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Application of polyacrylamide to reduce phosphorus losses from a Chinese purple soil: A laboratory and field investigation☆

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ABSTRACT

Use of anionic polyacrylamide (PAM) to control phosphorus (P) losses from a Chinese purple soil was studied in both a laboratory soil column experiment and a field plot experiment on a steep slope (27%). Treatments in the column study were a control, and PAM mixed uniformly into the soil at rates of 0.02, 0.05, 0.08, 0.10, and 0.20%. We found that PAM had an important inhibitory effect on vertical P transport in the soil columns, with the 0.20% PAM treatment having the greatest significant reduction in leachate soluble P concentrations and losses resulting from nine leaching periods. Field experiments were conducted on 5 m wide by 21 m long natural rainfall plots, that allowed collection of both surface runoff and subsurface drainage water. Wheat was planted and grown on all plots with typical fertilizer applied. Treatments included a control, dry PAM at 3.9 kg ha^{-1}, dry PAM at 3.9 kg ha^{-1} applied together with lime ($CaCO_3$ at 4.9 t ha^{-1}), and dry PAM at 3.9 kg ha^{-1} applied together with gypsum ($CaSO_4 \cdot 2H_2O$ at 4 t ha^{-1}). Results from the field plot experiment in which 5 rainfall events resulted in measurable runoff and leachate showed that all PAM treatments significantly reduced runoff volume and total P losses in surface runoff compared to the control. The PAM treatments also all significantly reduced water volume leached to the tile drain. However, total P losses in the leachate water were not significantly different due to the treatments, perhaps due to the low PAM soil surface application rate and/or high experimental variability. The PAM alone treatment resulted in the greatest wheat growth as indicated by the plant growth indexes of wheat plant height, leaf length, leaf width, grain number per head, and dried grain mass. Growth indexes of the PAM with Calcium treatments were significantly lesser. These results indicate that the selection and use of soil amendments need to be carefully determined based upon the most important management goal at a particular site (runoff/nutrient loss control, enhanced plant growth, or a combination).

1. Introduction

Nitrogen (N) and phosphorus (P) losses from agricultural non-point source (NPS) pollution are major factors contributing to excessive nutrients in surface water, leading to subsequent eutrophication; P losses are especially important, as P is typically the limiting nutrient responsible for eutrophication (Parry, 1998; Carpenter et al., 1998; Correll, 1998). Thus, decreasing the fluxes and concentrations of P in runoff, as well as in the receiving waters, is critical in controlling eutrophication in downstream water bodies. In China, with the construction of the Three Gorges Dam, the Three Gorges Reservoir has become a "hot spot" as some branches of this water body are already showing evidence of eutrophication (Li and Huang, 2006; Liu et al., 2003). One way to control water quality degradation caused by NPS is the management of soil and associated nutrients transported in runoff from sloping agricultural fields.

Water-soluble, high molecular weight, anionic polyacrylamide (PAM) is often used as a soil amendment to manage infiltration, runoff and soil erosion as well as prevent the loss of nutrients (Entry and Sojka, 2003; Lentz et al., 1992, 1996, 1998, 2001; Sojka

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Table 1
Selected properties of the purple soil (0–20 cm).

Sand (%)	Silt (%)	Clay (%)	Organic matter ($g\,kg^{-1}$)	pH	Total N ($g\,kg^{-1}$)	Total P ($g\,kg^{-1}$)	Total K ($g\,kg^{-1}$)	Water soluble P ($mg\,kg^{-1}$)	CEC ($cmol\,(+)\,kg^{-1}$)
50.33	31.05	18.62	12.76	7.63	0.57	0.48	14.02	4.01	25.3

et al., 1998). Sojka et al. (2007) thoroughly reviewed the full scope of PAM technology application in agriculture and environmental nutrient management, moreover including environmental and biological safety aspects. In the 1980s, researchers realized the effect of PAM on soil amelioration and gradually the potential of PAM application in soil management became recognized. Since the 1990s, PAM has become an important treatment for soil and water conservation in the USA, particularly in furrow irrigation systems. As a soil amendment, PAM has been widely studied (Aase et al., 1998; Barvenik, 1994; Entry and Sojka, 2003; Flanagan et al., 2003; Flanagan and Canady, 2006a, 2006b; Lentz et al., 1996), because of its unique characteristics for improving soil physical properties, enhancing aggregate stability, maintaining high infiltration rates, and reducing runoff and soil loss across a range of soil types (Busscher et al., 2006, 2007; Green et al., 2004; Levy and Miller, 1999).

PAM is commonly adsorbed to the soil through cationic bridges between the soil and polymer anionic groups, and multivalent cations (such as Ca^{+2}) in the soil solution will bridge the negatively charged soil particles and polyers together (Laird, 1997). Thus, the effectiveness of polymers can be increased when applied to a soil which is kept in a flocculated state (Shainberg and Levy, 1994), through the use of amendments such as gypsum which supplies Ca^{+2} to the surface soil solution. Flanagan et al. (2003) present results of the synergistic effect of combining PAM soil surface treatments with gypsiferous amendments, that help to supply a source of divalent cations, decreasing clay dispersion and bridging PAM molecules to the soil to increase aggregation.

Currently, much of the existing PAM research in the literature has focused on the study of soil physical properties, infiltration rates, runoff, and soil erosion, while less work has examined effects on nutrient transport, particularly P losses from sloping soils. Lentz et al. (1996) found PAM had little effect on orthophosphate but a 25% reduction in total P loss. Entry and Sojka (2003) in a field experiment with furrow irrigation found that PAM-treated water in the furrows reduced nitrate-N concentrations by 85%, and total P concentration in the runoff water by 90%. Soupir et al. (2004) examined different PAM treatment effects on sediment and nutrient losses from a construction site in Virginia, and found that PAM reduced total suspended solids (TSS), total P, sediment-bound phosphorus, and total nitrogen compared to the control. However, the PAM treatments were not as effective as use of straw mulch. Flanagan and Canady (2006b) studied the use of PAM in livestock lagoon effluent, and its effect on soluble and total nutrient losses. They found that PAM treatments reduced soluble phosphate-P, and soluble ammonium-N losses, as well as total N and P losses (but not soluble nitrite/nitrate-N losses). Several studies report the impact of PAM on reduction of nutrient losses, especially P, from runoff (Bjorneberg et al., 2000; Bjorneberg and Lentz, 2005; Oliver and Kookana, 2006). Spackman et al. (2003) found that application of PAM did not provide any extra protection from bacterial contamination of surface water from agricultural wastewater applications in irrigated forage production systems.

In China, more attention has been paid to the amendment of loesses or coarse sandy loams only for soil and water conservation in northwest China (Tang et al., 2002; Wang and Yang, 2006; Yang et al., 2006; Yuan et al., 2005a, 2005b). However, the impact of PAM on nutrient retention and release from some types of soil and slope is still not clear (Teng et al., 2008; Zhang et al., 2006).

Some previous research in China described the impacts of PAM on P absorption and desorption in soils in the laboratory (Teng et al., 2008; Yang et al., 2006). However, there have only been limited studies to extend the existing research findings to other soil types, climates, and land utilization types. Few studies have investigated how PAM affects nutrients, especially P losses from sloping purple soil, especially under field conditions. Moreover, the interaction of PAM and chemical enhancers (especially calcium electrolyte sources such as gypsum or lime) on P management of sloping soils has never been reported.

To fill this research gap, we focused on the effects of PAM on P losses from a sloping purple soil in this paper. Thus, the objectives of this research were to: (1) determine the effect of PAM on vertical P transport in purple soil in a column; and (2) investigate the effect of PAM application (including alone and with enhancers) on P losses from a sloping field soil under natural rainfall conditions. Overall, this research was aimed at developing and expanding PAM application research for a different geographic region and soil type in China, especially in the Chongqing area. It also offers scientific evaluation and a theoretical foundation for this new technology to control agricultural NPS pollution in the Chongqing area.

2. Materials and methods

2.1. Soil samples and PAM

Purple soil is the dominant soil type in southwest China, and is classified as a Eutric Regosol in the FAO soil taxonomy and as Pup-Calric-Entisol in the Chinese soil taxonomy (Gong, 1999). In this experiment, a topsoil sample (0–20 cm) from a fallow, grey-brown purple soil (Typic Purple-Udic Cambosols, TPUC) at the Backhill of Southwest University, Chongqing, China (Table 1) was used as it is a typical soil type in the Three Gorges area. The PAM used was of high molecular weight (6 million Daltons) or about 12 mg mol^{-1} with a hydrolysis degree of 20% (Lentz et al., 1992; Long et al., 2002; Orts et al., 2000), which was purchased from Yi-Sheng Environmental Technology Company, Chengdu, China.

Fig. 1. Diagram of soil column experiment.