Tannins Alter Soil Organic Matter Extraction, Solubility of Metals, and Root Physiology

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Understanding how tannins affect soil organic matter and nutrient cycling may be important in silvopastures.

Problem: Tannins are common plant-derived polyphenolic compounds that precipitate proteins and react with other biomolecules but knowledge of their effects on soil organic matter, metals, and root physiology is incomplete.

Goals: Determine if tannins or related phenolic compounds influence

1) solubility of organic matter in soils,

2) metal mobilization in soils,

3) root growth.

Why: This information is needed to determine the impacts of tannins and other phenolic compounds on soil organic matter formation, nutrient cycling and toxicity risk of some metals and to improve the management of silvopastures.

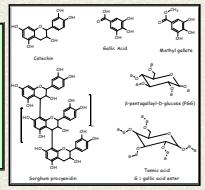
Extraction studies:

Soils (0-5 cm) were from paired pasture and forest sites in West Virginia (USA). The average pH was 4.5 (in 1:1 soil/water) and total C was 5.6%.

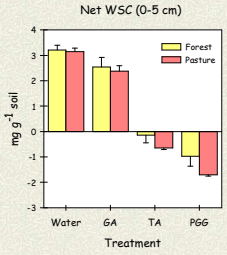
Procedure: Tannin/phenol solutions (10 mg g^{-1} soil) were added to soil. After shaking for 1 hour, samples were centrifuged, decanted, and analyzed.

Analysis: Water Soluble-C and -N (WSC, WSN) were analyzed with a Shimadzu TOC-VCPN. Net values were calculated by subtracting the C or N added by the compounds. **Elemental analysis** of the supernatant was performed using a Spectro ICP spectrometer. **Total "phenolic" content** was determined by the Prussian blue method (Hagerman, 2002). Error bars are the standard error of the mean.

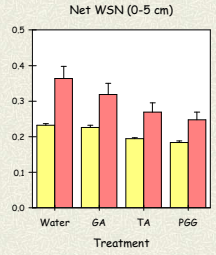
Compounds used in these experiments were selected because of their postulated role on plant nutrient cycling and varying complexity.



Net WSC (0-5 cm)

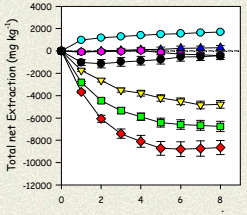


Net WSN (0-5 cm)

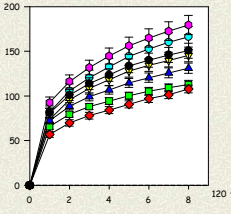


A single application of tannic acid (TA) reduced net total extraction of WSC and WSN in West Virginia soils (n=5) suggesting that TA-C sorbed on soil and interacted with labile soil-N. A purified gallotannin, PGG, sorbed more strongly than TA while gallic acid (GA), a non-tannin phenolic, had less effect.

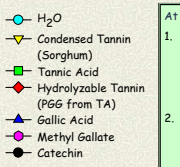
Extractable C (0-5 cm, n=8)



Extractable N (0-5 cm, n=8)

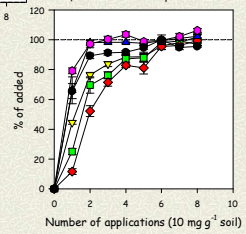


Number of applications (10 mg g^{-1} soil)



Multiple applications of tannins resulted in an L-type sorption curve for WSC, suggesting that soils had a maximum sorption capacity. Hydrolyzable tannins reduced the losses of WSN compared to the condensed tannin or the H_2O control. The Prussian Blue assay, a measure of the "total phenolic content", indicates that tannins were no longer sorbed by soil after 5 applications.

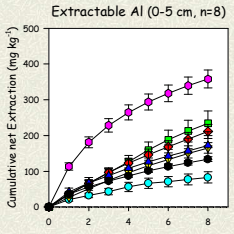
Prussian Blue Assay
µmol Gallic Acid equivalents



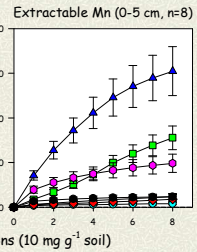
Number of applications (10 mg g^{-1} soil)

Multiple applications of methyl gallate increased extraction of Al and Fe (Fe not shown). Similarly, gallic acid increased extraction of Mn and Ca (Ca not shown) compared to the other treatments.

Extractable Al (0-5 cm, n=8)



Extractable Mn (0-5 cm, n=8)



Number of applications (10 mg g^{-1} soil)

At least two mechanisms are involved:

1. Complex formation.

   Metals in soils bind to organic ligands through H-bonding, coordination (one donor group), and/or chelation. The last two mechanisms form stronger complexes with Al and Fe and also might affect the P cycle since P forms complexes with Al and Fe.

2. Redox reactions.

   Phenolic compounds reduce the insoluble Mn(IV) to the soluble Mn(II) form:

   $Mn(IV)_{(s)}$ + Phenolics ⇨ $Mn^{2+}_{(aq)}$ + Quinones

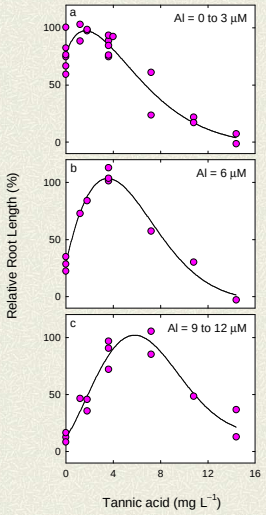
   Redox reactions are common and important in the formation and stabilization of soil organic matter. Quinones are reactive compounds that self-polymerize or co-polymerize with other compounds such as amino-containing compounds to form humic-like substances.

Pretreatment of wheat roots with tannic acid enhances the adsorption of Al.

Not Preincubated Preincubated

Roots were pre-incubated or not in TA, rinsed, incubated in Al, and then stained with haematoxylin. This Al stain demonstrates that TA pretreated roots adsorb more Al than roots not pretreated. Measurements with microelectrodes indicate that TA treatment of roots enhances the surface negativity of the roots. This effect may be part of the reason for greater adsorption of the cationic Al.

Interactions between TA and Al in root elongation.



Tannic acid and Al are both intoxicating, but each will alleviate the toxicity of the other within appropriate concentration ranges. In the top figure (a) small concentrations of TA alleviate the intoxication by small Al concentrations, but continued additions of TA result in toxicity. In the next two figures (b and c) one can see that greater concentrations of TA are needed to alleviate the toxicity of the greater Al concentrations. Note too that Al alleviates TA toxicity, shown by increased root length at 8 mg L^{-1} TA in response to greater Al concentration. We estimate that each TA molecule may bind five Al^{3+} ions.

Conclusions

- Reactions between some tannins and soil organic matter might rapidly decrease the solubility of labile soil C and interact with soil N.
- Phenolic compounds solubilize and/or mobilize metals in soils and affect important in soil chemical processes.
- Roots incubated with TA and Al together are less intoxicated than roots incubated in TA or Al alone possibly signifying that TA-Al complexes on the root surface are not intoxicating.

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