Improving CA Agricultural Soils Using Algae from Municipal Wastewater Treatment Plants

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Background

- Phosphorus is a macro-nutrient that is highly important for all living organisms.
- The majority of global P demand is for fertilizer use in agricultural production. But at the current rate of extraction, it is likely that the global phosphate rock reserves will be exhausted. Without the input of mined P, maintenance of food production at current global yield levels will not be possible.
- Phosphorus is usually applied as a fertilizer in crops, but only 10-30% is used by the plant. This is a huge challenge in agriculture because P is a limiting resource and needs to be managed correctly to prevent P use inefficiencies and pollution in waterways.
- This project aims to assess if algae collected from wastewater treatment plants can be used as a P source to help reduce P inputs from synthetic fertilizers.

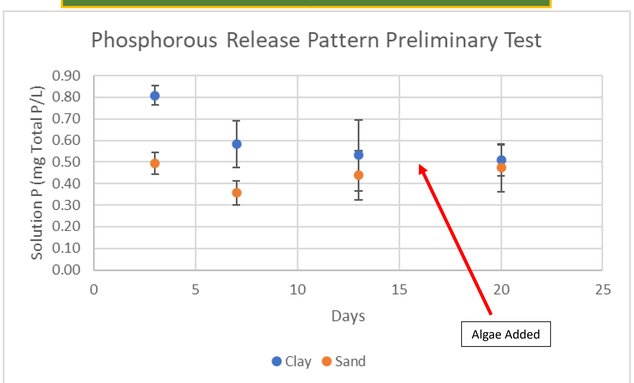
Research Questions:

1. What are the P-release patterns of algae compared to synthetic fertilizers?
2. After being released from the algae or synthetic fertilizer, in which pool does the P accumulate in the soil?
3. Which P extraction methods are most suitable to target pools where algae and synthetic fertilizer-derived P are expected to accumulate?

Objectives:

- Conduct a literature review
- Optimize experimental design

Research Question #1



Preliminary Trial

- After 2 weeks of incubation soil P levels appear to stabilize, thus, pre-incubating soil for 2 weeks before adding algae was effective.
- Clay had more P in solution in the first few days but decreased over time. A decrease in solution P could be due to adsorption into mineral surfaces or immobilization through microbial activity.
- Algae was amended to soil on day 14, and 6 days after application there was no notable released P.
- The preliminary incubation will continue to determine the time when P starts to be mineralized and released into soil solution.
- Preliminary findings support the design of a larger incubation experiment, which I will conduct this summer.

Research Question #2

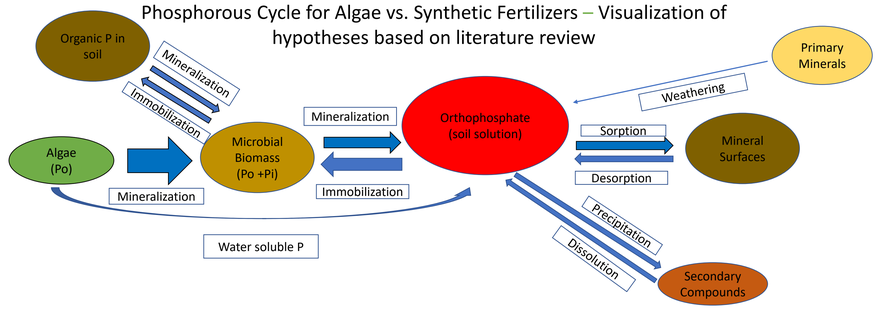


Figure 1. Phosphorous pools where algae derived P is expected to accumulate after 5-10 weeks of incubation. When algae is applied there is a rapid small concentration of available P released into the soil solution, but most of the P is in an organic form which is mineralized by microorganisms and eventually released into soil solution. This is expected to lead to a longer availability of P in the algae compared to the synthetic P treatments. Solution P undergoes an equilibrium phase with P adsorption into mineral surfaces and immobilization and re-mineralization of P by microorganisms.

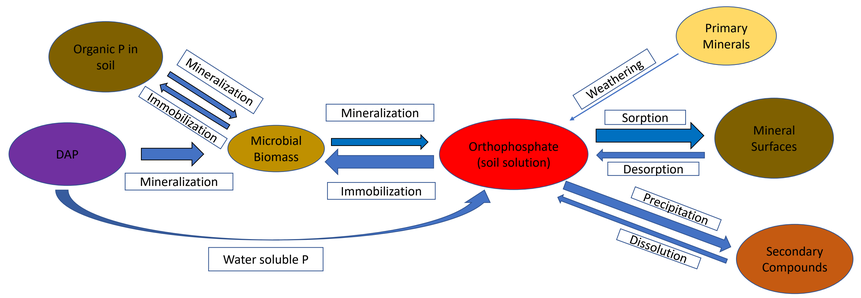


Figure 2. Phosphorous pools where synthetic fertilizer diammonium phosphate (DAP) is expected to accumulate after 5-10 weeks of incubation. In an early stage most phosphorous from DAP dissolves and becomes part of the soil solution P. However, overtime most phosphorous adsorbs to mineral surfaces and is immobilized. Since DAP does not add any organic material microorganisms need to use P in solution as a source of energy, which causes net immobilization in the soil. Some P also precipitates as secondary minerals, but this is highly dependent on the soil pH. Therefore, availability of P following the application of DAP is expected to be short-lived.

Research Question #3

Table 2. Data table with method information for P extraction.

Method	Description	Pros	Cons	Pool Targeted
Olsen P	Estimates the relative bioavailability of inorganic ortho-phosphate in soils with neutral to alkaline pH	Hydroxide and bicarbonate completely desorb phosphate from soil particles and secondary absorption is minimized because of high pH	The detection limit is only 1ppm (soil basis). Mostly useful only in neutral to alkaline soils	Inorganic P located in secondary compounds, mineral surfaces, and soil solution pools
Bray P	Estimates the relative bioavailability of inorganic ortho-phosphate in soils with acid to neutral pH	The complex formed after the chemical reaction is correlated to crop response	The method detection limit is 0.5 mg/kg soil and is reproducible within 8%	Inorganic P forms secondary compounds
Mehlich-3 Extractable P (M3EP)	A weak acid is used to displace P from the soil sorption complex. P is extracted by a reaction with acetic acid and fluoride compounds	Highly correlated with plant P uptake	Destructive and high disturbance in soil aggregates	Organic and Inorganic P
Phosphatase Extractable	Determines phenol released by enzymatic hydrolysis of phenyl phosphate, which assays phosphatase activity	Mineralization processes from organic P to inorganic P and immobilization processes can be assessed	Can only be done in alkaline soils	Organic and Inorganic P
Water Extractable	Demineralized water is used at different water-soil ratios, both water and soil on a volume basis. Extraction is done under intensive shaking and then P in solution is measured.	Determines plant available P in solution	Only measures dissolved P in solution	Soil Solution P
Rhizon Soil Solution Samplers	In-situ extraction of soil solution for nutrient analysis and mineral soils.	Fast, non-destructive, simple, economical, and has minimal effect on the nutritional status of the medium in the pot.	RSSS can be easily damaged. The RSSS must have a high moisture content medium before the sample can be extracted, which limits when the sample can be taken.	Soil Solution P (Total P)

Discussion and Conclusion

Phosphorous is highly important for microorganisms and plants as it is a yield-limiting nutrient in many soils. Conventional agriculture uses high amounts of synthetic fertilizers and ignore the use of organic fertilizers. Only a small fraction of the organic pool, about 1 % per year, is mineralized, supplying inorganic P for plant uptake. For this reason, it is important to implement the use of organic amendments to build the organic P pool to sustain healthy soils and high crop yields for many generations.

Literature Review:

- Diammonium Phosphate is categorized as a water-soluble P synthetic fertilizer with 85-90% water-soluble. There is no organic form of phosphorous for microorganisms to mineralize, thus there is a net immobilization process and sorption of P into mineral surfaces.
- Algae is an organic amendment that supplies organic P. There might be some immediate release of available P in the soil solution, this is soluble inorganic P fractions in the algae. However, microorganisms process all organic P through biochemical processes and extracellular hydrolysis to mineralize the organic material.
- Algae is a labile P source with a low C/N ratio that microorganisms can constantly use as fuel. The carbon source in algae fuels microbial activity which causes nutrients to stay in constant circulation and prevents it from being stuck in mineral surfaces for a long time.
- The following table summarizes the P form, and P pool where algae and DAP is expected to accumulate as well as the best method to extract phosphorous from the soil:

Table 1. Best extraction methods based on fertilizer amendment.

Amendment	P Form	Residing Pool After Applied	P Extraction Method
Algae	Organic and Inorganic P	Microbial biomass, and soil solution	Phosphatase extractable and rhizon sampler
Diammonium Phosphate (DAP)	Inorganic P	Water-soluble P, so resides in the solution P pool	M3EP

Optimization of Experimental Design:

- A preliminary incubation trial and research planning were conducted to improve the outcome of the algae incubation research experiment.
- There were 2 different soil textures used (clay and sand), at 50% and 60% field capacity (FC) in a blank treatment to analyze differences in evacuated volumes.
- It was determined that the largest extracted volume of soil solution occurred at 60% FC. Algae were then added to evaluate the release of total P in the soil solution over time.
- At least 1 to 2 weeks of pre-incubation of soil are required for solution P to stabilize. Once stable, soil amendments can be added to analyze change in soil solution P.
- The incubation trial will be continued to observe and compare P release patterns between algae, humic acid, DAP, and a blank treatment.
- Rhizon samplers will be used as the extraction method for a period of 6 weeks or more to determine the total concentrations of P released into soil solution over time.
- Phosphatase extractable carbon and M3EP will be conducted at the end of the incubation to assess where P released from the fertilizer products accumulated.

Acknowledgements & References

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Argo, W.R., Weesies, B.J., Bergman, E.M., Marshal, M., and Biernbaum, J.A. (1997). Evaluating Rhizon Soil Solution Samplers as a Method for Extracting Nutrient Solution and Analyzing Media for Container-grown Crops. *HortTechnology*

Errati, H., Bencheqroun, S.K., Aboutayeb, R., Abail, Z., Lebbar, S., Dari, K., and Hilali, L. (2022). Assessment of Red Seaweed Gelidium sesquipedale By-Products as an Organic Fertilizer and Soil Amendment. *Sustaiability.*

Jalali, M., and Jalali, M. (2020). Effect of organic and inorganic phosphorous fertilizers on phosphorous availavility and its leaching over incubation time. *Environmental Science and Pollution Research 27: 44045-44048.*

Kwabiah, A.B., et. al. (2003). Soil P availability as affected by chemical composition of plant materials: implications for P-limiting agriculture in tropical Africa. *Agriculture Ecosystems & Environment 53-61.*

Moller, K., et. al. (2017). Improved Phosphrous Recycling in Organic Farming: Navigating Between Constraints. *Advances in Agronomy 159-237.*

Oberson, A., and Joner, E.J. (2005). Microbial Turnover of Phosphorus in Soil. *Organic Phosphorous in the Environment 133-164.*

Shayesteh, H., et. al. (2022). Microalgae grown in abattoir wastewater: influence on te soil biotic and abiotic properties. *Journal of Cleaner Production.*

Tabatabai, M.A., Bremner, J.M. (1969). Use of p-Nitrophenyl phosphatase for assay of soil phosphatase activity. *Soil Biol. Biochem. Vol. 1, pp.301-307.*

Van Der Paauw, F. (1971). An effective water extraction method for the determination of plant-available soil phosphorous. *Plant and Soil 34: 467-481.*

Vaneeckhaute, C., Janda, J., Vanrolleghem, P.A., Tack, F.M.G., and Meers, E. (2016). Phosphorous Use Efficiency of Bio-Based Fetilizers: Bioavailability and Fractionation. *Pedosphere 26: 310-325.*

Zou et. al. (1992). A new method for estimating gross phosphorous mineralization and immobilization rates in soils. *Plant and Soil 147: 243-250.*