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Uptake and accumulation of phosphorus by dominant plant species growing in a phosphorus mining area

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ABSTRACT

Phosphorus accumulation potentials were investigated for 12 dominant plant species growing in a phosphorus mining area in Shifang, as well as their corresponding non-mining ecotypes growing in Ya'an, China. High phosphorus concentrations were observed in the seedling and flowering stages of two species, *Pilea sinofasciata* and *Polygonum hydropiper*, up to 16.23 and 8.59 g kg^{-1}, respectively, which were 3.4 and 7 times higher than in the non-mining ecotypes. Available phosphorus levels in the respective rhizosphere soils of these plants were 112.84 and 121.78 mg kg^{-1}, 12 and 4 times higher than in the non-rhizosphere soil. Phosphorus concentrations in shoots of the mining ecotypes of all 12 species were significantly negatively correlated with available phosphorus in the rhizosphere soils ($p < 0.05$), whereas a positive correlation was observed in the non-mining ecotypes. The biomass in shoot of the mining ecotype of *P. hydropiper* was nearly 2 times that in the non-mining ecotype. The results suggested that *P. sinofasciata* and *P. hydropiper* were efficient candidates among the tested species for phosphorus accumulation in shoots, and that further studies should be conducted to investigate their potential to be adopted as phosphorus accumulators.

1. Introduction

Intensive chemical fertilizer application and animal-raising pose significant threats to surface water and therefore agricultural areas should be a priority for implementation of environmental management measures and the adoption of best management practices [1]. Water-soluble phosphorus that comes from runoff is the cause of eutrophication in the aquatic environment, which is a serious and growing environmental problem worldwide [2]. Reduction of phosphorus inputs to surface water is thus receiving much attention.

One common approach to reducing soluble phosphorus losses from cropland has been the use of chemical amendments and biosolids to immobilize phosphorus in soils [3,4,5,6]. However, chemical amendments could not prevent the accumulation of phosphorus in soils but merely reduce the amount of water-soluble phosphorus, thus regulating the runoff loss [7]. Moreover, phosphorus immobilization in soil by these amendments may not be stable on a long-term basis and, instead result in higher soluble phosphates as in case of Ca and ferric phosphate-dissolution under certain normal soil conditions [8]. Another strategy to address the excess manure phosphorus involves the treatment of animal feed with additives such as phytase and vitamin D that can increase the digestibility of phosphorus in diet [9]. Whereas, concerns have been raised that although phytase can decrease total phosphorus in litter, it could increase the water-soluble phosphorus in the litter and hence the potential for phosphorus losses to surface waters following land application [10].

Alternatively, plant-assisted removal of water-soluble phosphorus was proved to be an attractive strategy to relieve its potential hazard permanently. Utilization of grasses for phytoremediation of phosphorus from animal manure impacted soils is widely documented [11–13]. Grasses outperformed broad leafed forages in dry matter yields and nutrient uptake on application of animal manure. Grasses vary in their potential for removal of phosphorus from contaminated soils [14]. Other studies also indicate the usefulness of phytoremediation using stargrass [15] and perennial ryegrass [16] in phosphorus impacted soils. Enhanced accumulation of phosphorus by cultivars of annual ryegrass from P-enriched soil and hydroponic media has already been manifested [17,18].

Recent studies on phosphorus accumulators mostly concentrated on the phosphorus phytoremediation potential in different plant species and genotypes [19,20], while scarcely any parallel research was keen on different ecotypes of same variety. The same plant when growing in the different places could form different ecotypes. Knowledge of variations such as phosphorus concentration in different ecotypes is crucial for identifying phosphorus accumulator plants able to compete with other plant species. Current phosphorus uptake rates are low for forage grasses used to assim-

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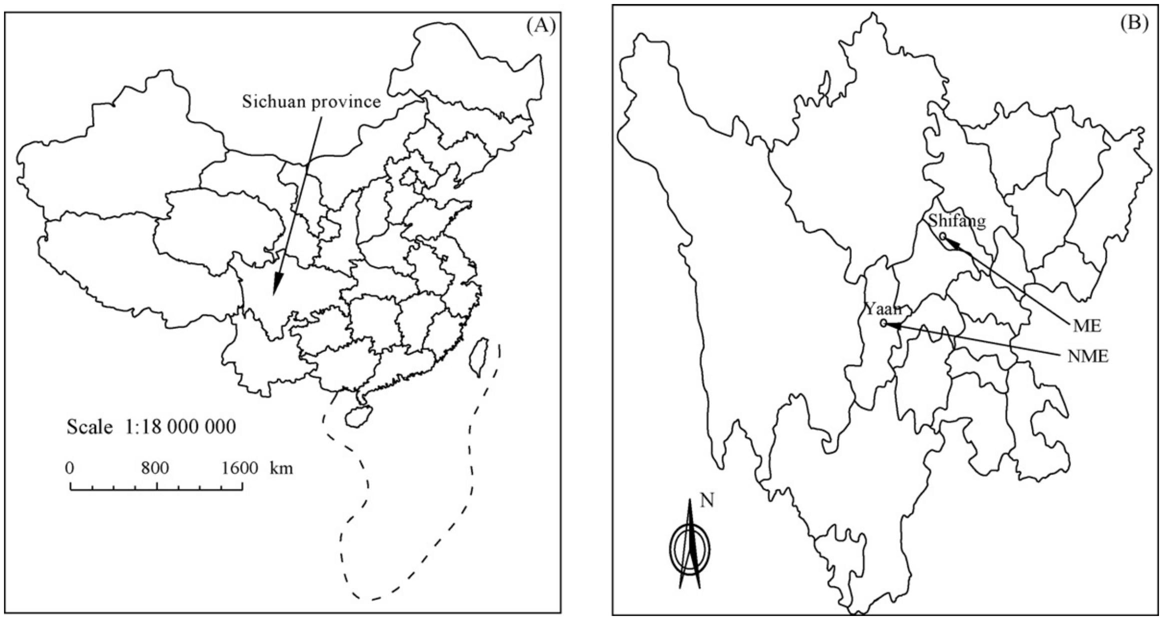

Fig. 1. (A) The map of China showing Sichuan Province. (B) Sites of the mining and non-mining ecotypes studied.

ilate phosphorus from soil [21]. Some phosphorus accumulators were screened out on the basis of phosphatic clay soil, but these plant species demonstrated low phosphorus accumulations in their shoots [11,22]. The ability of vegetation to assist in the remediation of phosphorus remains largely unknown. Annual ryegrass is one of the most efficient in extracting phosphorus and also highly productive [23]. However, annual ryegrasses are not resistant to freezing and summer drought. A hybrid grass resulting from the cross between Meadow Fescue and a ryegrass has overcome the difficulties [21], while more experiments in the form of field trials are needed to assess the utility of this grass for P phytoremediation.

Some plant species grow well in phosphorus mining areas. Hence, such species have potential to be suitable for phytoremediation of phosphorus-contaminated land. In this study, 38 plant species belonging to 7 families, collected from the phosphorus mining areas of China, were closely examined. According to accumulation concentration in plant shoots and the concentration time levels compared to plants from non-mining areas, 12 plant species were shown to have the ability to accumulate phosphorus, reflected by being the predominant plant species in their areas and growing very well during the 2 years of the study. The objectives of the present study were to determine which of the 12 species the best at accumulating phosphorus were, and to get better understanding of the accumulation capacity of the species to phosphorus in such an environment condition.

2. Materials and methods

2.1. Soil and plant sampling

The mining ecotypes were collected in a phosphorus mining area. The phosphorus mine is located in the town of Shifang, Sichuan, Southwest China (104°50′E, 30°25′N) (Fig. 1). The site has a subtropical moist monsoon climate with an average temperature of 15.9 °C. The concentration of P_2O_5 of the mine was about 27%. The relative elevation of the phosphorus mining area was nearly 1100 m. The landform gradient was 40–80°. The annual rainfall was 1259.5 mm. The non-mining ecotypes were collected from another place with similar climatic and topographic condition, in Yucheng, Ya'an (102°51′–103°12′E, 29°40′–30°14′N), Sichuan, China, also with a subtropical moist monsoon climate and an average annual temperature of 16.1 °C.

The sampling times chosen were the seedling and flowering stages. There are at least three replicates of a species. The photographs of predominant plant species were listed in Fig. 2. At least 6 individual plants of each plant species were randomly collected within the sampling area, then were mixed to give a composite whole plant sample of 1 replicate. For the collection of rhizosphere soil, the large clods were first discarded and the soil adhering to the plant roots was shaken off into a labeled plastic bags [24]. Non-rhizosphere soil was collected from the surface soil (0–20 cm depth).

The basic physiochemical characteristics of the phosphorus mining area were as follows: pH was 7–9. The content of available nitrogen and phosphorus were 7.97–33.57 and 52.43–112.84 mg kg^{-1}, respectively. The content of available potassium under 11 species were 18.30–59.11 mg kg^{-1}, that in P4 (a potassium accumulators) was 114.04 mg kg^{-1}. The content of organic matter was 2.45–5.02%.

2.2. Sample preparation and analytical methods

All plants were harvested whole and washed, first thoroughly with tap water and then 3 times with distilled water. The plants were divided into aboveground and underground parts and oven-dried at 70 °C to constant weight. The oven-dried samples were ground with a stainless steel grinder (FW-100, China) to pass through a 100 mesh sieve. The phosphorus concentrations in the plant samples and total phosphorus concentration in rhizosphere soils were measured colorimetrically at 700 nm after reaction with molybdenum blue method determined following thick H_2SO_4–H_2O_2 and H_2SO_4–$HClO_4$ digestion procedures, and the available phosphorus concentration was extracted with 0.5 M $NaHCO_3$ (soil:water = 1:20). The pH value (solid:distilled water = 1:5) of the soil samples was measured with a pH meter [25]. Three replicates of each sample were measured to ensure the precision of the determinations.