Research Article

Erigeron annuus (L.) Pers., as a Green Manure for Ameliorating Soil Exposed to Acid Rain in Southern China

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Abstract

Background, Aims, and Scope. Increasing soil acidification is a growing concern in southern China. The traditional green manures applied in the fields mostly comprise legumes that tend to accelerate soil acidification. Moreover, acid deposition can act as a source of nitrogen (N). Hence, we looked for new plant species that would enhance nutrient concentrations when used as green manure and would reduce soil acidity or at least not worsen it.

Materials and Methods. We studied the use of *Erigeron annuus* (L.) Pers. for ameliorating acid soil in a pot experiment with simulated acid rain (SAR) treatments (pH 5.8 to 3.0) in an open area in Guangzhou City. The pots were divided into two groups named A and B groups. On day 0, pots of A group were filled with soil and planted with *Erigeron annuus* seedlings. Pots of B group were only filled with soil as the control. On day 40, seedlings of *Erigeron annuus* were harvested and buried in the corresponding pots. On day 54, two seeds of *Phaseolus vulgaris* L. were sown in each pot in both groups. The growth and bean yield of *Phaseolus vulgaris* seedlings were then used to evaluate the effects of *Erigeron annuus* on acid soil. Plant and/or soil samples were collected on day 0, day 40, day 54 and day 150, corresponding parameters were measured.

Results. Results showed that *Erigeron annuus* could maintain a good growth even on very acid soil. On the day 40, the pH decreased significantly ($P < 0.0001$) in the B group pots without *Erigeron annuus* compared with the A group. On the day 54 after *Erigeron annuus* was buried as a manure, the soil pH of all A group treatments except the pH 4.0 treatment showed a significant increase compared to the day 40 ($P <0.01$). At the same time, the application of *Erigeron annuus* as a manure produced a significant increase of soil K and P ($P < 0.001$), Ca ($P < 0.05$) and Mg ($P < 0.001$) concentrations of all A group SAR treatments compared to their B group counterparts (except control pots for Ca). The soil exchangeable K and available P concentration doubled and Ca and Mg increased by around 25 % in the presence of the *Erigeron annuus* manure application.

Discussion. The higher soil pH in the A group than B group on the day 40 was due to a great absorption of NO_3^- by the roots of *Erigeron annuus*. The soil pH increase after the *Erigeron annuus* was applied to the soil of A group was attributed to the release of high amount of K, the mineralization of organic N and the oxidation of organic acid anions. Nutrient increase in the A group after *Erigeron annuus* application was mostly the result of the nutrient release during the residue decomposition. The amelioration of the soil was effective as demonstrated by the enhanced growth and bean yield of *Phaseolus vulgaris* seedlings on the manured soil compared to the seedlings grown on a control that was not manured.

Conclusions. *Erigeron annuus* could maintain a good growth in the acid lateritic field soil. Cultivating this plant and applying it to the soil with a rate of 1.6 t ha^{-1} doubled the soil K and P concentrations and increased soil exchangeable Ca and Mg concentrations by around 25 %. This species would be a good green manure candidate for growing in the acid soils of southern China. Application of *Erigeron annuus* also has beneficial effects on crop growth through reduced Al toxicity and cation leaching.

Recommendations and Perspectives. Since *Erigeron annuus* would improve soil pH and nutrient concentrations with minimum care, it is recommended for treating acid soils with poor yield whenever a lowcost solution is required.

Keywords: acid deposition, acid soil, *Erigeron annuus* (L.) Pers., green manure, phytoremediation

1 Background, aim and scope

Soil acidification has been a serious problem in China. After comparing soil data from the 1970's and the 1990's obtained in several locations from southern China, Pan (1992) and Dai et al. (1998) found that soil pH had decreased by 0.1 to 1.0 unit. Soil acidification is mostly due to acid deposition of sulfur and nitrogen oxides in southern China (Liao et al. 1998). In a fast developing country like China, the traffic is expected to increase and thus the emissions of gaseous NO_x. The same happens to the SO_2 emissions from coal-fired power plants although policies are being implemented to restrict them. Acid deposition in China is likely to become stronger and extend to larger areas which may result in further soil acidification in the future (Larssen et al. 2000; Busch et al. 2001; Xue et al. 2003).

Acting to reverse soil acidification is possible. The methods generally undertaken imply the supply of organic residues to the soil that will consume H^+ through decarboxylation reactions during decomposition (Yan et al. 1996; Tang et al. 1999). Moreover, organic acid anions from vegetable organic residues appear to have the ability to detoxify Al by complexing the metal (Patiram 1996). The amount of organic acid anions in plant residues can be measured as the ash alkalinity, which is the concentration of excess cations to anions in the plant material (Pierre and Banwart 1973). Methods of applying organic residues include application of animal residues (Lungu et al. 1993), plant residues (Noble et al. 1996) and addition of paper pulp sludge (Voundi et al. 1999). Another set of methods consists of adding large amounts of base cations that are usually depleted in acid soils and deficient for the plant growth. These methods are liming (Pierce and Warncke 2000; de Andrade et al. 2008) and addition of wood ash (Voundi et al. 1999). However, animal manures have environmental side effects (nitrate pollution) and the cost of liming is too high for most of the farmers in southern China.

In China, most of the green manures in use are part of the legume family. They are used to enrich the soil N content as most crops require large supply of this nutrient. However, high aerial deposition of N oxides occurs in southern China and we can expect it to act as natural N fertilizers (Fabian et al. 2005). Moreover, where N fertilizer was intensively used alone in the past, other major nutrients like K and P have become the limiting factors for plant growth (Gao et al. 2006). Although the acidification is supposedly nil when the carbon cycle is complete, the monsoon climate let us expect a net soil acidification with legume manures in this area as a consequence of high nitrate leaching (Dolling 1995). This limits the use of legumes as manures in southern China. Our aim in this work was to find a good method that would help to alleviate the soil acidity problem. We chose to study *Erigeron annuus* (L.) Pers. (*Erigeron*) as a new green manure to reverse soil acidification. *Erigeron* is already scarcely used and seems to have a benefit on crop growth. And *Erigeron* is a common herbaceous species in China that is known for accommodating a broad range of soil pH. It is inexpensive, has a fast growing cycle and does not require much care. In this experiment we assessed whether *Erigeron* complied with the following requirements when it was cultivated in an agricultural soil: (1) sustaining a good growth in very acid soils exposed to simulated acid rain (SAR), (2) enhancing soil base cation nutrient content and (3) decreasing the soil acidity or at least not increasing it.

2 Materials and methods

2.1 Experimental design and sample collection

Erigeron is an annual plant species from the composite family. It is found in arable lands, pastures and wastelands over large areas in southern China. The study was carried out in Guangzhou City, Guangdong Province, 23°20′ N and 113°30′ E. The mean annual temperature is 21.5 °C, the precipitations range from 1600 to 1900 mm and the mean relative humidity is 77 %.

On 11March 2003 (Day 0), we collected *Erigeron* plants with a height around 8 cm from a field near the research area and transplanted them into ceramic pots (30 cm diameter, 19 cm height and three plants per pot). In order to avoid damages to the root tips, seedlings were collected and transplanted without removing the soil around their roots. The remaining volume of pots was filled with field soil collected in the same place from the 0-10 cm layer that showed the lowest pH values. The soil was a typical agricultural acid lateritic soil in southern China. No fertilizer had been supplied to this field before the seedling collection. The concentrations of major soil elements at the collection time were assessed and shown in Table 1.

Table 1

The pots were divided into two even groups: 30 A group (*Erigeron* treatment) pots received *Erigeron* seedlings and 30 B group (*Erigeron* control) pots were left bare as a control. The pots were then put in an open area where they were exposed to the natural rain. The rainfall was about 40 mm during the first part of the experiment that lasted for 54 days. From 11 March 2003 (Day 0) to 4 May 2003 (Day 54), pots of both A and B group were sprayed every five days with 600 ml of one of the four simulated acid rain (SAR) solutions or rain water as a control (SAR control). This means that each pot received about 6 mm rainfall. We considered that this would not have extra effects on the plants natural growth. Pots were arranged in a randomized complete block design made with 6 blocks and 10 treatments per block (5 SAR treatments for A and B group each). The SAR solutions were prepared using the same rain water that we used for the SAR control which pH was adjusted to one of the following values using an acid mix made of H_2SO_4 and HNO_3 in a 1:1 mole ratio: pH 3.0, 3.5, 4.0 and 4.4. The use of these acids to get the SAR solutions was dictated by their high contribution to acid rains in southern China (Liao et al. 1998). As a consequence, SAR solutions also acted as N and S fertilizers and no fertilizer was added to the SAR control in accordance to the rain element concentrations in southern China. No other fertilizer was added. The composition of the basified rain water for SAR preparation is shown in Table 1. Because most acid rains in the area have a pH of 4.35 and we expect that the rain acidity will increase in the future, we chose our values for the SAR pH to start around the lowest pH values observed in the natural rain and then decrease by steps of 0.5 units. Moreover, we showed in a previous study (Liu et al. 2007) that severe soil acidification on similar soil occurs only when applying SAR with a pH of 3.0.

On 20 April 2003 (Day 40), pot soil was sampled with three 2-cm diameter cores from the upper soil layer (0-10 cm) in both groups and their pH was measured. The investigation was limited to the upper soil as the plant roots did not reach the lower layer. At the same time, all seedlings of the A group were harvested and weighted and 20 g of fresh weight for each pot (all plant parts) were kept aside to measure the dry biomass and element concentrations in the plants. Remaining plant parts (around 80 g fresh weight) were chopped (into about 1cm small parts) as soon as the samples were collected then they were buried evenly from surface to 10 cm in their respective pots. Hence, the application rate of the green manure was about 11.32 ton/ha. On 4 May 2003 (Day 54), a visual examination showed that the applied plant residues had completely disappeared. The upper 10 cm of soil was again sampled for pH measurements and element analyses. After this, two seeds of *Phaseolus vulgaris (Phaseolus)* were sown in each pot. The difference in the productivity of *Phaseolus* plants between the A and B group pots was a direct assessment of *Erigeron* ability to enhance soil nutrients for cultivating other species. *Phaseolus* is an important crop species in China that is susceptible to the soil acidity. The plants were watered to the field capacity with rain water and no fertilizer was supplied to them. Their productivity was measured after three months of growth (Day 150) as the plant biomass per pot (sum of root and shoot biomass, pod biomass excluded), the number of bean pods per pot and the dry weight per pod.

2.2 Soil analyses

The rain water pH was determined with a glass electrode. The water Ca, Mg, Fe, Cu and Mn concentrations were measured by atomic absorption spectrometry (GBC932AA, GBC Scientific Equipment, Australia) and Na and K concentrations by flame emission photometry. Al was determined using Inductively Coupled Plasma - Atomic Emission Spectrometer (ICP-AES) (Optima2000). NO_3^- concentrations were determined by the phenol disulfonic acid spectrophotometric method (Nicholas and Nason 1957), SO_4^{2-} concentrations by the barium sulfate gravimetric method (APHA Standard Methods, 20th ed., Method 4500-SO4 D, 1998) and P concentrations by the stannous chloride method (APHA Standard Methods, 20th ed., Method 4500-P D, 1998).

The dry weight of *Erigeron* and *Phaseolus* seedlings and bean pods was determined after they were washed in de-ionized water and dried for three days at 70 °C in an oven. The dried *Erigeron* plant tissues were grounded to a powder using a stainless-steel mill (30 Hz, 30 s). Plant total N, S and P concentrations were determined photometrically after tissue powder was digested using K_2SO_4-H_2O_2 (N and P) or HNO_3-$HClO_4$ (S). *Erigeron* total Ca and Mg after powder incineration and total K after powder digestion using K_2SO_4-H_2O_2 were measured by ICP-AES.

Soil samples were air dried and sieved to pass a 2 mm mesh and plant residues were picked out. Soil pH was determined with a glass electrode in the supernatant after shaking for 2 h and sedimentation in a beaker for 24 h with 0.1 mol L^{-1} KCl (soil to extractant 1:2.5). The exchangeable K^+, Ca^{2+} and Mg^{2+} were extracted with a 1 mol L^{-1} ammonium acetate solution adjusted to pH 7.0 and the extracted Fe, Mn, Zn and Cu with a 1 mol L^{-1} HCl solution (1:10 soil to extractant, 30 min shaking). Element concentrations in the extracts were determined by atomic absorption spectrometry. The soil reactive Al was extracted by the oxalate/oxalic acid method (Lofts et al. 2001) and measured by ICP-AES. Soil NO_3^- was extracted using a 10 mmol/L $CaSO_4$ solution with a 1:5 soil to extractant ratio and soil for SO_4^{2-} determination was dissolved in water (soil water ratio of 1:5) then filtered. Soil available P was extracted with a solution containing 25 mmol L^{-1} HCl and 30 mmol L^{-1} NH_4F (soil to extractant 1:7). NO_3^-, SO_4^{2-} and P concentrations in the extracts were measured by the same methods used for rain water.

Erigeron total cation uptake was calculated as the sum of K, Ca, Mg, Fe, Cu, Mn and Al concentrations in the plant tissues and total anion uptake as the sum of N, S and P. Cl was not taken into account so total anion uptake may be underestimated and Na uptake is negligible in non halophyte plants. The concentration of excess cations was calculated as the difference of charges $\{K^{+}+Ca^{2+}+Mg^{2+}\}$ - $\{SO_4^{2-}+H_2PO_4^{-}\}$ assuming that most of the nitrogen uptake is available in the plants as organic N (Noble et al. 1996).

2.3 Statistical analyses

Data analysis was carried out using the SAS software (SAS Institute Inc., Cary, USA, version 8.0). We chose α to be equal to 0.05. We analysed the *Erigeron* seedling weight and leaf element concentrations on day 40 as a function of the SAR treatment using ANOVA and Tukey multiple comparison test (HSD). The effect of the SAR treatment and the *Erigeron* treatment on the soil parameters on day 40 and 54 and on the *Phaseolus* seedling growth and yield on day 150 were analysed with a general linear model and Tukey multiple comparison test performed on the least square means. In order to determine which soil improvement affected most the *Phaseolus* growth, the seedling growth and yield on day 150 were analysed with a general linear model as a function of soil pH and soil element concentrations on day 54. Before being used for analysing *Phaseolus* results, soil element concentrations were summarized using a principal component analysis that gave the following result. The first three eigenvector explained 83 % of the total soil element variance. The first vector correlated positively with K, Ca, Mg and P. The second vector correlated positively with Fe and Cu and negatively with Al. The third vector correlated positively with Mn.

3 Results

3.1 *Erigeron* parameters

The SAR spray only caused direct damage to *Erigeron* leaves in the pH 3.0 treatment (yellow dots). The SAR had significant effects on *Erigeron* (Table 2). Seedling dry weight was 10 % greater in the pH 4.4, 4.0 and 3.5 treatments than in other SAR treatments ($P < 0.05$). It was not different between the control and pH 3.0 treatment. In plant tissues, total N and S increased ($P < 0.01$ and $P < 0.05$, respectively) when the pH of the SAR decreased. Other element concentrations did not change significantly. Nutrient uptake by *Erigeron* seedlings was clearly dominated by the anions ($P < 0.001$) and the ratio of total cation uptake over total anion decreased when the pH of the SAR decreased ($P < 0.05$). The concentration of cation charges in the plant material was greater than that of anion charges ($P < 0.001$), resulting in an excess concentration of cations. The excess cation concentration was lower in the pH 3.5 and pH 3.0 treatments ($P < 0.01$).
Table 2

3.2 Soil parameters

On the day 40, there was no pH difference between A and B group soils in the control (Fig. 1). Compared to the control, the pH decreased significantly ($P < 0.0001$) in the B group pots with SAR treatment. The decrease reached up to 0.2 pH units in the pH 3.0 treatment. Compared to the control, the pH also decreased significantly in the A group pots ($P < 0.001$) however the decrease was limited to 0.05 pH unit and there was no difference between the pH 4.0, 3.5 and 3.0 treatments. For every treatment except the control, the pH was higher in the A group after 40 days of *Erigeron* growth ($P < 0.001$) compared to their B group counterparts. On the day 54 after *Erigeron* was buried as a manure, the soil pH of all A group treatments except the pH 4.0 treatment showed a significant increase compared to the day 40 ($P < 0.01$), up to 0.05 pH unit more (Fig. 1). After the application of the manure, all SAR treated soils reverted to the original pH of the field soil. At the same time, the pH values in the B group pots decreased (not significantly) compared to the day 40 (not shown).
Fig. 1
Fig. 2 shows the results for the soil element analyses carried out on the day 54 after *Erigeron* had been buried as a green manure. In the B group pots, soil K, Mg and Ca concentrations decreased when the acidity of the SAR treatment increased ($P < 0.05$ for K and Mg, $P < 0.01$ for Ca). In the A group, Mg and Ca showed the same results whereas K was not affected by the SAR treatment and P showed a decrease only in the pH 3.0 treatment ($P < 0.01$). The application of *Erigeron* as a manure produced a significant increase of soil K and P ($P < 0.001$), Ca ($P < 0.05$) and Mg ($P < 0.001$) concentrations of all A group SAR treatments compared to their B group counterparts (except control pots for Ca). The soil exchangeable K and available P concentration doubled and Ca and Mg increased by around 25 %. When comparing the SAR control pots of both A and B group with the soil before the experiment, it appears that the nutrient concentrations in the B group SAR control pots were not different from the soil before experiment while in the A group SAR control pots showed doubled K and P concentrations ($P < 0.001$) as well as greater Ca and Mg concentrations (not significant).
Fig. 2

On the day 54, the soil K concentrations were positively correlated with *Erigeron* seedlings K concentration ($P < 0.01$, $r^2=0.88$) and soil Ca and Mg concentrations correlated negatively with the soil pH ($P < 0.05$, $r^2=0.73$). The soil P correlated negatively with the soil pH and reactive Al concentration (($P < 0.05$ and $P < 0.01$, $r^2>0.8$). But it correlated positively with the *Erigeron* P concentration ($P < 0.05$, $r^2>0.8$).
Reactive Al exhibited the highest concentrations amongst all measured soil elements in both A and B groups (47 mmol kg^{-1} on average). There were no significant differences of reactive Al and extracted Fe, Cu and Mn concentrations in the soil among different SAR treatments. Fe, Cu and Mn were not affected by the *Erigeron* treatment. Only reactive Al decreased in all A group treatments except the control compared to B group ($P < 0.05$). The decrease was about 4 mmol kg^{-1}.

3.3 *Phaseolus* yields

In the B group, decreasing pH of SAR treatments led decreasing total plant biomass ($P < 0.001$), bean pod yield ($P < 0.001$) and bean pod biomass ($P < 0.001$). The plant biomass decreased by more than 50 % between the SAR control and the pH 3.0 treatment and the pH 3.0 treatment yielded no bean. Moreover, three plants died in the B group pots exposed to the pH 3.0 treatment. Plants from the A group were affected to a lesser extent by the SAR treatment. Pod biomass was only different between the control and the pH 3.0 treatment ($P < 0.05$) and the slopes of the relations between the plant biomass or number of pods and the pH of the SAR treatment were flatter than in the B group ($P < 0.01$). All A group SAR treatments including the SAR control had greater plant biomass and number of pods than their B group counterparts ($P < 0.001$ for both) and the biomass per pod exhibited comparable results for the SAR pH 4.0, 3.5 and 3.0 treatments ($P < 0.01$). The A group SAR pH 3.0 treatment produced the same yield as the B group SAR control treatment.
The analysis of the effect of soil pH and soil element concentrations on day 54 on the *Phaseolus* seedlings growth on day 150 showed the following results: plant biomass, pod biomass per pot (number of pod per pot time biomass per pod) and number of bean pods per pot were positively affected by the soil nutrient concentrations ($P < 0.001$) and the soil pH to a lesser extent ($P < 0.05$) and negatively by the soil reactive Al concentration ($P < 0.001$). There was no effect on the soil Mn concentration.
Fig. 3

4 Discussion

Although *Erigeron* seedlings suffered from some direct damages to the leaves exposed to pH 3.0 SAR spray, this is not an issue since there has been no report of rains with pH below 3.5 in southern China. Moreover, the biomass of *Erigeron* was not negatively affected by the SAR treatments. Hence *Erigeron* is a good candidate as a green manure since it is able to endure acid rains. Our results indicate that acid rains with a pH between 4.4 and 3.5 led to a biomass increase in this species although there is no report that it prefers acid soils. The greater growth of *Erigeron* seedling was probably a consequence of the soil NO_3^- enrichment by the SAR treatments.
During their growth until day 40, *Erigeron* seedlings had a positive effect on the soil pH. All A group SAR treatments except the SAR control showed slightly increased pH values compared to their B group counterparts. When analysing the total cation and anion concentrations in the plants, it appeared that the seedlings had high concentrations of NO_3^-. *Erigeron* seedlings absorbed around 60 % more anions (NO_3^- and SO_4^{2-}) than cations which is probably one of the mechanisms that helped to reduce soil acidity during the plant growth. Anion uptake by the roots has been proved to be done in exchange of OH^- excretion or concurrent H^+ uptake (Haynes 1990; Hinsinger et al. 2003). The lack of pH changes in the SAR control of the A group may be attributed to a lower anion uptake. Indeed, the cation/anion uptake ratio was higher in this treatment where plants showed lower S and N concentrations, probably due to a lack of SO_4^{2-} and NO_3^- fertilization by the SAR control solution.
After *Erigeron* residues were applied to the soil, they produced another pH improvement. This is probably due to the three well documented mechanisms. *Erigeron* seedlings contained high concentrations of K that was released in the soil during the decomposition. Addition of base cations to the soil has been proved to increase the soil pH (Shuman et al. 1983; de Vries et al. 1995). The seedlings also had great N concentrations. During the decomposition of organic matter in the soil, the organic N is turned into NH_4^+ through decomposition that consumes protons (Pocknee and Sumner 1997). Finally, *Erigeron* seedlings showed an excess concentration of free cations over free anions in their tissue (probably over estimated since Cl^- measures were not available). Noble et al. (1996) showed on a large array of plant species that there exists a linear relationship between the concentration of excess cations and ash alkalinity. Plants maintain the charge equilibrium in their tissues through the production of organic acid anions when there is an excess of cations (Naramabuye and Haynes 2006).

The release and oxidation of these organic acid anions during the plant residue decomposition would consume protons in the soil (Yan et al. 1996; Tang et al. 1999). The fast changes in soil pH following the application of the green manure could be attributed to a fast decomposition of the manure. Subtropical climate with high temperature and rainfall causes fast decomposition which in our experiment could be accelerated by chopping the plant residues into small parts. The use of *Erigeron* as a green manure improved the soil pH up to 0.2 pH unit when the green manure was applied with a rate of around 1.6 ton ha^{-1} and an additional improvement might be obtained by cultivating the plants *in situ*.
Soil exchangeable K, Ca and Mg decreased in both A and B group when the SAR treatment acidity increased. This process is well documented in the literature (Ulrich 1983; Koptsik and Mukhina 1995; Tomlinson 2003). In contrast, soil available P was little affected by the SAR treatment. This result is consistent with a previous study on a similar soil where we showed that a SAR with a pH of 3.0 generates a significant decrease of soil available P concentrations only after 2 years of treatment (Liu et al. 2007).
In our experiment, the application of *Erigeron* residues to the soil greatly improved the exchangeable K and P concentrations in all A group pots as well as Ca and Mg concentrations to a lesser extent. The increase in soil nutrient concentrations appeared to depend upon various mechanisms. Soil K concentrations depended mostly on the high K concentrations in *Erigeron* seedlings. The increase in exchangeable K was probably mainly due to a great release of this nutrient by the decomposing residues that contained large amounts of K. Soil Ca and Mg concentrations were well related with the soil pH. Although there was also probably a release of these elements by the decomposition of *Erigeron* residue. The increased concentrations in soil available P were probably due to a release of this nutrient by *Erigeron* residues as well as to the release of organic acid anions by the decomposing residue and decreased soil reactive Al concentrations. Reactive Al has been shown to bind strongly with phosphates in acid soils (Sanchez 1976; Haynes and Molokobate 2001) and decreased reactive Al concentrations lead to improved P solubility and accessibility for plants. Moreover, organic acid anions can increase P availability in acid soils by competing P for the complexion with soil metals like Al (Ohno et al. 1996). Our results above showed that *Erigeron* enables to limit the Ca and Mg depletion in soils exposed to acid rain and increases exchangeable K and P concentrations, two major nutrients for plants. It is a good potential green manure for improving soil nutrients in areas exposed to acid rains.
Soil reactive Al concentrations were very high, e.g. 3 times higher than Ca^{2+}, which is common in acid soils. There were no significant differences of reactive Al and extracted Fe, Cu and Mn concentrations in the soil among different SAR treatments since the nature soil is quite acid. The green manure treatment had no effect on soil extracted Fe, Cu and Mn concentrations. However, the use of *Erigeron* as a green manure led to a decrease of reactive Al concentrations in all A group soils. This result is interesting since this metal is toxic for plants in acid soils (Vitorello et al. 2005). The lower Al concentrations in the A group soils compared to the B group were probably due to the pH increase in A group following the green manure application. It has been demonstrated that the solubility of both Al and Mn decrease at higher soil pH (Bessho and Bell 1992).
The proof test we made using *Phaseolus* demonstrates that the treatment of acid soils exposed to acid rains by the culture of *Erigeron* is very effective in improving crop yields. The manure treatment with *Erigeron* had a beneficial effect on *Phaseolus* survival, growth, pod initiation (greater number of pods) and biomass per pod. These improvements were due to both higher soil pH and nutrient concentrations, the later being the main factor that determined the improved yields in our experiment (ANCOVA analysis). This may be due to the fact that the soil pH increase was still reduced. No nodulation was recorded on the root systems of *Phaseolus* seedlings in both manured and unmanured treatments, which indicates that they had to rely on the soil nitrogen pool. This should not be a problem for soils exposed to acid rains since acid rains in southern China can act as NO_3^- fertilizers.
Our experiment clearly demonstrated the benefits that we can draw from using *Erigeron* as a manure and at the same time an inexpensive mean to reduce soil acidification both during its growth and after it is applied as a manure. However, it is probable that the cultivation of *Erigeron* to improve soil pH will be less effective in areas without acid deposition as the process appears to depend for part on the root uptake of NO_3^- and SO_4^{2-} provided by acid deposition.

5 Conclusions

Erigeron maintained a good growth in acid lateritic field soils in southern China. Acid rains that are a major concern in this area had little effect on its growth and health. Cultivating this plant and applying it to the soil with a rate of 1.6 t ha^{-1} doubled the soil concentration of K and P and increased soil exchangeable Ca and Mg concentrations by around 25 %. This species would be a good green manure candidate for base cations nutrients and P in soils exposed to acid rains. Moreover, the cultivation and application of *Erigeron* led to increased soil pH by up to 0.2 pH unit, which should have beneficial effects on crop growth through reduced Al toxicity and cations leaching. These theoretical beneficial effects were verified by growing *Phaseolus* seedlings that yielded doubled growth and bean pod production in the soils manured with *Erigeron.* This plant has a good usability as a green manure since its cultivation requires little care and little time to provide good results. The soil pH improvements after the plant residues were applied to the soil were due to the release of high amounts of K, the mineralization of organic N and the oxidation of organic acid anions.

6 Recommendations and perspectives

Erigeron is an annual plant species and can maintain a good growth in acid lateritic field soils. As it can improve soils both for pH and nutrient concentrations with minimum care, it is recommended for treating acid soils with poor yield whenever a lowcost solution is required.

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Table 1: Major element concentrations and pH in the experimental soil on day 0 (n = 5± SD) and in the rain water for simulated acid rain preparation (n = 9± SD)
Table 2: Biomass, nutrient and excess cation concentrations and ratios of cation to anion uptake of *Erigeron annuus* (L.) Pers. Seedlings on day 40 (n = 18 ± SD). Different letters in a column indicate significantly different values (P < 0.05)

Fig. 1 Soil pH on day 40 in (A) A group (Erigeron annuus (L.) Pers.) and (B) B group pots (control) as well as (C) on day 54 in A group (Erigeron applied). Each data point is the mean (+ SD, n = 18)
Fig. 2 Effect of simulated acid rain (SAR) and Erigeron annuus (L.) Pers. treatments on the soil exchangeable cations, available P and metal concentrations in 0-10 cm soil depth in the pots on the day 54. Each data point is the mean (+ SD, n = 18)
Fig. 3 Effect of simulated acid rain (SAR and *Erigeron annuus* (L.) Pers. treatments on the total biomass (excluded pods), the bean pod yield and the pod biomass of *Phaseolus vulgaris* L. seedlings. Each data point is the mean (+ SD, n = 18)

Table 1

Sample	pH	Exchangeable ions				Extracted ions				Available P	NO_3^-	SO_4^{2-}
		K	Na	Ca	Mg	Fe	Cu	Mn	Al			
Soil (mmol kg^{-1})	3.21 ±0.02	3.58 ±0.34	0.08 ±0.00	11.60 ±0.39	2.50 ±0.05	4.03 ±0.12	0.03 ±0.00	0.05 ±0.01	59.70 ±1.13	0.70 ±0.03	2.65 ±0.04	4.74 ±0.02
Rain water (µmol L^{-1})	6.80 ±0.07	18.70 ±3.67	10.20 ±0.23	36.80 ±5.55	29.80 ±4.32	0.93 ±0.05	0.03 ±0.00	0.56 ±0.14	9.20 ±2.15	2.01 ±0.04	28.20 ±2.34	105.60 ±8.59

Table 2

Treatment	*Erigeron* biomass	K	Ca	Mg	P	S	N	Cation/anion	Excess cation
	g pot^{-1}	µmol g^{-1} plant dry weight							cmol kg^{-1}
Control	10.6±0.56^a	460±13^a	133±5.3^a	61±4.2^a	93±1.2^a	141±4.3^a	1614±47^a	0.398±0.020^a	47.2±2.4^a
pH 4.4	12.0±0.49^b	461±12^a	128±10.0^a	60 ±6.9^a	94±0.9^a	143±4.7^a	1709±68^b	0.376±0.010^{ab}	45.7±1.6^a
pH 4.0	11.9±0.63^b	463±16^a	131±7.8^a	62 ±3.3^a	93±0.9^a	164±5.9^{ab}	1723±96^b	0.373±0.015^{ab}	42.8±1.7^{ab}
pH 3.5	12.0±0.51^b	457±14^a	122±4.2^a	58 ±5.2^a	94±1.0^a	166±4.2^b	1728±63^b	0.363±0.021^b	39.2±2.1^b
pH 3.0	10.0±0.55^a	457±10^a	122±6.9^a	59 ±5.7^a	93±0.9^a	178±6.6^b	1945±73^c	0.328±0.012^c	37.0±1.3^b

Fig. 1

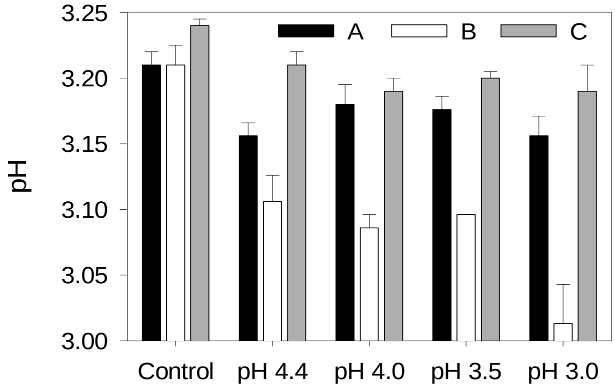


Fig. 2

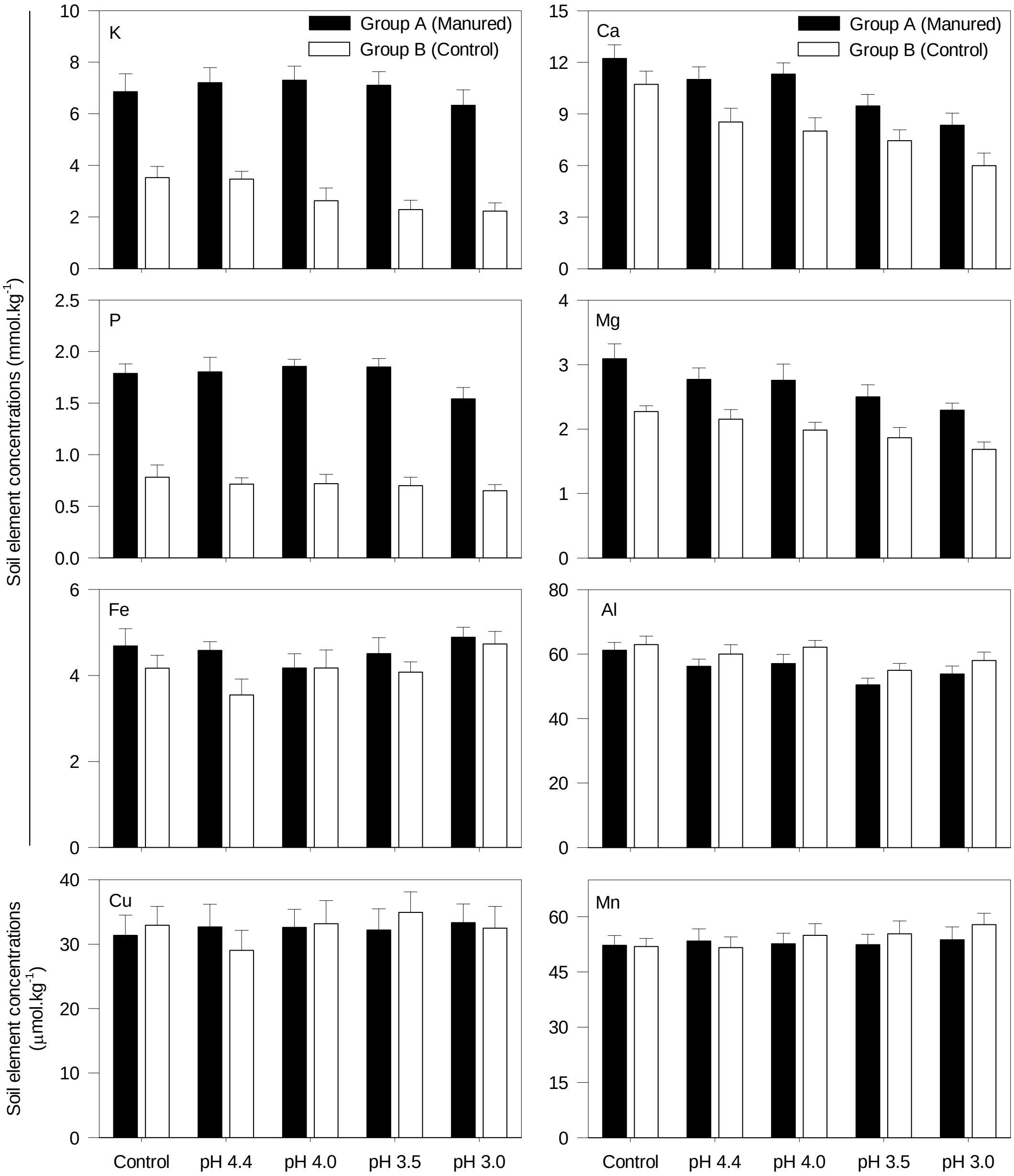
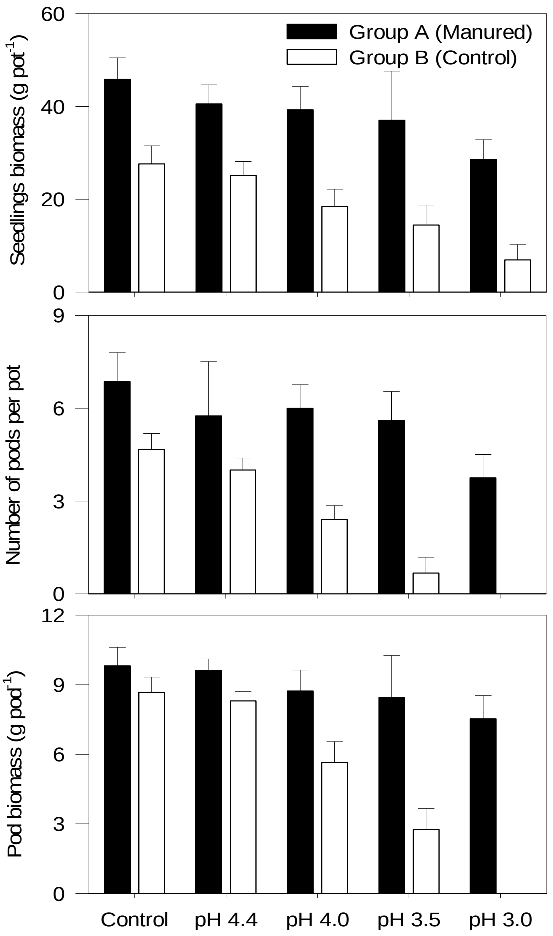

K
Ca
P
Mg
Fe
Al
Cu
Mn
Group A (Manured)
Group B (Control)
Soil element concentrations (mmol.kg-1)
Soil element concentrations (μmol.kg-1)
Control
pH 4.4
pH 4.0
pH 3.5
pH 3.0

Fig. 3


Group A (Manured)
Group B (Control)
Seedlings biomass (g pot-1)
Number of pods per pot
Pod biomass (g pod-1)
Control
pH 4.4
pH 4.0
pH 3.5
pH 3.0