Reduction of soluble nitrogen and mobilization of plant nutrients in soils from U.S. northern Great Plains agroecosystems by phenolic compounds

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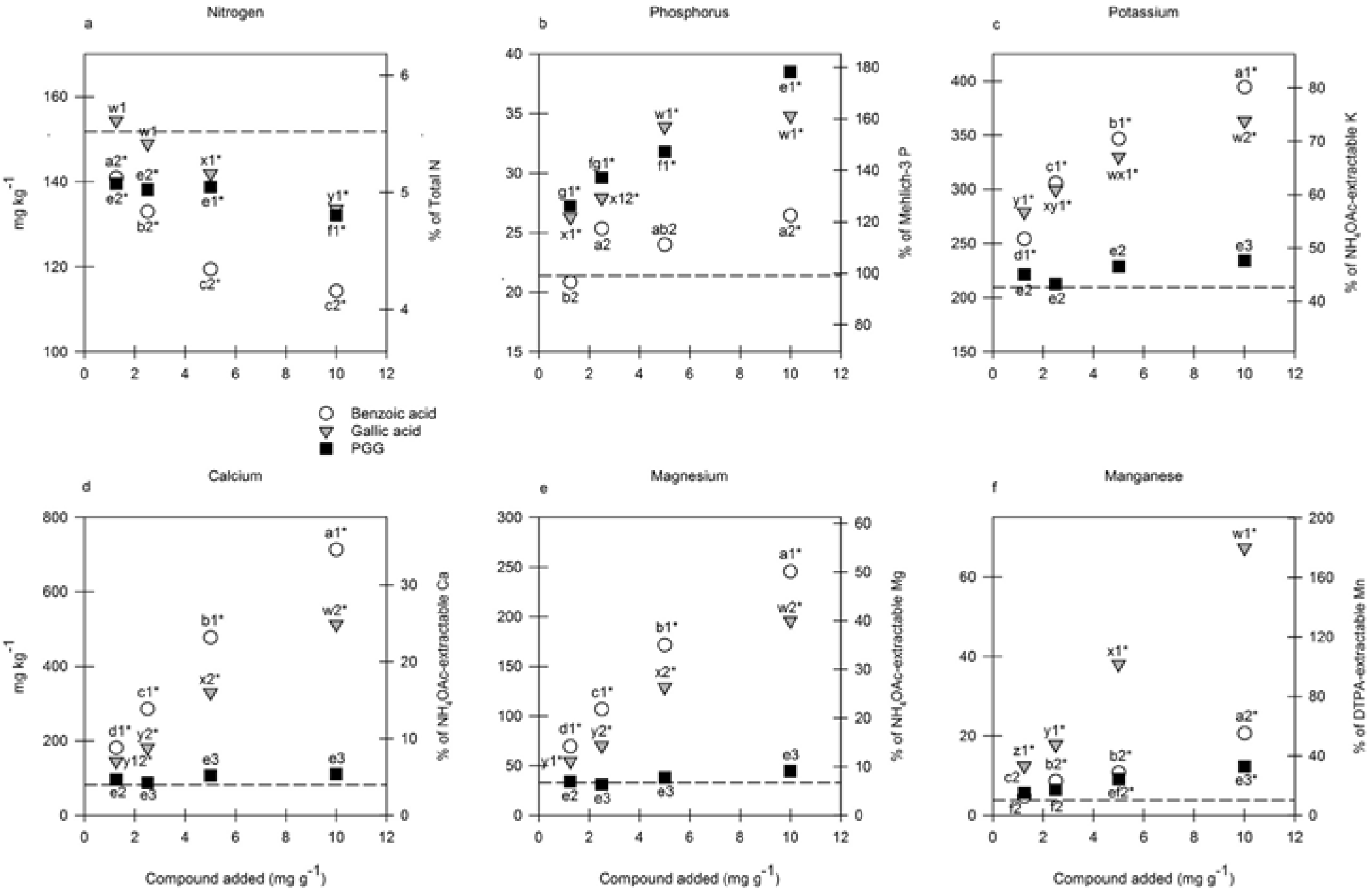
Phenolic compounds are a large class of plant secondary metabolites, ranging in complexity from simple organic acids, through complex polyphenolics such as tannins. They exert direct and indirect effects on livestock nutrition and health, plant physiology and soil processes. They could play a role in adaptive management strategies that include dynamic cropping or combing cover crops and livestock production. While the potential beneficial and detrimental effects of polyphenolic compounds such as tannins on livestock have been documented, much less is known about how phenolic compounds, entering the soil ecosystem through feces or crop residues, will affect key soil functions that govern formation and retention of soil organic matter or nutrient cycling. The objectives of this study were to quantify potential impacts of different kinds of phenolic compounds on N solubility and mobilization of major plant nutrients in order to evaluate their importance in soil management. We hypothesized that solubility of N would be decreased while that of important nutrients would be increased. We treated samples of North Dakota soil collected from pastures and cultivated land with solutions of increasing complexity including benzoic acid (BA), gallic acid (GA), or *β*-1,2,3,4,6-pentagalloyl-O-D-glucose (PGG) at four concentrations (1.25, 2.5, 5 or 10 mg compound gram^{-1} soil). We selected these compounds because they represent common classes of compounds that enter the soil with plant residues or exudates or are formed through the actions of microorganisms. We measured extractable nitrogen (N), phosphorus (P), potassium (K), calcium (Ca),magnesium (Mg) and manganese (Mn) in treatment supernatants and after a subsequent incubation in hot water (16 h, 80 C).

Cool water extracted an average of about 41 mg N kg^{-1} soil, an amount identical to that reported for a broad range of soils from various locations throughout the United States and Canada. The subsequent extractions of these North Dakota soils with hot water yielded an additional 111 mg N kg^{-1} soil. Cool and hot water-extractable N are associated, respectively, with pools of immediately soluble or potentially mineralizable soil N and thus are useful as indicators of how agricultural management affects soil N dynamics. Together, these labile pools were equivalent to nearly 200 kg N ha^{-1} in the 0-10 cm depth, a pool of potentially manageable N greater than the annual N requirement for many crops. Inorganic forms of nitrogen, extracted from the soil, were small (about 25%), compared to cool water-soluble N, indicating most of the labile pool of N is in an unspecified organic form.

Consistent with our hypothesis, each treatment reduced the total amount of N extracted from soil in a compound by concentration dependent manner with BA exerting the largest effect (about 25%). Although PGG had little effect or even increased soluble N in treatment supernatants, all concentrations of PGG reduced the amount of N extracted with hot water. As a net effect, PGG reduced total soluble N. In agreement with our earlier work, this study suggests both tannins and low molecular weight organic acids can result in physico-chemical fixation of soluble organic nitrogen in soil that might otherwise leach. Unlike N, GA and PGG increased extraction of P, relative to water, while BA had less effect. Extraction of the major cations, K, Ca, and Mg, was strongly increased by BA and GA but unaffected by PGG. Extraction of Mn was increased most by treatments of GA but less so by BA. The effects of PGG on Mn were consistent with GA when expressed on a molar basis.

These findings indicate some phenolic secondary compounds affect the dynamics of nitrogen and phosphorus and major cations in soil, and thus could be part of future management strategies to improve nutrient-use efficiency. In addition to their possible effects on soil fertility, phenolic compounds may affect the rates of decomposition or the stability of existing organic matter. Secondary compounds may be applied to soil in an engineered approach, via direct applications of the compound or included as part of the fertilizer application especially in concert with drip irrigation or fertigation with the goal of reducing the reactivity of N leading to losses. However, further research is needed to determine how long the mobility of organic N is affected and



Average total mass of a) nitrogen, b) phosphorus, c) potassium, d) calcium, e) magnesium, and f) manganese extracted by treatment solutions and a subsequent hot water treatment (N = 12). Treatment solutions consisted of a water control or supplied 1.25, 2.5, 5, or 10 mg of BA, GA, or PGG per g soil. Significant differences among treatments within each concentration are denoted by numbers while differences among concentrations within each treatment are denoted by lower case letters (Holms-Tukey adjustment for multiple means, $P < 0.05$). Significant differences from the control, shown as the dashed line, are denoted by an asterisk (Dunnett's test).

more importantly, if retained nitrogen is available to plants. Phenolic secondary compounds may also enter the soil from crop roots and residues. Thus, a crop known to be a source of a desirable compound could contribute to the suite of ecosystem services provided by a cropping sequence. Together with direct inputs from plants, forages and crop residues may recycle through animals and be applied to soil as feces. When incorporated into drinking water or feed rations or as part of an integrated livestock-cropping system, phenolic compounds can impart nutritional advantages or other health benefits while employing animals as the mechanism for delivery.

Whether they operate mainly at the root-soil interface of the individual crop plant or affect soil quality at the field scale as crop residues or manure, more research is needed to determine just how plant secondary compounds can be fruitfully harnessed in agroecosystems. A comprehensive perspective is needed to integrate our limited understanding of the basic chemical principles and mechanisms governing their interactions with plants, crops, and soil, with economic and environmental management goals.

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