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Surface liming and nitrogen fertilization for crop grain production under no-till management in Brazil

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ABSTRACT

Supplying a large amount of NO_3^- in the subsurface can be a strategy to combat subsoil acidity under no-till systems. However, soil acidification caused by ammoniacal fertilizers can increase both aluminum toxicity and lime requirement. A field experiment was performed in the period from 2004 to 2012 in Parana State, Brazil, on a loamy, kaolinitic, thermic Typic Hapludox to evaluate the effects of surface liming and ammoniacal fertilization on soil chemical attributes and yields of crops in rotation under continuous no-till. The region has a mesothermal, humid subtropical climate, with mild summer, frequent frosts during the winter, and no defined dry season. The average altitude is 970 m and the annual precipitation is about 1550 mm. The treatments consisted of annual applications of NH_4NO_3 at 0, 60, 120, and 180 kg N ha^{-1} to subplots within plots with surface-applied lime previously at 0, 4, 8, and 12 Mg ha^{-1}, calculated to raise the base saturation in the topsoil (0–20 cm) to 40, 65, and 90%. Lime was broadcast on the soil surface in May 2004. The nitrogen rates were applied during the period from 2004 to 2011 in top dressing at tillering of winter crops [black oat (*Avena strigosa* Schreb.) or wheat (*Triticum aestivum* L.)], before growing corn (*Zea mays* L.), soybean (*Glycine max* L. Merr.) or bean (*Phaseolus vulgaris* L.) during the summer (2004–2012).

Surface-applied lime under no-till was effective in alleviating soil acidity from the soil surface to a 20 cm depth. The soil pH increased in the layers below the soil surface to 20 cm depth during a 6 years period following surface lime application. Ammoniacal fertilization had an acidifying effect and did not change the effectiveness of surface applied lime to alleviate subsoil acidity. Soil organic matter content was higher in the upper few centimeters under no-till and remained unchanged over time after surface liming and ammoniacal fertilization. Increasing the rate and frequency of ammoniacal fertilizer application increased crop response to surface liming, but did not change the lime requirement to achieve higher crop grain yields. The lime rate estimated by the soil base saturation method at 70% in the 0–20 cm depth was appropriate for surface liming recommendation, even when substantial amounts of ammoniacal fertilizer were applied in a no-till system. The results suggest that nitrogen fertilizer use for winter crops could be dramatically reduced in areas under a continuous no-till system, particularly where lime has been applied.

1. Introduction

No-till systems have stood out as one of the most effective strategies to improve the sustainability of agriculture, and to minimize soil and nutrient losses by erosion, in tropical and subtropical regions (Lal, 1995; Hobbs et al., 2008). No-till is defined as a system of seeding crops into untilled soil by opening a narrow slot, trench or band only of sufficient width and depth to obtain proper seed coverage; no other soil tillage is done (Phillips and Young, 1973). Residues from previous cash crops or green manure cover crops should remain undisturbed on the soil surface after seeding. Crop rotation and cover crops are essential practices that need to be applied in this system (Derpsch et al., 2010). The extent of no-till adoption worldwide is just over 111 million hectares (Mha) (Derpsch et al., 2010). The growth of the area under no-till has been especially rapid in South America, where some countries such as Argentina, Brazil, Paraguay and Uruguay are using this system on about 70% of the total cultivated agricultural area (Derpsch et al., 2010). In Brazil, the cultivated agricultural area under no-till has rapidly increased to 32 Mha. Brazil continues to be one of the leading countries in the world in terms of adoption of the no-till system. Green manure cover crops are often used on no-till in Brazil and

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many farmers are convinced that they are a must in this cropping system.

Soil acidity limits crop yield in extensive areas in the world. Calcium deficiency and aluminum toxicity are considered a major yield-limiting factors of tropical and subtropical acid soils (Coleman and Thomas, 1967). Soil pH plays a dominant role in determining the solubility of aluminum in the soil (Ayres et al., 1965). Besides, the amount of aluminum in the soil solution is related to the percent Al^{3+} saturation of the effective cation exchange capacity (CEC) (Kamprath, 1970). However, because of complexing of aluminum by organic matter, soils with increasing organic matter content have a lower content of soil solution aluminum at a given pH (Evans and Kamprath, 1970). Thus, the higher organic matter contents in topsoil layers under no-till compared with soils cultivated under conventional systems (Bayer et al., 2000; Rhoton, 2000; Amado et al., 2006) have provided a natural buffer against low pH and aluminum toxicity (Ismail et al., 1994; Brown et al., 2008; Alleoni et al., 2010). Studies have suggested that aluminum toxicity is low in no-till systems only during cropping seasons that have adequate and well-distributed rainfall. With unfavorable rainfall conditions, the toxicity of aluminum severely compromises root growth and yield (Caires et al., 2008a; Joris et al., 2013). Because aluminum toxicity is greater during drought periods and also because aluminum-sensitive genotypes are compromised by soil acidity, even with adequate soil moisture (Joris et al., 2013), surface application of lime is an effective and important practice to maximize crop grain yields under no-till systems (Caires et al., 2005, 2008a; Joris et al., 2013).

Surface liming ameliorates topsoil acidity over a relatively short-term period, but it is generally slow to neutralize subsoil acidity, particularly in variable-charge soils (Ernani et al., 2004). Long-term no-till systems are known to cause chemical stratification, including pH, where high pH levels are formed in the upper few centimeters of the soil profile (Caires et al., 2005; Godsey et al., 2007). Movement of lime to depth depends on the leaching of salts throughout the soil profile. Sumner (1995) summarized many experiments where lime was surface applied. The review indicated that changes in subsoil pH and Ca^{2+} were slow with lime additions when no- or little-acidic nitrogen fertilizer was applied.

Ammoniacal fertilizers are used as the nitrogen source in most agricultural systems. Increases in soil acidification as a result of the nitrification of ammoniacal fertilizers have been well documented (Ayres et al., 1965; van Breemen et al., 1983; Ismail et al., 1994; Bowman and Halvorson, 1998; Conyers et al., 2003; Sumner and Noble, 2003). Application of lime with ammoniacal fertilizers can neutralise the acidifying effect and stimulate nitrification in acid soils (Weligama et al., 2010b; Garbuio et al., 2011). So, the surface application of lime can increase the possibility of downward movement of exchangeable Ca^{2+} and Mg^{2+}, which accompanies NO_3^- anions (Ridley et al., 2001; Crusciol et al., 2011). The uptake of NO_3^- by plants can increase the rhizosphere pH in subsoil provided that roots are established in deeper layers (Tang et al., 2000, 2011; Weligama et al., 2010a,b). Although supplying a large amount of NO_3^- in the subsurface can be a strategy to combat subsoil acidity (Weligama et al., 2010b; Tang et al., 2011), soil acidification caused by ammoniacal fertilizers can increase both aluminum toxicity and lime requirement.

This study reports a field trial that examined the effects of surface application of lime and ammoniacal fertilization on soil acidity, production of black oat biomass as a cover crop and grain yields of corn, soybean, wheat, and bean in rotation under a long-term no-till system. We hypothesized that: (i) the depth of change in soil pH increases with time after applying lime to the surface, (ii) application of lime with ammoniacal fertilizer is an efficient strategy to combat subsoil acidity, and (iii) increasing the rate and frequency of ammoniacal fertilizer application increases the surface-applied lime requirement to achieve higher crop grain yields.

2. Materials and methods

2.1. Site description and soil

The experiment was carried out in Ponta Grossa, PR, Brazil (25°10′S, 50°05′W), on an oxisol (loamy, kaolinitic, thermic typic hapludox). According to Köppen–Geiger System (Peel et al., 2007), the climate at the site is categorized as a Cfb type (mesothermal, humid, subtropical), with mild summer and frequent frosts during the winter. The average altitude is 970 m with average maximum and minimum temperatures of 22 and 13 °C, respectively. The annual precipitation is about 1550 mm. Table 1 shows the results of chemical, particle-size distribution and mineralogical analyses of the topsoil (0–20 cm) in May 2004 before the establishment of the experiment. The experimental area was converted from grassland vegetation (Campos) to crop production in 1969. In the period from 1969 to 1978, three crops of rice and seven double crops (wheat in the winter and soybean in the summer) were cultivated under conventional tillage. A continuous no-till system was established in 1978, and during the period from 1978 to 2004 were cultivated wheat, triticale or black oat in the winter and soybean or corn in the summer. No-till involved no disturbance to the soil other than the sowing operation.

2.2. Experimental design, treatments, and crop studies

A randomized complete block design was used, with three replications in a split-plot arrangement. Plot size was 26.0 by 6.4 m and subplot size was 6.5 by 6.4 m. The treatments consisted of annual applications of NH_4NO_3 at 0, 60, 120, and 180 kg N ha^{-1} to subplots within plots with surface-applied lime previously at 0, 4, 8, and 12 Mg ha^{-1}. The lime rates were calculated to raise the base saturation in the topsoil (0–20 cm) to 40, 65, and 90%. The dolomitic

Table 1
Results of chemical, particle-size distribution and mineralogical analyses of the topsoil (0–20 cm) in May 2004 before the establishment of the experiment in Ponta Grossa, Southern Brazil.

Attributes	Results
pH (1:2.5 soil:0.01 mol l^{-1} $CaCl_2$ suspension)	4.1
Total acidity pH 7.0 (H + Al) (mmol$_c$ dm^{-3})	110
Organic matter (g dm^{-3})	31
P (Mehlich-1) (mg dm^{-3})	6
Exchangeable cations (mmol$_c$ dm^{-3})	
Ca^{2+}	5
Mg^{2+}	5
K^+	1.7
Al^{3+}	12
Effective cation exchange capacity (ECEC) (mmol$_c$ dm^{-3})	23.7
Cation exchange capacity pH 7.0 (CEC) (mmol$_c$ dm^{-3})	121.7
Base saturation (%)[a]	10
Al^{3+} saturation (%)[b]	51
Particle-size distribution (g kg^{-1})	
Clay	295
Silt	240
Sand	465
Mineralogical composition (g kg^{-1})	
SiO_2	162
Al_2O_3	136
Fe_2O_3	46
Kaolinite	266
Goethite	27
Hematite	2

[a] Base saturation = 100 (Ca^{2+} + Mg^{2+} + K^+/CEC pH 7.0).
[b] Al^{3+} saturation = 100 (Al^{3+}/ECEC).