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Evaluation of Plant Residues on the Mobility of Surface Applied Lime

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ABSTRACT

Greenhouse experiments were conducted with leaching columns (60 cm long by 15 cm diam.) of disturbed acid soil to evaluate the effect of plant residues on the mobility of surface-applied calcite lime in the soil profile. Plant residues were: black oats, rye, mucuna, leucaena, and wheat straw at a rate of 40 Mg ha^{-1}. Lime and plant residues were applied on soil surface and after an irrigation program equivalent to 1500 mm rainfall per year the following observations were made: pH, exchangeable Ca, Mg, K, and Al and the chemical composition of drainage water. Effect of lime without plant residues was limited to the upper 10 cm profile. Lime with plant residues changed pH, Ca, Mg, and Al in the soil profile. The efficiency of plant residues on lime mobility followed the order: black oats > rye > mucuna > leucaena. Wheat residue had no effect on the mobility of lime. The decrease in Al, Ca and Mg in the upper layer of the profile was followed by an increase in K. Metal-organic complexe reactions were assumed to be the main mechanism on lime mobility through plant residues.

Key words: Subsoil acidity, Ca leaching, green manure

INTRODUCTION

Large areas in Brazil contain acid soils and some of which have subsoil acidity with toxic levels of aluminum (Al) and deficient amount of calcium (Ca). These chemical characteristics restrict root proliferation and the major consequence is drought stress (Ritchey et al., 1982). The efficacy of surface applied lime on alleviating subsoil acidity is uncertain. In some cases no effect was observed (Gonzales-Erico et al., 1979; Pavan et al., 1984), in others was rapid (Wright et al., 1985; Oliveira and Pavan, 1996). This apparent contradiction in the way in which lime moves in soil are nothing new. This state of confusion has persisted for the last fifty years. Many strategies have been used to speed up the mobility of surface applied lime, such as: physical incorporation with machinaries (Farina and Channon, 1988), inorganical with acid input (Adams and Pearson, 1969) and with gypsum (Schainberg et al., 1989) and organical (Wright et al., 1985).

Recent studies have demonstrated that lime applied on soil surface with high amount of plant residues serving as mulch, moved down to subsurface layers increasing pH and Ca and decreasing Al (Pavan and Miyazawa, 1998; Miyazawa et al., 1999; Ziglio et al., 1999). This technique with organic plant residue has an especial interest due to high production of biomass of the main crops used in several agricultural system in Brasil (Calegari et al., 1993; Chaves et al., 1997). The objective of this study was to

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evaluate the effect of plant residues on the mobility of surface applied lime.

MATERIAL AND METHODS

Acid soil samples taken from the 0-20cm horizon were air-dried and passed through a 2mm sieve. The soil had an original pH-$CaCl_2$ value of 4.0; exchangeable Al, Ca, Mg, and K contents of 1.9, 2.1, 1.0, and 0.4 cmol dm^{-3}, respectively; organic carbon content of 30.9 g kg^{-1}; and clay, silt, and sand contents of 750, 100, and 150 g kg^{-1}, respectively. The soil was a Typic Haplorthox (U.S. Soil Taxonomy). Soil samples were transferred to PVC columns (60 cm high by 15 cm diameter) and compacted to a homogeneous bulk density (mean 1 g cm^{-3}).

The treatments were: control (without lime and plant residue); lime without plant residue; lime with black oats (*Avena strigosa*); lime with rye (*Secale cereale*); Lime with gray mucuna (*Stizolobium cinereun*); lime with leucaena (*Leucaena leucocephala*), and lime with wheat straw (*Triticum aestivum*). Black oats, rye, gray mucuna and leucaena were collected at flowering stage and wheat straw after grain's harvest. Plant materials were dried at 65°C for 48 h and ground to pass 1mm sieve. Table 1 shows the chemical composition of the plant materials.

Table 1 - Chemical composition of the plant materials.

Plant residues	Chemical composition ($g\ kg^{-1}$)				
	N	P	K	Ca	Mg
Black oats	26.6	2.2	42.2	2.0	2.0
Rye	7.7	2.6	27.6	3.0	2.0
Leucaena	40.9	1.7	13.0	13.4	3.6
Mucuna	25.6	1.6	44.8	7.3	2.8
Wheat straw	14.2	0.5	4.0	2.7	1.5

Plant materials and lime were applied at rates equivalent to 40 and 3 Mg ha^{-1} of dry weight, respectively. Plant materials and lime were applied on the soil surface without any physical incorporation. The irrigation program was: 1000 ml of water per column per week (soil's water holding capacity or porous volume, pV), equivalent to 60 mm of rainfall, during 24 weeks, with a total of 24000 ml of water per column, equivalent to 1500 mm of rainfall per year. During the irrigation period, drainage water was collected weekly, measured and analyzed for pH, Ca, Mg, and K. At the end of the experiment plant materials and lime particles remaining on the soil surface were removed and soil samples were collected at 0-5, 5-10, 10-20, 20-30, 30-40, and 40-50 cm depth. Soil samples were air-dried, ground to pass 2 mm sieve and analyzed for pH $CaCl_2$, exchangeable Ca, Mg, K, and Al (Pavan et al, 1992).

RESULTS

The curves of Figures 1 and 2 indicate the effects of treatments on soil composition. These figures show the effects of treatments control, lime on bare soil, lime with black oats (the most efficient plant material), and lime with wheat straw (least efficient plant material). The others plant materials (rye, mucuna, and leucaena) presented intermediate effects between black oats and wheat straw. The effects of surface lime application on bare soil without plant residues on pH, Ca, Mg, K, and Al were limited to the upper 5-10 cm layers. These results confirmed the low mobility of lime in variable charge soil with low input of organic material, corroborating data presented in previous studies (Gonzalez-Erico et al., 1979; Pavan et al., 1984). The effect of plant residue on lime mobility was highly variable and depended on plant species.

Except wheat straw the other residues changed the soil pH and the concentrations of Ca, Mg, K, and Al in the soil profile. The soil pH increased, Ca and Mg decreased, and K increased mainly in the 0 to 30 cm layers. The reductions in Ca and Mg were, 64 and 68% for black oats and 62 and 70% for rye, respectively. Changes in soil chemical composition under wheat straw were of 8% decreased for Ca and 7% increased for Mg. The reductions in Ca and Mg were 600 and 90 mg per column, respectively, in the presence of black oat residue in the 0 to 20 cm layer of the soil. Considering that the total Ca and Mg inputs were 2140 mg/column (2000 mg from $CaCO_3$ + 140 mg for black oat residue) and 140 mg/column (black oat residue), respectively, it was expected increases in Ca and Mg. However, black oats markedly decrease Ca and Mg in the 0-30 cm layer. Similar effect was observed for rye, mucuna, and leucaena residues. The concentration of Al decreased mainly in top 0-10 cm surface layer. Black oats showed the highest effect on decreasing subsurface Al.

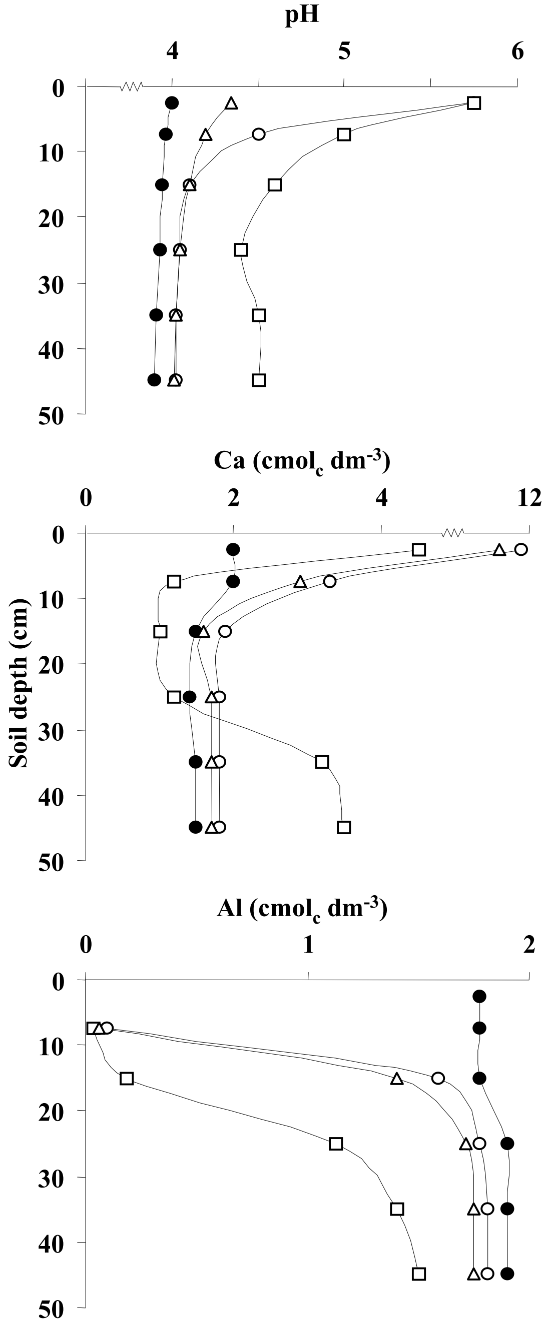

Figure 1 - Soil pH and exchangeable Ca, and Al distribution with depth following surface lime and plant material applications. ●—● control; ○—○ lime; □—□ lime + Oats; and △—△ lime + wheat.

The decrease in Ca, Mg, and Al followed an increase in K, mainly in the 0-20 cm layer. Black oats and rye residues showed the highest increase in K (Fig. 2). Black oats utilization resulted an increase of 340% of K in the 0-5cm layer of the soil in relation to the control.

Fig. 3 shows the chemical composition of the effluent solution. The total Ca, Mg, and K leached out in the control soil were 1.11, 0.82 and 0.07 mmol kg^{-1}, respectively. Lime without plant residue and lime with wheat straw showed solution drainage composition similar to the control soil.

On the other hand, the presence of black oat residue showed high Ca and Mg leaching. Under organic system Ca and Mg appeared first with maximum peak at 2 pV and K showed maximum peak at 4 pV (Fig. 3). The total Ca, Mg and K leached under lime with black oat treatment were, respectively 645, 265 and 726 mg/column. Assuming that the total Ca, Mg, and K added with back oats were 140, 140, and 2950 mg/column, it can be concluded that some Ca from lime and Ca and Mg from soil exchangeable sites were also leached out.

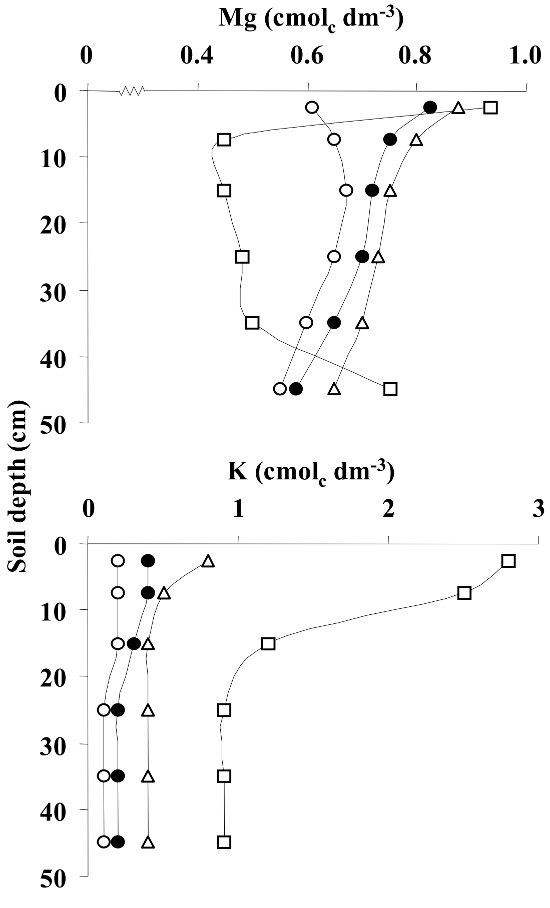

Figure 2 - Exchangeable Mg and K distribution with depth following surface lime and plant material applications. ●—● control; ○—○ lime; □—□ lime + Oats; and △—△ lime + wheat.

DISCUSSION

The dissolution of $CaCO_3$ in acid soil forms a cation (Ca^{2+}) and two anions (OH^- and HCO_3^-), being the HCO_3^- very unstable due to its decomposition in CO_2 and H_2O. Therefore, $CaCO_3$ reacs completely if the soil remains acid. The chemical neutralization of the subsurface acidity occur only if the basic anions are transported in the mass flow. The problem is that in the mass flow there are acid cations such as H^+, Fe^{2+}, Al^{3+} and Mn^{2+} (Lewis hard acids) which react with basic anions (Lewis soft bases) stopping the alkaline front. Thus, it is expected that while acid cations exist in soil solution the alkalinity is not transferred to the subsoil layers.

The equilibrium between alkaline and acidity is achieved in the pH range from 5.2 to 5.6 due to the insolubility of Fe^{2+}, Al^{3+} and Mn^{2+} ions and the parcial neutrality between HCO_3^- and H^+ (Helyar, 1991). Thus it is expected that the alkalinity front of the soil surface applied lime will move into the subsurface layers only under pH > 5.6 where the concentrations of HCO_3^-, OH^-, and CO_3^{--} increase logarithmically. Lime mobility is more complicated in variable charge soils where the alkaline front is also used to neutralize the acidity of the negative sites (pH-dependent) on the colloidal surface. Under this condiction the mobility of Ca^{2+} is restricted due to its high electrochemical attraction by the pH-dependent negative charges. Pavan and Roth (1992) observed that although lime increased exchangeable Ca, the soil solution Ca was not changed in the pH range from 4 to 6. Soil solution Ca increased under pH > 6 only. They concluded that the low soluble Ca concentration in the pH range from 4 to 6 was due to higher negative charge density on the soil colloidal surface.

On the other hand, in the presence of selected plant residue the mobility of lime was quite rapid. These results indeed supported the view that soluble organic compounds released from the plant residue contained carboxyl (-COOH) and phenolic (-OH) groups which reacted with basic and acid cations allowing the mobility and the capability of detoxifying acid subsoils.

The decrease in Ca and Mg was followed an increase in K. Probably the organic ligands released from the plant residues showed more affinity for Ca^{2+} and Mg^{2+} than K^+. It is important to understand that under inorganic system K^+ is the first cation to be leached followed by Mg and Ca.

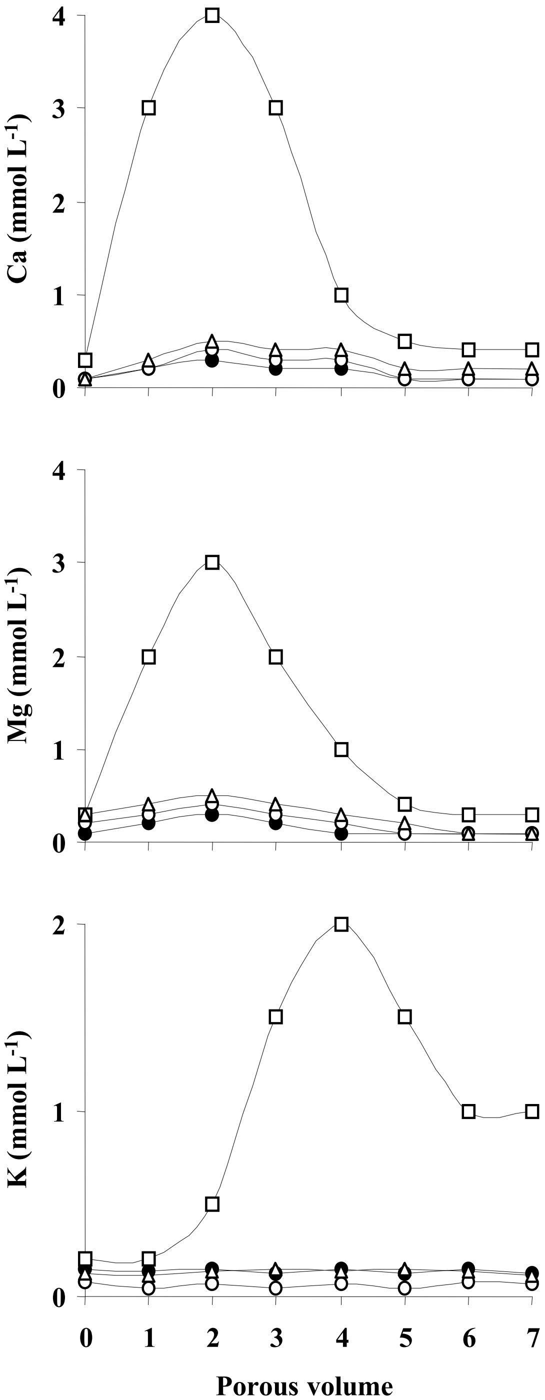

Figure 3 - Concentration of Ca, Mg, and K in the drainage solution following surface lime and plant material applications. ●—● control; ○—○ lime; □—□ lime + Oats; and △—△ lime + wheat.

The minimal effect of wheat residue on the mobility of cations in soil may be due to its lower concentration in organic acids (Pierre and Banwart, 1973). Apparently, the hydrolysis of Ca^{2+} and Mg^{2+} organic complexes it was not observed because pH and Al were unchanged in subsurface layers. The risk of Ca^{2+} and Mg^{2+} removed from the root zone could be minimized through crop rotation. The mobility of Ca^{2+} and Mg^{2+} with organic ligands appear to occur like uncharged complexe (ML^{o}) or negatively charged complexe (ML^{-}). The following reaction is proposed:

$$M(H_2O)_x^{m+} + L^{n-} \Leftrightarrow ML^{(mn)} + H_2O$$

where M = metal, L = ligand, m and n = metal and ligand valences, respectively.

Because of the soil used presented net negative charge, these soluble metal-organic complexes have their leaching facilitated. Thus, where organic strategy is adopted, surface lime can move in the soil profile alleviating subsoil acidity.

RESUMO

A baixa mobilidade do calcário aplicado na superfície do solo diminui sua eficiência na redução da acidez subsuperficial. Foram estudados os efeitos de alguns resíduos orgânicos sobre a mobilidade do calcário calcítico aplicado na superfície do solo em colunas de PVC (60 cm de altura por 15 cm de diâmetro). Avaliaram-se resíduos de aveia preta, trigo, centeio, mucuna cinza e leucena na dose equivalente a 40 Mg ha^{-1}. Adicionaram-se os resíduos vegetais e o calcário na superfície do solo e, após um programa de irrigação equivalente a 1500 mm de chuva por ano, avaliaram-se o pH e os teores de Ca, Mg, K e Al trocáveis no solo e solúveis na água efluente. O efeito do calcário sem resíduos vegetais limitou-se aos primeiros 10 cm de profundidade. Os resíduos vegetais quando aplicados junto com o calcário aceleraram os transportes de Ca e Mg na seguinte ordem: aveia > centeio > mucuna > leucena. O resíduo de trigo não afetou o pH e a mobilidade do Ca e do Mg no solo. As reduções nos teores de Ca e Mg do solo foram acompanhadas por aumentos no teor de K. A formação de complexos organo-metálico hidrossóluveis provavelmente foi o principal mecanismo envolvido nas lixiviações de Ca e Mg após a aplicação de calcário e resíduos vegetais na superfície do solo.

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