

After 90 days, exchangeable Al was also analysed. The results indicated that in treatments with FA, pH values were significantly higher up to the 90 days period. The exchangeable Ca contents were significantly lower for the PG-FA blends than PG alone treatments initially, but after 30 days all the treatments were at par, and significantly superior to

control. These treatments were equally effective in decreasing exchangeable Fe, Mn and Al contents during the period of study.

The results indicated the over all superiority of the PG-FA blends among which PG-FA at 20:1 ratio stood superior with respect to reduction of Mn and maintenance of high pH. Fly ash blending, though it reduced the Ca content initially, made good after thirty days, and its favourable pH makes its ideal for over all effect.

Based on the suitability of PG-FA blends, a pot culture experiment was conducted in the second stage with ten treatments. The treatments consisted of four ameliorants, *i.e.* PG and three PG-FA blends, mixtures of these four with equal quantities of Vermicompost (VC), VC alone and an absolute control.

The treatments were imposed on pots filled with five kg of soil at rates equivalent to liming rate for pepper. Biometric observations were made at monthly intervals upto six months and leaf and soil samples were collected at three months stage and six months stage for chemical analysis. From the biometric observations recorded, the six months mean data indicated that ameliorant treated plants were superior to control with respect to growth.

Mixing of vermicompost with ameliorants showed some superiority, which was significant only in a few months. The ameliorants blended with vermicompost showed better performance for increase in shoot length. With respect to the nutrient content of leaves, N content of leaves significantly increased in all ameliorant treated plants as compared to control and the highest value was recorded for PG-FA blends combined with vermicompost.

The leaf P content, though it decreased initially, increased at six months stage. A similar trend was noticed for leaf K also. The treatment also helped in reducing Fe and Mn content of leaves. Exchangeable Zn contents, though decreased, never went below critical limit of 20 ppm. The soil analysis also revealed the beneficial effect of reducing Fe, Al and Mn contents in soil upto 6 months period.

In the third part, an investigation was carried out at Pepper Research Station, Panniyur with the same ten treatments as that of the pot culture experiment. Leaf and soil samples were collected and analysed for their nutrient status at three months intervals upto six months. Also, biometric characters and yield attributes were recorded at the time of harvest.

Nitrogen and phosphorus contents of leaves were increased in PG-FA-VC treated plants and Ca and Mg content of leaves were enhanced by PG-VC and VC alone. Though K content was decreased by some treatments, PG-VC at 1:1 and PG-FA-VC recorded superior values for K content. Vermicompost alone and PG-FA-VC applied plants showed significantly reduced Fe content and Cu uptake improved by 30:1 PG-FA treatment. Plants treated with PG-FA-VC helped in reducing the toxic effect of Mn and PG-VC treated plants showed improved Zn content.

In case of soil exchangeable nutrients such as Fe, Al and Mn, content was reduced and pH was increased in treatment applied soils. Phosphogypsum and PG-FA helped in reduction of Fe and Mn toxicity and Al toxicity was reduced by PG-FA applied plants. However, where vermicompost alone was applied such an effect was not seen.

After eight months of treatment application, observation of yield characters such as weight of spikes per plant, number of spikes required for 100 g weight, number of berries per spike and length of spike were recorded.

The berries were also subjected to chemical analysis to evaluate their nutrient status. PG-FA combination blended at 20:1 ratio showed increase in yield and number of spikes as well as number of berries. Length of spikes increased by PG-FA-VC treatments. Combination of PG-FA-VC registered lower number of spikes that were required for 100g weight. Vermicompost also helped in yield improvement of pepper vines.

With regard to nutrient status of berries, P, K and Ca contents increased significantly in ameliorant treated plants and N content was increased by 1:1 PG-VC treatment. Iron and Mn toxicity was reduced by PG-FA treatment. Zinc uptake was also enhanced by application of 1:1 PG-VC.

From the results it could be concluded that the PG-FA blends are better ameliorants than their separate application with respect to pH increase and reduction of Fe, Mn and Al concentrations. Mixing the blends with vermicompost further enhances their superiority.