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Short Communication

Dicyandiamide enhances liming potential of two legume materials when incubated with an acid Ultisol

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ABSTRACT

The incorporation of two legume materials increased soil pH, while the nitrification of the ammonium–nitrogen (N) from the ammonification of organic N weakened the liming potential of these materials at the later stages of incubation experiments. The addition of dicyandiamide (DCD) enhanced the liming potential of the two legume materials through its inhibition of nitrification of ammonium-N. At the end of the 60-d incubation, soil pH of the treatment using Chinese milk vetch shoots with DCD was 1.48 units higher than that of control and 1.16 units higher than of the treatment using only Chinese milk vetch. The corresponding data for the pea straw were 1.24 and 1.01 units higher, respectively.

Large areas of acid soils are distributed in subtropical regions of southern China and around the world. Aluminum (Al) toxicity and infertility are two important factors limiting plant growth in these acid soils. In recent years, it was observed that some plant materials including crop straws can directly neutralize the soil acidity (Noble et al., 1996; Yan et al., 1996; Pocknee and Sumner, 1997; Noble and Randall, 1999; Tang et al., 1999; Xu and Coventry, 2003), but the liming potential of these plant materials in acid soils depends on the properties of both plant materials and soils. Generally, legume materials contain relatively higher ash alkalinity and organic N and so induce larger increases in soil pH than non-legume materials (Wang et al., 2009). However, some investigators reported that when acid soils were incubated with legume materials, soil pH increased early in the incubation followed by an apparent decrease at later stages, due to nitrification of ammonium (NH_4^+) ions produced in mineralization of organic N earlier in the incubation (Yan et al., 1996; Tang et al., 1999; Xu and Coventry, 2003; Xu et al., 2006; Yan et al., 2006). Legumes accumulate higher amounts of organic anions during their growth than non-legumes, and hence possess greater ash alkalinity and liming potential for remediation of soil acidity. However, legume materials contain a large amount of organic nitrogen (N), which is easily mineralized to NH_4^+–N and then to NO_3^- and NO_2^- through nitrification. Therefore, the nitrification of NH_4^+ produced in mineralization of organic N may somewhat counteract the amelioration effect of legume materials in acid soils. Hence, nitrification limits the role of legume materials in amelioration of acid soils. Inhibiting nitrification of NH_4^+, after incorporation of legume materials into acid soils, will likely enhance their amelioration effects.

In this study, an Ultisol collected from the suburb of Yingtan, Jiangxi Province, China was employed for incubation experiments to investigate the effect of dicyandiamide (DCD) on liming potential of two legume materials. A sample taken from the top layer (0–10 cm) was air-dried, and then ground to pass a 2-mm sieve. The soil pH was 4.54 as determined in a 1:2.5 soil:water suspension. The content of soil organic matter determined by the dichromate method was 25.7 g kg^{-1}, soil total N determined by Kjeldahl method was 1.19 g kg^{-1}, and the soil cation exchange capacity (CEC) measured by ammonium acetate method was 8.72 $cmol_{(+)}$ kg^{-1}. These soil measurements were conducted with the methods suggested by Pansu and Gautheyrou (2006). pH buffer capacity of the soil was 18.90 mmol kg^{-1} pH^{-1}, determined using the method of Aitken and Moody (1994). Pea straw and the shoots of Chinese milk vetch (CMV) were used in this study, since CMV is normally used as a green manure in southern China and pea straw is easy to obtain in the region. Both legumes have high ash alkalinity and N concentration, and can be used to correct soil acidity

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(Wang et al., 2009). Plant materials were obtained locally, oven-dried at 80 °C and then ground to powder.

The ash alkalinity of the plant materials was determined with a modified titration method (Slattery et al., 1991). Of ground plant material, 2.0 g was heated at 200 °C for 1 h, and then at 500 °C for 4 h in a muffle furnace. The ash of the sample was dissolved in 25 mL of 1.0 M HCl, and then titrated by a standardized solution of 0.25 M NaOH to obtain ash alkalinity. The total carbon and N concentrations of the plant materials were determined at 1200 °C using a Leco CN-2000 analyzer (LECO Corporation, St. Joseph, Michigan, USA). After digestion in HNO_3–$HClO_4$, the calcium (Ca) and magnesium (Mg) of plant materials were determined by atomic absorption spectrophotometry (AAS), and potassium (K) and sodium (Na) by flame photometry. The elemental compositions and ash alkalinity of the plant materials are provided in Table 1.

Each of 350.0 g air-dried soil samples was mixed with 7.0 g of the plant materials and 17.5 mg of DCD in plastic pots, and then wetted with deionized water to obtain 70% of the field water-holding capacity. Treatment without DCD addition was also prepared for comparison. There were three replicates for all treatments including one soil sample without addition of plant material and DCD as a control. Each of pots was covered and a small hole was made to allow gas exchange but minimize moisture loss (Xu and Coventry, 2003). The incubation was conducted at a constant 25 °C. Soil moisture was adjusted every 3 d throughout the experiment duration. Sub-samples were taken from each replicate for pH and N determinations at specified intervals throughout the incubation period. The incubation lasted for 60 d, and then the remaining soil samples were removed from the pots, air-dried, and ground to pass a 1-mm sieve for the measurements of soil exchangeable Al and exchangeable base cations.

The exchangeable acidity (H^+ and Al^{3+}) was extracted with 1.0 M KCl, and then titrated with 0.025 M NaOH; added 10 mL of 1 M KF in 25 mL extractant, the mixed solution was titrated by 0.025 M NaOH to obtain exchangeable H^+; the difference between exchangeable acidity and exchangeable H^+ is exchangeable Al^{3+} (Pansu and Gautheyrou, 2006). The exchangeable base cations were extracted with 1.0 M ammonium acetate (Pansu and Gautheyrou, 2006). Ca and Mg were measured by AAS, and K and Na by flame photometry. The soil $NO_3^- + NO_2^-$ and NH_4^+–N were extracted by 2.0 M KCl using 1:5 soil:solution (Pansu and Gautheyrou, 2006), and the NH_4^+–N was determined by the indophenol blue colorimetric method, the $NO_3^- + NO_2^-$ by UV spectrophotometry.

The data of soil pH, NH_4^+–N and $NO_3^- + NO_2^-$ are reported as means ± standard errors of the analytical replicates. One-way analysis of variance (ANOVA) was used to detect differences between treatments. Multiple comparisons of means used least significant difference (LSD) at $P < 0.05$, following the one-way ANOVA. The SPSS 15.0 software package was used for statistical analysis.

The dynamics of soil pH during the incubation of an Ultisol with CMV shoots, and CMV shoots with DCD, are presented in Fig. 1 along with the control. Soil pH for the control soil decreased with increased incubation time until 30 d, followed by smaller change thereafter. Nitrification of soil NH_4^+-N in the control soil led to declining soil pH during the incubation due to release of protons

Table 1
Concentrations of elements and ash alkalinity of plant materials used.

Plant material	Ash alkalinity	Ca	Mg	K	Na	Total base cations	Total C	Total N
	(cmol kg^{-1})	(g kg^{-1})					(g kg^{-1})	
CMV	87.0	5.46	0.54	9.39	0.21	15.60	438.7	43.9
Pea straw	61.6	3.46	0.78	10.60	0.15	14.99	430.3	36.2

CMV: Chinese milk vetch shoots.

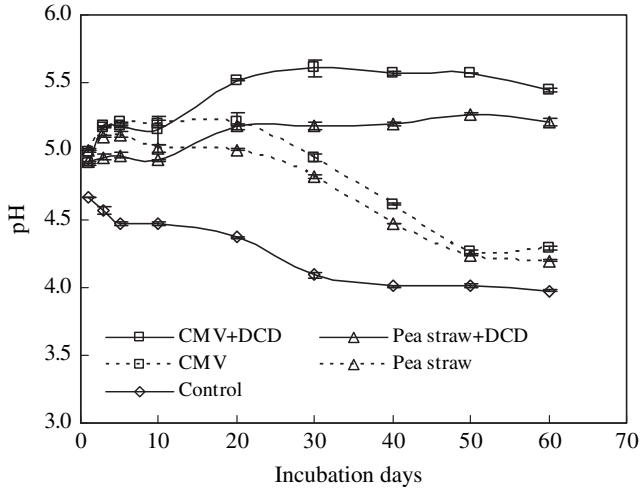

Fig. 1. Effect of DCD on soil pH during the incubation with CMV shoots and pea straw incorporated (CMV: Chinese milk vetch shoots; DCD: dicyandiamide). Standard error of each point is shown with a bar.

(H^+) from nitrification in the soil, which will be supported by the experimental data obtained (next section).

The soil incubated with CMV shoots showed a significant increase in pH with increased incubation time at the early stage ($P < 0.01$), this change became less pronounced during 10–20 d of incubation. Moreover, after 20 d, soil pH decreased sharply with increased incubation time up until 50 d ($P < 0.01$) and then changed only slightly. At the end of the incubation (i.e. 60 d), the soil pH was 0.32 units higher than that of control. The dynamics of soil pH during the incubation were consistent with a previous report (Xu and Coventry, 2003).

When soil was incubated with CMV shoots + DCD, the dynamics of soil pH differed from the control and CMV shoot treatments. Soil pH for the CMV shoots + DCD treatment increased with incubation time until 30 d and reached an almost steady-state thereafter. During the initial 10 d of incubation, the soil pH for the CMV shoot treatment was similar to that of the CMV shoots + DCD treatment; however, after 10 d, the difference between the two treatments increased with incubation time ($P < 0.01$), with higher pH for the CMV shoots + DCD treatment. At the end of incubation in the CMV shoots + DCD treatment, soil pH was 1.48 units higher than the control and 1.16 units higher than the CMV shoot treatment. Therefore, the addition of DCD enhanced the liming potential of CMV shoots in the acid soil.

Similarly, soil pH for the pea straw treatment increased with incubation time up until 5 d ($P < 0.01$) and then decreased slightly; however, after 20 d the soil pH decreased sharply until 50 d ($P < 0.01$) followed by very slight change (Fig. 1). At the end of incubation, soil pH was 0.23 units than the control. However, in the presence of DCD, pea straw led to continuous increase in soil pH during incubation. Although soil pH for the pea straw + DCD treatment was lower than the pea straw treatment until 10 d of incubation, beyond this period it was higher than the pea straw treatment ($P < 0.01$); this difference increased with increased incubation period ($P < 0.01$). At the end of incubation for the pea straw + DCD treatment, soil pH was 1.24 units higher than the control and 1.01 units higher than the pea straw treatment. Thus, addition of DCD greatly enhanced the liming potential of pea straw in the acid soil.

When soil was incubated with CMV shoots, the content of soil NH_4^+–N increased with the incubation time ($P < 0.01$), and reached its maximum 30 d and then decreased; however, it changed little