Graphite nanomaterial mediated alteration in soil N cycling in a soil plant system

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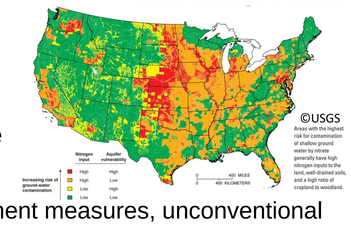
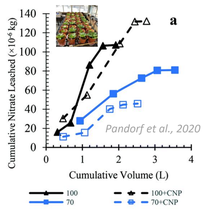
Background

- N loss from agriculture is a major contributor to groundwater nitrate pollution as around 40 -70% of applied N and 50-70% of applied conventional fertilizer is lost to the environment.[1]



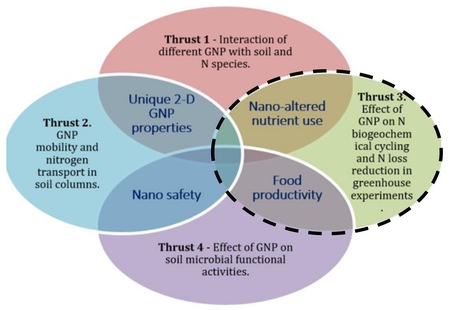
- Along with conventional management measures, unconventional measures such as application of nanotechnology can be a potential solution to this problem.
- Graphite nano-additive (GNA) applied directly to soil at a rate of 2.85 kg ha^{-1} along with NPK fertilizer reduced fertilizer use by 30% and nitrate leaching by 57% without compromising lettuce yield in a greenhouse study. [3]



- **Overall project goal:**

This project aims to experimentally investigate the efficacy and mechanisms of engineered graphene-based nanoparticles in affecting the mobility and transformation of inorganic nitrogen species in soil/plant systems.

- **Major research thrusts:**

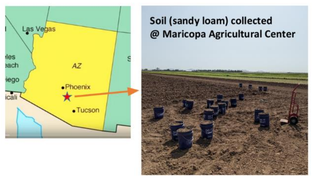


Objectives of this study:

How GNA impacts soil microbial functional activities, N biogeochemical cycling & soil bacterial community in a greenhouse plant-soil system ?

Materials & Methods

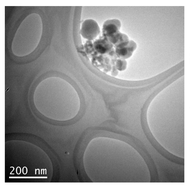
Soil:



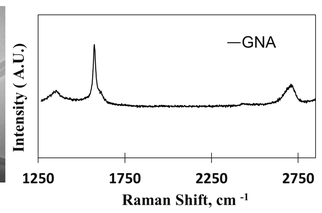
Physiochemical characteristics of soil:

- ✓ Sandy Clay Loam soil (Sand: 58%, Silt: 20%, Clay: 22%).
- ✓ Alkaline (pH: ~ 8.2)
- ✓ Low organic content (~ 1.24%)
- ✓ CEC (meq/100 g): ~ 10.4

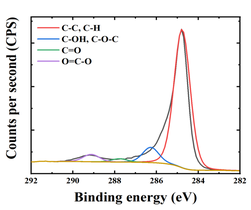
TEM image of GNA



Raman spectrum of GNA



XPS spectra of GNA



Features of greenhouse experiment:

❖ *Plant type:* Butterhead lettuce *(Lactuca sativa* 'Adriana')

❖ *Types of GNA treatments:*

a) 100% NPK
b) 100% NPK + GNA (*1 mg/kg soil*)
c) 100% NPK + GNA (*5 mg/kg soil*)
d) 100% NPK + GNA (*100 mg/kg soil*)
e) 100% NPK + GNA (*500 mg/kg soil*)

Figure: Greenhouse experiment (a) Plant growth experiment in ASU polytechnic research greenhouse (b) Rhizosphere soil sampling.

Materials & Methods (contd.)

❖ **3 sampling :** Sampling#1 (week 3), Sampling#2 (week 5) and Sampling#3 (week 7).

1. No of leaves, Plant Diameter, Leaf Area, Leaf Chlorophyl, Shoot mass, Root mass
2. Bulk soil
3. Rhizosphere soil

❖ **For bulk soil & rhizosphere soil:**

- *Soil microbial biomass carbon (SMBC):* Using chloroform fumigation extraction method.
- *Enzyme activity:* C cycle (β-glucosidases, Cellobiosidase), N cycle (Leucine aminopeptidases), P cycle (Phosphatase), and S cycle (Sulfatase).
- *Gene abundance:* total bacterial community (16S rRNA gene), fungal community (ITS), nitrification (amoA, Archaeal amoA), dentrification (nirK, nirS and nosZ) and N fixation (nifH).
- *Change in bacterial community composition.*

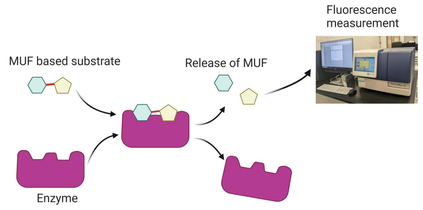


Figure: Methodology for soil enzyme activity assessment.

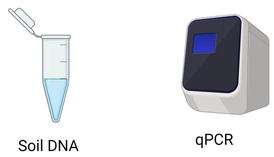


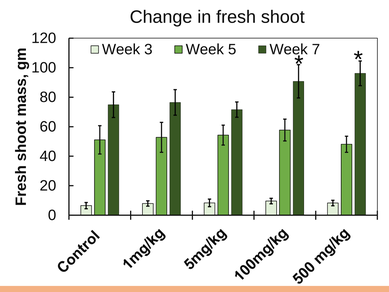
Figure: Methodology for gene abundance assessment using real time quantitative polymerase chain reaction (qPCR).

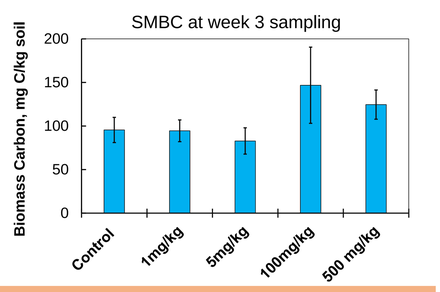
Results

Results of plant yield and SMBC:

Plant yield improved for GNA dose ≥ 100 mg/kg soil during final harvest during week 7

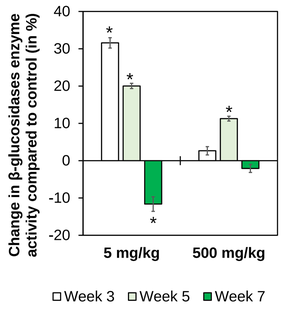
SMBC increased 35 to 54% for GNA dose ≥ 100 mg/kg soil indicating potential N immobilization

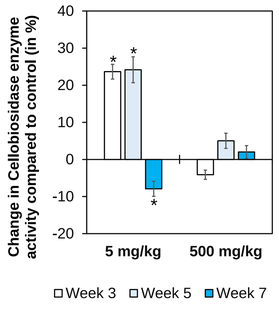




Preliminary results on soil enzyme activity:

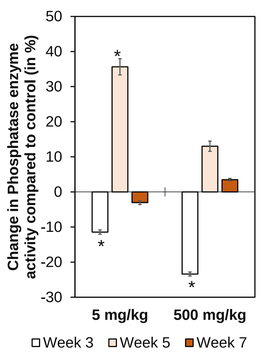
❑ Soil enzyme activities in rhizosphere soil were impacted by GNA amendment.

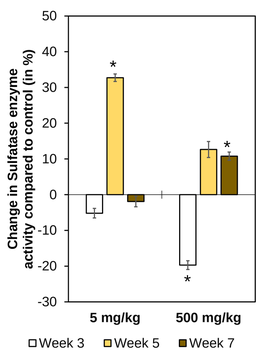


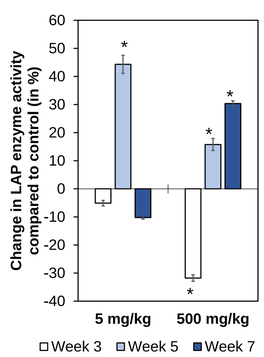


Key observations:

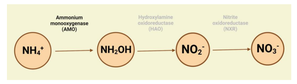
- ✓ Cellulose decomposition enhanced in early growth stage of plant.
- ✓ Organic P,S,N decomposition altered in a transient way.

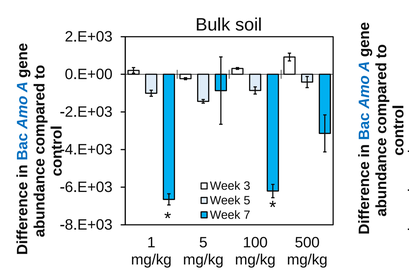


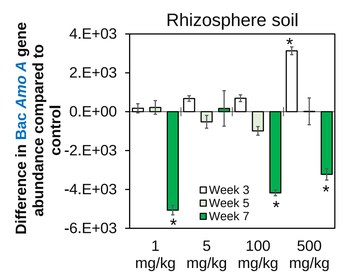




Preliminary results

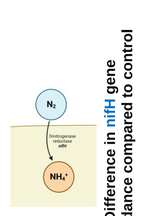


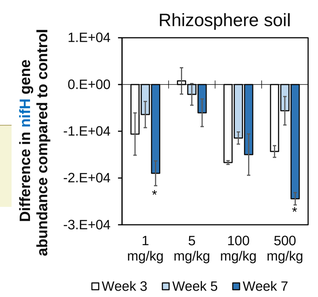


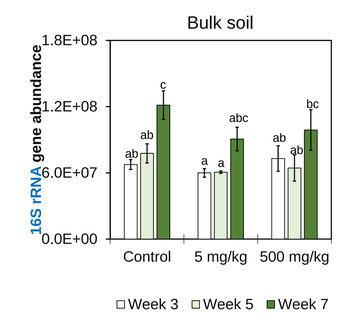


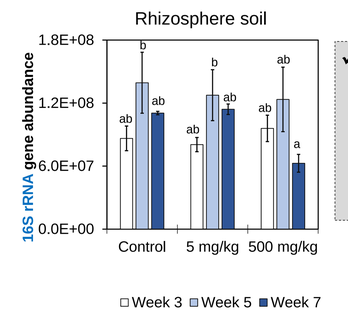
Here,
One way ANOVA followed by Tukey post hoc analysis was performed. Bar with asterisk (*) means a significant difference at P< 0.05.

Gene	Change in abundance	
	Bulk soil	*Rhizosphere soil*
nirK	↓	↓
nirS	↑	→
nosZ	→	↓









✓ No alteration in total bacteria population size.

Conclusion & Future work

Key points:

- Plant yield significantly improved for GNA dose ≥ 100 mg/kg soil.
- Soil microbial biomass carbon (SMBC) showed a 35 to 54% increase for GNA dose ≥ 100 mg/kg soil during early incubation period (week 3 sampling) with no impact on later samplings.
- Enhanced decomposition of cellulose to simple glucose.
- Altered S,P,N mineralization in a transient way.
- Decreased nitrification in bulk & rhizosphere soil.
- Decreased denitrification rhizosphere soil.
- Increased N fixation in bulk soil.
- No change in total bacterial population.

Future work:

16S rRNA community sequencing to assess the shift in community composition.

References

1. Das, P., Davis, K., Penton, C.R., Westerhoff, P. and Bi, Y., 2022. Impacts of graphitic nanofertilizers on nitrogen cycling in a sandy, agricultural soil. *Journal of Nanoparticle Research*, *24*(6), p.120.
2. https://www.usgs.gov/media/images/areas-high-risk-nitrogen-contamination-groundwater
3. Pandorf, M., Pourzahedi, L., Gilbertson, L., Lowry, G.V., Herckes, P. and Westerhoff, P., 2020. Graphite nanoparticle addition to fertilizers reduces nitrate leaching in growth of lettuce (Lactuca sativa). *Environmental Science: Nano*, *7*(1), pp.127-138.
4. Das, P., Penton, C.R., Bi, Y. and Westerhoff, P., 2023. Unraveling mechanisms behind reduced nitrate leaching with graphite nanomaterials addition with fertilizers in soil column experiments. *Chemosphere*, p.139417.
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