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13th Western Nutrient Management CONFERENCE

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13th Western Nutrient Management CONFERENCE

Speaker Presentations

Biostimulants: Their Function and Effective Use in Modern Agriculture

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Humic Products in Agriculture: Potential Benefits and Research Challenges

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ABSTRACT

Humic products have been used in cropland agriculture for several decades, but lack of widespread credibility has restricted their use to small proportions of farmers. To improve the credibility of humic products, we propose future actions to close four knowledge gaps. First, while the capacity of humic products to improve plant growth has been proven in greenhouse and growth chambers, more such work is needed in field conditions, especially to determine the modifying effects on humic product efficacy of environmental and management factors, including crop type, annual weather patterns, soil type, tillage, and fertilizer and water management. Most field studies on humic products fail to address any of these factors. Second, full acceptance of humic products by the research community may first require a mechanistic explanation for plant responses to humic products. Some research groups are exploring plant-based mechanisms, but almost entirely in controlled conditions, not under the variable stress conditions of the field. Industry often attributes yield responses to enhanced availability of one soil nutrient or another, without citing much evidence beyond increased nutrient uptake caused by greater crop biomass. Microbial-based explanations are also possible, but remain largely untested. Most recently humic products have become grouped together with biostimulants, in agreement with the plant-based mechanisms favoured by research groups. Third, consumer trust in available humic products would be strengthened through industry-wide measures for quality control of humic product production and sale. A standard procedure for measuring their humic and fulvic acid contents has been approved by state fertilizer regulators (Association of American Plant Food Control Officials) and the International Organization for Standardization (ISO). This procedure might be best used for distinguishing genuine humic products from fraudulent materials. To discern quality differences among genuine products, an assay for the as yet unidentified active ingredient(s) would be needed. Finally, humic products are widely presumed to promote root growth, which offers the potential to increase soil C inputs and thereby improve soil health, a topic of current great interest. Yet virtually no evidence has been presented for soil health benefits with humic product use, due to the absence of long-term field trials. Humic product companies have organized a trade association to promote a more knowledge-based industry and to collaborate with government regulators and researchers. We believe the industry will indeed become more knowledge-based and the credibility of humic products will improve as (i) we learn more about their field efficacy for improving crop yield and soil health in a variety of field conditions, (ii) we gain further insights into possible mechanistic explanations, and (iii) the consumer gains the ability to discern high-quality genuine products from fraudulent or lower-grade materials.

Winning the Battle Against Environmental Stress by Better Understanding Biostimulant Responses

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ABSTRACT

Biostimulants are increasingly being used by growers to manage environmental stress. Some examples of biostimulants include seaweeds, organic acids, plant based extracts, amino acids, fermentation products, algae, and reprocessed vegetative matter.

Holden Research and Consulting (HRC), an independent agricultural research firm in California, has conducted over 500 trials with biostimulants over the last ten years. HRC's findings indicate that they can be valuable tools in the management of problems caused by abiotic stress factors such as salt and heat.

HRC has closely studied and compiled data from various trials with multiple biostimulant products: the marine plant *Ascophyllum nodusum,* FB Sciences' Complex Polymeric Polyhydroxy Acids (CPPA), and California Safe Soils Harvest-to-Harvest (H2H - recycled food from supermarkets). These products have all demonstrated improved yields under high-induced salt conditions by an average of 28%, 96% and 112% respectively. A series of forty-three strawberry trials treated with biostimulants under good growing conditions resulted in 36% of these products improving yield by more than 10% prior to an environmental stress event. However, under heat stress brought on by a four day heat wave, 71% of these products showed better than 10% increase in yield after the heat event, indicating that optimum benefit may be seen from these products when utilized under stress conditions.

Although biostimulants are neither nutrients nor pesticides, they offer real value to the grower against environmental stress factors and are quickly becoming a valuable resource in the agricultural industry world-wide.

A Science-based Approach to Trialing Biostimulants and Interpreting Trial Data

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ABSTRACT

Whether you're reviewing product technical bulletins, or preparing to ramp up your field trial program, this talk will help you avoid common pitfalls in interpreting product data, designing trials, and analyzing trial data. This user-friendly introduction will help you put key statistical and scientific principles into practice. Topics to be covered, loosely ordered from simple to more involved:
(1) the effects of outliers on mean estimates, (2) the importance of controls that allow direct assessment of the active ingredient, (3) the dangers (and prevalence) of spatial bias in randomized complete block designs, (4) correcting p-values for multiple-hypothesis testing, (5) using power analyses to set the scope for your trial program. Get ready to love Latin squares, and data visualization! I will share real-world examples from field and greenhouse testing of products in the Koch Biological Solutions pipeline, using data generated by our plant physiology and agronomy teams.

Overview of the Efficacy of Biostimulants

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ABSTRACT

So-called “biostimulants” have been around a long time, but interest in these crop production products is growing exponentially. A survey of major fertilizer companies indicates it is one of the top three current trends in their businesses—with significant research, development, and investment. However, this major trend in agriculture is fraught with misperception, confusion, and generally lacking credentialed recommendations. Biostimulant is not listed as a word in major dictionaries or defined in encyclopedic references. The United States Department of Agriculture National Agricultural Library does not list biostimulant in their glossary of defined agricultural terms. Surveying the definitions provided by the organizations and individuals, including published scientists, immersed in this arena leads to the following definition used for the purposes of this presentation: a biostimulant is any combination of chemical substance(s) and/or microorganism(s) enhancing plant growth, abiotic stress tolerance, and/or crop quality traits, but not including fertilizers, pesticides, or large-scale soil amendments (such as limestone and gypsum). Biostimulants can be classified in the following categories: 1) humic and fulvic acids (or, more broadly, organic acids), 2) protein hydrolysates and other N containing compounds (such as amino acids), 3) seaweed extracts and botanicals, 4) chitosan and other biopolymers, 5) inorganic compounds (such as silicon), 6) beneficial fungi, and 7) beneficial bacteria. In our research, we have completed lab, greenhouse, and field trials with each of these classes of products (178 trials over the last two decades). Most of this work has been done in well managed, high yield environments for: potato, wheat, barley, corn, sugar beet, alfalfa, soybean, and dry bean. Additionally, we have conducted many trials on turfgrass, mostly Kentucky bluegrass. A meta-analysis shows only 22% of these trials resulted in significant positive increases in yields (financial considerations were not evaluated) with an average increase of 0.9%. Most of the positive responses were with use of organic acids in combination phosphorus (P) fertilizer. We have been able to show conclusively that, when applied properly to soils with a high likelihood of response (low soil-test P with poor P solubility) that we have a consistent increase in P uptake, often with a yield and/or quality increase. This organic acid data will be presented, as well as other examples of positive responses in other categories of biostimulants. Additionally, evidences and speculations on which crops and environmental/soil conditions are most likely to result in successful use of biostimulants, with an attempted explanation of why so many of our trials have failed to produce positive results. The overall objective of this presentation will be to attempt to answer the question “is the use of biostimulants a best management practice in agriculture?”

Adopting Quinoa in Eastern Idaho – An Investigation of Agronomic Practices

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ABSTRACT

Quinoa production area has been increasing rapidly in eastern Idaho in recent years. However, best management practices for quinoa production are yet to be determined in this area. Field experiments were thus conducted at two locations (e.g., Aberdeen and Tetonia) in eastern Idaho from 2016 to 2018 to evaluated agronomic practices for quinoa production. More successful quinoa production was demonstrated in Tetonia, where air temperature is mostly below 30°C during the summer. In contrast, quinoa plants failed to produce seeds in environments with high summertime temperatures (e.g., Aberdeen). Weed biomass from plots of narrower row spacing (e.g., 18 cm) was less than wider row spacing (e.g., 36 and 53 cm). Leaf area index of quinoa at 18-cm row spacing was greater than wider row spacing. Quinoa plants were thus able to develop a dense canopy under narrow row spacing to suppress weed growth.

INTRODUCTION

Quinoa (*Chenopodium quinoa* L.) originates from the Andes Mountains of South America (e.g., Bolivia, Chile, and Peru) (Bhargava and Srivastava, 2013). Its seeds are superior to some of cereal grains in the quantity and quality of protein and mineral nutrients (Wu, 2015).

For agronomic practices, quinoa does not have a high N requirement, and N rates in the range of 100 to 150 kg N/ha have been reported to produce reasonable yields (Erley et al., 2005; Geren, 2015). Quinoa yield could reach 3,500 kg/ha with an N rate of 120 kg N/ha (Erley et al., 2005). Quinoa is relatively drought tolerant, and it can produce acceptable yields (e.g., 1,053 kg/ha) with a seasonal water input (e.g., rainfall and irrigation) as low as 183 mm (Garcia et al., 2003; Razzaghi et al., 2012). It has also been reported yields reaching 3,700 kg/ha with water input of 450 mm (Garcia et al., 2003).

In eastern Idaho, quinoa production area increased from a few hectares in 2014 to 1,416 hectares in 2018 (Figure 1) (O'Connell, 2017). Despite the rapid increase, there are still limiting factors in quinoa production that have not been thoroughly investigated. One of the challenges is high temperatures during the summer. Quinoa performs better under cool temperatures (e.g., 15 to 20°C), and temperatures above 35°C could cause plant dormancy and pollen sterility, which can lead to severe yield losses (Liang et al., 2015; Peterson and Murphy, 2015). Thus, planting quinoa in locations of cool temperatures and/or adjusting planting dates to avoid high temperatures during its critical stages (e.g., flowering and seed fill) might be effective to maintain quinoa yield when varieties of heat tolerance are not available.

Weed management is another challenge in quinoa production. Quinoa is from the *Amaranthaceae* family, the same as redroot pigweed (*Amaranthus retroflexus* L.) and common lambsquarters (*Chenopodium album* L.) (Garcia et al., 2015). As such, available broadleaf herbicides could cause damage to quinoa, and to date, very few herbicides have been registered for weed control in quinoa production. Moreover, quinoa grows slowly after emergence (Garcia et al., 2015), and it does not compete well with weeds of early emergence and rapid development.

Adjusting agronomic practices (e.g., seeding rate, row spacing, seeding date, etc.) might thus enable quinoa to develop a dense canopy before the growth and development of weeds.

Since agronomic practices for quinoa production have not been thoroughly investigated in eastern Idaho, the objectives of the current study were 1) to evaluate quinoa growth and production in different environments, and 2) to evaluate the effects of planting date and row spacing on quinoa growth and weed competition.

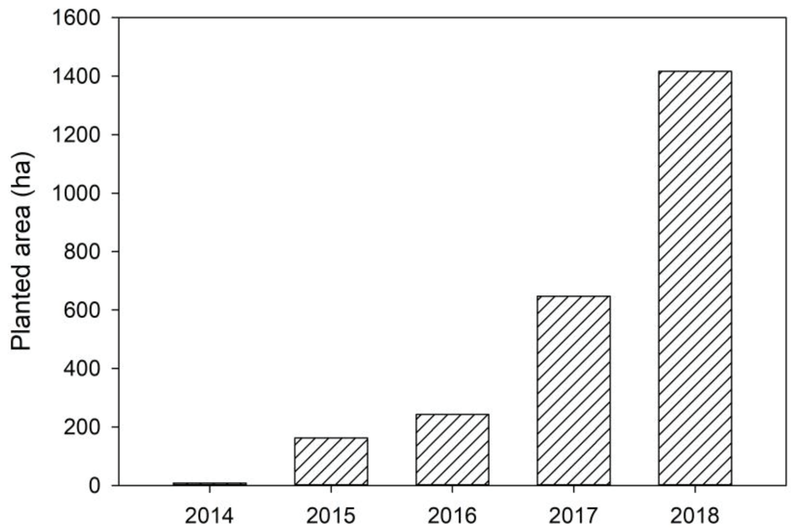

Figure 1 Quinoa production in eastern Idaho has been increasing rapidly.

MATERIALS AND METHODS

Field experiments were conducted at Aberdeen and Tetonia from 2016 to 2018 to evaluate effects of row spacing, planting date, and variety on quinoa growth and production.

Field Experiment at Aberdeen

A field experiment was conducted during the 2016 growing season at the Aberdeen Research and Extension Center at Aberdeen, Idaho. The soil was Declo loam. The quinoa variety was Cherry vanilla and planted in plots of 4.6 by 6.1 m. Quinoa plots were established at three row spacing (i.e., 18, 36, and 53 cm) and three planting dates (i.e., April 5, April 15, and April 25). The experiment followed a randomized complete block design with four replicates. Weed biomass was collected between quinoa rows in mid-June 2016. Irrigation was applied as needed through pipelines to ensure good crop establishment. No seeds could be harvested from any quinoa plot at the end of the season, and no result of seed yield was reported.

Field Experiments at Tetonia

Field experiments were conducted at Tetonia, Idaho in 2016 and 2017. Approximately 150 kg N/ha was applied prior to planting in both years following the recommendations for cereal production. Experimental plots of 4.6 by 6.1 m were established on June 3, 2016 and June 1, 2017. Plots were seeded using an Earthway Precision Garden Seeder at row spacing of 18 cm in 2016 and 36 cm in 2017. The experiments consisted of quinoa varieties of Cherry vanilla, French vanilla, Oro de Valle, and Red head, and arranged in a randomized complete block design with four replicates in both years. At maturity, quinoa plants were harvested from each plot on September 19, 2016 and September 12, 2017. Harvested plants were brought back to Aberdeen Research and Extension Center and air dried, and six to ten plants from each plot were selected and manually threshed. Biomass samples from each plot from 2017 were sent to an analytical lab for chemical composition analysis, including cell wall, cellulose, lignin, non-fiber carbohydrates, protein, and fat. Since quinoa was newly introduced to Tetonia area, irrigation was applied to ensure good crop establishment in 2016 and 2017. Irrigation application was through wheel lines following the irrigation recommendation for cereals.

In 2018, quinoa variety Cherry vanilla, French vanilla, Ore de Valle, and Biobio were planted at 18-, 36-, and 53-cm row spacing, and were arranged in a randomized complete block design with four replicates. Experimental plots of 3.0 by 4.6 m were established on June 6 and harvested on September 12, 2018. All plots were maintained under dryland conditions. In early July, each plot was evenly divided into weed-free and weedy subplots, and weeds were manually removed in weed-free subplots. Weed biomass was harvested between quinoa rows from each weedy subplot in July. Leaf area index was measured from each weed-free subplot in mid-August.

Data Analysis

In each experiment, data was analyzed using the generalized linear mixed model of SAS (ver. 9.4, SAS institute, Cary, NC) by considering treatment (e.g., variety, row spacing, and planting date) as fix effects and replicate as a random effect. All figures were generated using SigmaPlot (ver. 13.0 Systat Software Inc. San Jose, CA).

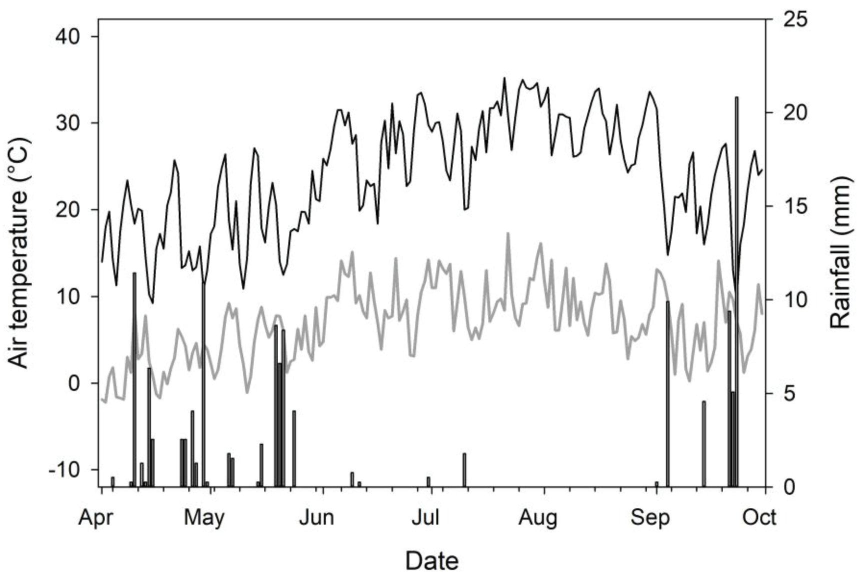

Figure 2 Daily maximum (black) and minimum (grey) air temperature and rainfall during the growing season of 2016 at Aberdeen, Idaho (https://www.usbr.gov/pn/agrimet/).

RESULTS AND DISCUSSION

Weather Conditions for Quinoa Growth and Production

Quinoa performs better under cool temperatures (e.g., 15 to 20°C), and temperatures above 35°C could cause plant dormancy and pollen sterility (Liang et al., 2015; Peterson and Murphy, 2015). At Aberdeen, total rainfall from April to September was 131 mm in 2016, and there were 44 days with daily maximum air temperature above 30°C (Figure 2). At Tetonia, total rainfall from May to September was 170 mm in 2016, 165 in 2017, and 245 mm in 2018. The number of days with daily maximum air temperature above 30°C was 7 in 2016, 4 in 2017, and 8 in 2018 (Figure 3). Quinoa plants are more tolerant to light frosts (e.g., -1°C) during vegetative stages, but more susceptible during flowering (Garcia et al., 2015). At Tetonia, the number of days with daily minimum air temperature below -1°C was 7 in 2016, 14 in 2017, and 17 in 2018, and most of these days were in May and late September.

Since air temperature during the summer at Tetonia is mostly between -1 and 30°C (Figure 3), which makes it a promising area for quinoa production. In contrast, quinoa failed to produce seeds in an environment like Aberdeen in 2016 (Figure 2).

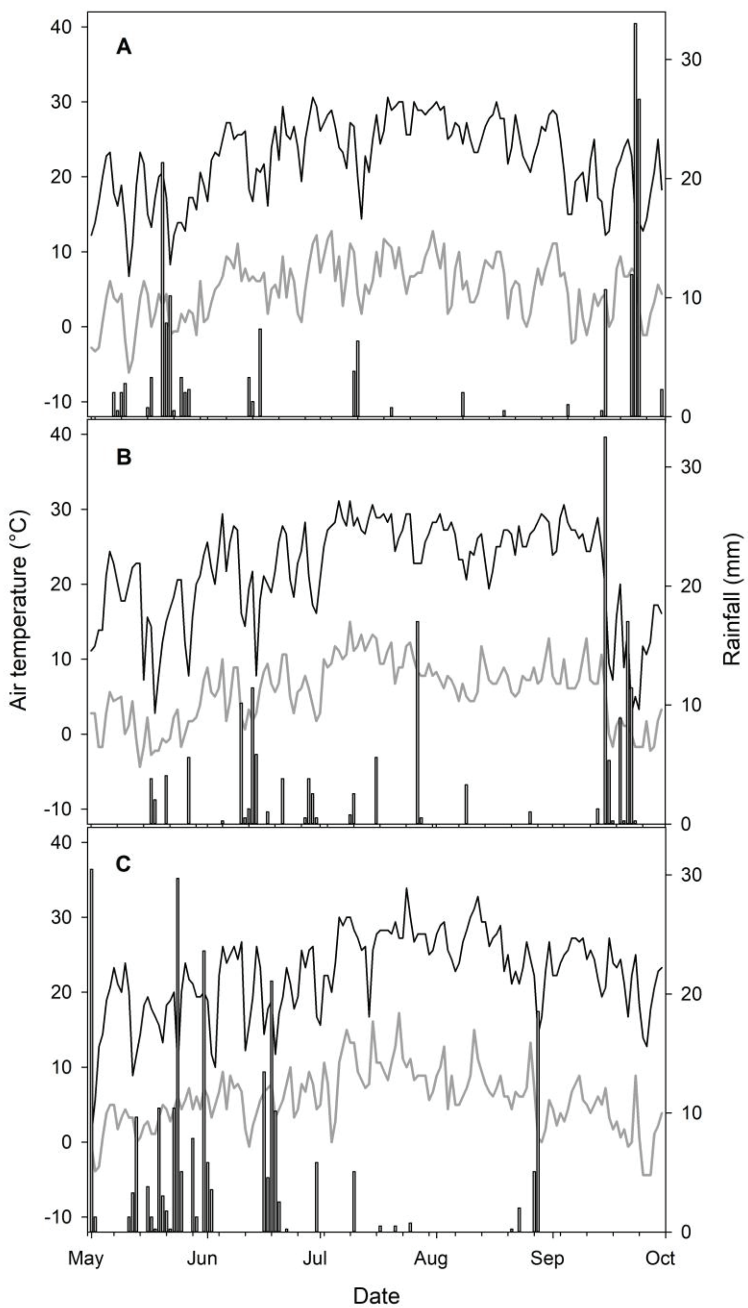

Figure 3 Daily maximum (black) and minimum (grey) air temperature and rainfall during the growing seasons of 2016 (A), 2017 (B), and 2018 (C) at Tetonia, Idaho (https://www.usclimatedata.com).

Effects of Row Spacing and Planting Date on Quinoa Growth and Weed Pressure

In the experiment conducted at Aberdeen in 2016, common lambsquarters and witchgrass (*Panicum capillare* L.) were the most prevalent weeds, and other weed species included redroot pigweed, common mallow (*Malva neglecta* Wallr.), cutleaf nightshade (*Solanum triflorum* Nutt.), hairy nightshade (*Solanum physalifolium* Rusby), common purslane (*Portulaca oleracea* L.), and shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.). No interaction between row spacing and planting date was found. Total weed biomass collected between quinoa plant rows was significantly less at 18-cm than 36- and 53-cm row spacing (Figure 4A). Weed biomass collected from plots planted in early April was lower than that collected from plots planted in mid- and late April, and the difference was almost significant (Figure 4B).

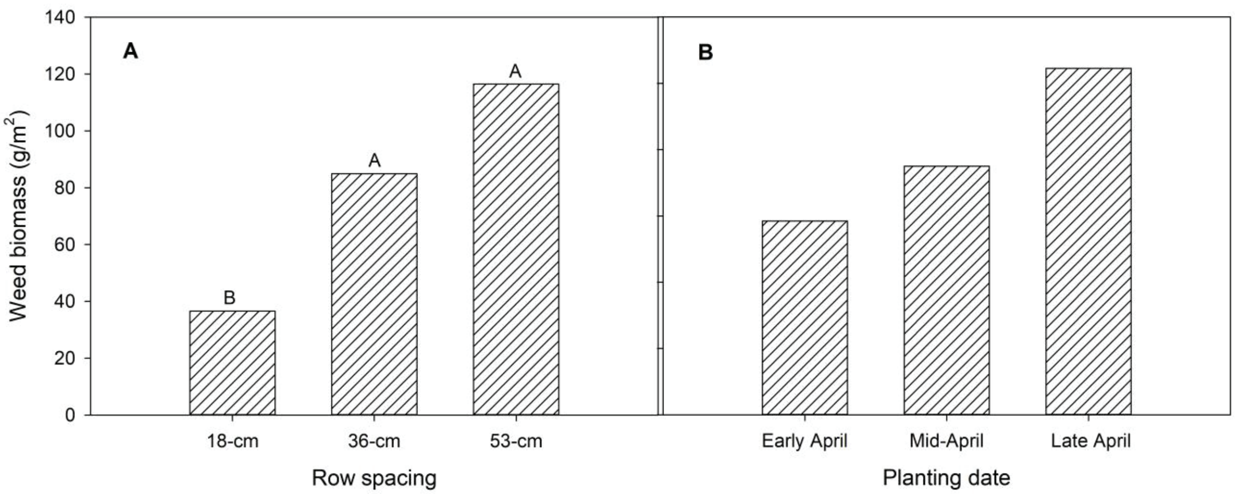

Figure 4 Weed biomass collected between quinoa rows was affected by row spacing ($P = 0.001$) (A) and planting date ($P = 0.065$) (B) at Aberdeen in 2016.

In the experiment conducted at Tetonia in 2018, redroot pigweed, shepherd's purse, cutleaf nightshade were the most prevalent weeds. No interaction between row spacing and variety was found. Total weed biomass collected between quinoa rows was significantly less at 18-cm than 53-cm row spacing (Figure 5A). Leaf area index of quinoa planted at 18-cm row spacing was greater than 36- and 53-cm (Figure 5B).

Similar results were reported in United Kingdom that weed competition was intense following late sowings (e.g., May) (Risi and Galwey, 1991). Long duration of weed interference could reduce crop leaf area index, which causes a reduction in light interception for photosynthesis (Ghanizadeh et al., 2014). Thus, planting quinoa at an early date and/or narrow row spacing enables quinoa to develop a dense canopy before the growth and development of weeds.

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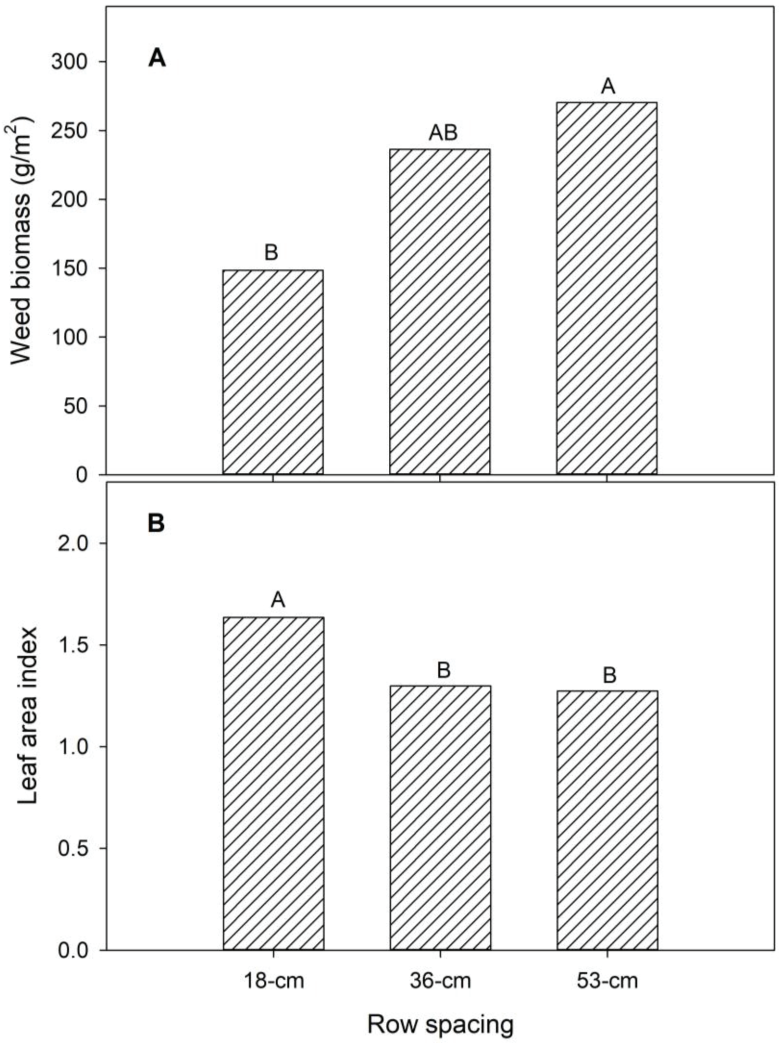

Figure 5 Weed biomass (P = 0.044) collected between quinoa rows and quinoa leaf area index (P = 0.005) were affected by row spacing at Tetonia in 2018.

Seed Yield and Biomass Chemical Composition

In 2016, seed yield was averaged 19 g/plant among quinoa variety Cherry vanilla, French vanilla, Oro de Valle, and Red head (Figure 6). In 2017, French vanilla and Oro de Valle produced relatively higher seed yield than the other two varieties, but the differences were not significant ($P > 0.05$). Cellulose concentration of Oro de Valle was relatively higher than other varieties, although the differences were almost significant (P = 0.060) (Table 1). No difference was found among varieties in concentrations of cell wall, lignin, non-fiber carbohydrate, protein, or fat ($P > 0.05$).

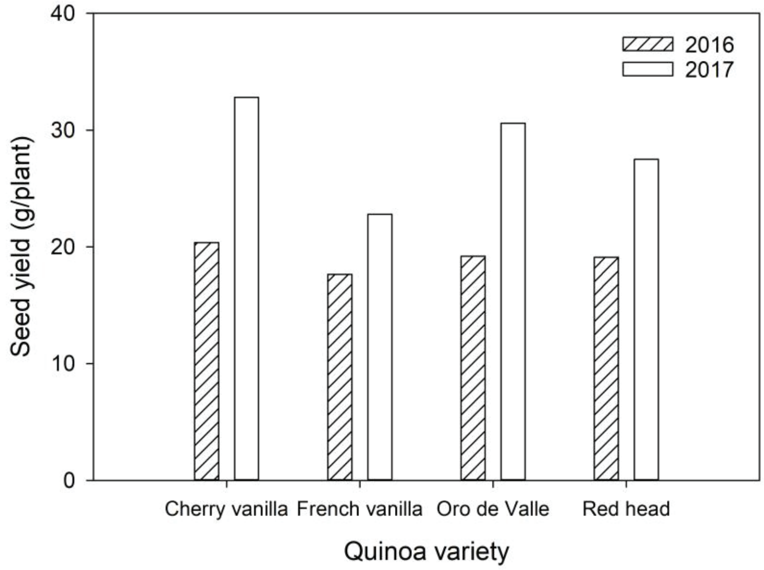

Figure 6 Quinoa seed yield was not different among varieties in 2016 or 2017 ($P > 0.05$). The row spacing was 18 cm in 2016 and 36 cm in 2017 at Tetonia.

Table 1 Chemical composition of quinoa biomass.

Variety	Cell wall	Cellulose	Lignin	Non-fiber carbohydrate	Protein	Fat
			% dry matter			
Cherry vanilla	72.6	47.2	9.91	12.0	5.25	0.45
French vanilla	71.4	45.4	9.68	13.9	4.90	0.38
Oro de valle	70.6	43.9	9.65	13.4	5.18	0.52
Red head	72.8	47.0	10.2	12.5	5.72	0.36
P-value	0.435	0.060	0.635	0.342	0.719	0.160

Biomass samples were from the experiment at Tetonia in 2017.

Compared with straws of cereals (e.g., barley, oat, and wheat), quinoa has higher concentrations of protein and lignin, similar cellulose, but lower cell wall and fat (Anderson and Hoffman, 2006; Feyissa et al., 2015). Non-fiber carbohydrate, protein, and fat are categorized as labile components, whereas lignin is classified as recalcitrant. Generally, decomposition rates of plant tissues are negatively associated with concentrations of recalcitrant components (Prescott, 2010). Considering the differences in chemical composition, the decomposition of quinoa biomass might be different from cereal straws, but further research is need to investigate contributions of quinoa biomass to soil carbon and its impacts on soil health.

SUMMARY

From the current study, more successful quinoa production was demonstrated in Tetonia, where air temperature is mostly lower than 30°C during the summer. In contrast, quinoa plants failed to produce seeds in environments with high summertime temperature (e.g., Aberdeen). According to the weed biomass collected between quinoa rows and quinoa leaf area index, planting quinoa early and/or in narrow rows enables quinoa to develop a dense canopy before the growth and development of weeds. No differences were found in seed yield or chemical composition among quinoa variety Cherry vanilla, French vanilla, Oro de Valle, and Red head, but there might be slight differences in chemical composition between quinoa biomass and cereal straws. Such differences might result in variances in contributions to soil carbon and impacts on soil health, where further research is needed.

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Nutrient Management for Optimum Fruit Quality in Apple Orchards with High Density Systems

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Nutrient Management in Asian Leafy Vegetables

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ABSTRACT

Asian leafy vegetables are grown intensively in open field and protected agricultural systems. In protected agricultural systems some of the vegetables are grown 6-7 times per year in continuous rotations with a 15-day gap between each rotation. Grown primarily in Fresno, Monterey, Riverside, San Bernardino, Santa Clara, San Luis Obispo, and Ventura counties on around 7026 acres, Asian vegetables are valued at $79 million. In Fresno and Santa Clara counties these crops are grown primarily by limited resource, small farm, minority and disadvantaged Chinese, Hmong, and other Asian immigrant farmers. A recent survey of nitrogen (N) fertilizer use for some of the Asian vegetables was found to be as follows: bok choy up to 140 lb/acre, garlic chives up to 500 lb/acre, on choy (Water Spinach) up to 400 lb/acre. With proposed regulations under the Irrigated Lands Regulatory Program by the Central Coast Regional Water Quality Control Board (CCWQCB) and the Kings River Water Quality Coalition to control N application, it's important to understand N uptake in crops that have significant acreage but do not have commodity board support. The overall goal of this project was to provide detailed measurements of total N uptake and the N uptake pattern of bok choy, on choy, garlic chives, daikon and lemongrass. Total N is crucial for viable crop production, but irrigation efficiency is vital to retaining the applied N within the crop root zone. This project also evaluated the current irrigation management practices of these crops and compared it with their water requirements to help identify potential practices that may help reduce nitrate leaching. The information collected will provide the basic information necessary for growers to better manage N inputs to these crops and protect water quality. We report here on the first year of research on bok choy, its crop canopy development and nutrient uptake patterns under greenhouse production systems.

Evaluating and Revising Guidelines for Blueberry Tissue Nutrient Standards in Washington

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ABSTRACT

Leaf tissue nutrient analysis is frequently used in perennial fruit crops to develop nutrient management plans. In blueberry, samples historically are collected between 15 July - 15 August and the results are used for planning nutrient management the next growing season.

Northern highbush blueberry tissue nutrient standards were initially developed by Michigan State University and have recently been revised for western Oregon.

However, the proliferation of blueberry production in eastern Washington and Oregon has raised the question as to whether blueberries grown in acidified soils that have a calcium-based chemistry would show the same nutrient profile as those grown in traditional areas where the soils are naturally acidic. Climate also differs, which could impact the temporal dynamics of perennial plant nutrition.

To answer this question, we conducted survey work in both eastern and western Washington during the 2015, 2016, and 2017 growing seasons. Two to three fields of early- ('Duke'), mid- ('Draper'), and late-season ('Aurora' or 'Liberty') cultivars were identified in each of the two growing regions. Beginning in mid-May, leaf tissue samples were randomly collected from three replicated areas in each field. The samples were collected twice monthly, at the middle and end of each month, through mid-September each year. Samples were dried, ground, and analyzed for plant nutrient concentration.

In addition to collecting leaf samples from a single position in the blueberry plants, intensive sampling on one cultivar (Duke) was done in both eastern and western Washington in late July 2016 and 2017. To determine if canopy or lateral position influenced nutrient concentration, leaves were sampled at three different positions in the canopy (lower, mid, and upper 1/3rd) as well as three different lateral positions (youngest fully expanded leaf, leaf subtending the basal fruiting cluster, or oldest fully expanded leaf).

Consistent with other research, there were no significant differences in leaf nutrient concentrations by cultivar. However, there were differences by growing region (east or west) as well as by canopy, but not lateral, position. The results of this study suggest that leaf tissue samples in blueberry should be collected mid-canopy. In addition, the results suggest that most of the nutrients are most stable between mid to late August, which is a later sampling period than recommended from research in both Michigan and Oregon. Recommended tissue nutrient ranges for eastern and western WA, plus the current ranges for Oregon and Michigan, are provided in **Table 1**.

Element (unit)	Oregon State [1]	Michigan State[2]	E Washington	W Washington
Nitrogen (%)	1.76 - 2.00	1.70 - 2.10	1.25 - 1.75	1.50 - 2.00
Phosphorus (%)	0.11 - 0.40	0.08 - 0.40	0.08 - 0.15	0.10 - 0.20
Potassium (%)	0.41 - 0.70	0.40 - 0.65	0.40 - 0.50	0.50 - 0.65
Calcium (%)	0.41 - 0.80	0.30 - 0.80	0.50 - 0.85	0.50 - 0.85
Magnesium (%)	0.13 - 0.25	0.15 - 0.30	0.11 - 0.17	0.15 - 0.20
Sulfur (%)	0.11 - 0.16	0.12 - 0.20	0.12 - 0.15	0.12 - 0.15
Boron (ppm)	30 - 80	25 - 70	30 - 60	40 - 70
Copper (ppm)	5 - 15	5 - 20	5 - 10	5 - 10
Iron (ppm)	60 - 200	60 - 200	60 - 200	60 - 200
Manganese (ppm)	30 - 350	50 - 350	100 - 300	100 - 300
Zinc (ppm)	8 - 30	8 - 30	10 - 15	10 - 25

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Soil Acidification: Identification, Prevention, Adaptation and Restoration

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ABSTRACT

Low soil pH is becoming far more common in Montana soils, with at least 23 counties having at least one field with pH less than 5.5. Soil pH levels in the top 6 inches as low as 3.8 have been measured, resulting in complete crop failure in some locations, yet the problem is highly variable across fields and within soil profiles. Nitrogen fertilizer rates applied above crop nitrogen needs are the largest cause of the acidification. Low soil pH should be verified before management practices that could prevent or restore low pH soil are adopted. Plants and roots can show symptoms of aluminum toxicity, and legumes often have poor nodulation. Soil pH testing the top 0 to 3, and 3 to 6 inch depths is recommended in suspected low pH areas because the standard 0 to 6 inch field-composited sample can mask pH problems. Prevention strategies include modifying fertilizer source, rate, placement, and timing to maximize nitrogen use efficiency and selecting crops that require less N such as pulses, malt barley, and perennials. In addition, leaving more crop residue can help slow acidification. Adaptation includes selecting crops and varieties that are more tolerant to low pH, or applying high rates of phosphorus with, or near, the seed. Restoration strategies revolve around liming, yet there is a lack of readily available and inexpensive lime in Montana. Determining liming rates require soil buffer pH tests, soil pH, or strip trials. Lime sources and rates appropriate for Montana soils are still being evaluated. Opportunities are numerous for crop advisers, including providing advice on prevention/adaptation strategies, as well as mapping low pH areas to apply variable rates of nitrogen and/or lime across a field.

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Lime Management

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Soil Sodicity

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ABSTRACT

Soil sodicity refers to the amount of sodium held on soil cation exchange sites. It is typically expressed either as the percentage of the soil cation exchange capacity filled with sodium ions (exchangeable sodium percentage or ESP), or as a ratio comparing exchangeable sodium to exchangeable calcium plus magnesium (sodium adsorption ratio or SAR). Our primary interest in soil sodium is its impact on soil structure. Sodium, like all soil cations, can flocculate clay particles if present in adequate quantities, but sodium is a very weak flocculator. As a consequence, soils affected by high levels of sodium are likely to be poorly aggregated or to have weak, unstable aggregates. These soils often exhibit slow water infiltration and poor internal drainage, as well as elevated pH. We will explore the relationship between soil salinity, soil sodicity, and physical soil attributes as well as management options for dealing with sodium-affected soils.

INTRODUCTION

Soil sodium is of interest primarily because of its impact on soil structure. Soil aggregates are conglomerations of sand, silt, clay, and organic matter particles. Aggregate size, shape, and strength comprise what is referred to as soil structure. Aggregates are larger than primary soil particles and the relatively large pores between aggregates (inter-aggregate pores; open spaces in the soil volume) are critical for water infiltration into soils, root penetration, soil drainage, and soil aeration. Aggregation is to some extent a *manageable* soil physical property, unlike soil texture for example. Inter-aggregate pores are large relative to the pores within aggregates which may be too small for effective water movement, and may be too small even for root hairs to enter. In all but the sandiest soils, which have large pores between sand grains, good aggregate structure is critical for maintaining conditions conducive to plant growth. Good soil structure provides open pathways that roots grow through and large pores that transmit water and, when empty, supply plant roots with essential oxygen.

PRINCIPLES

In most temperate-region soils, clay particles carry a negative electrical charge. Negatively-charged particles repel one another due to electrostatic repulsion forces, but soil particles can be bound together into aggregates by positively charged molecules (cations). The process of aggregate formation, flocculation, is promoted by the presence of adequate levels of flocculating cations. The dominant soil cations in medium to high pH soils are the monovalent cations (one positive charge per molecule) sodium (Na^+) and potassium (K^+), and the divalent cations (two charges per molecule) magnesium (Mg^{2+}) and calcium (Ca^{2+}). In acidic soils the trivalent aluminum cation (Al^{+3}) is present. Of these cations Al^{3+}, Ca^{2+}, and Mg^{2+} are effective flocculators; Na^+ and K^+ are not. The relative amounts of “weak” and “strong” flocculators can give an indication of how likely a soil is to flocculate or to remain flocculated. Exchangeable Sodium Percentage (ESP) or Sodium Adsorption Ratio (SAR), can be used for this purpose:

$$ESP = 100\times\left(\frac{Na^{+}}{Cation\ Exchange\ Capacity}\right)$$

$$SAR = \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}}$$

where Na^{+}, Ca^{2+}, Mg^{2+} concentrations and Cation Exchange Capacity are expressed in units of charge ($cmol_c$/kg of soil).

Rengasamy and Marchuk (2011) proposed the Cation Ratio of Structural Stability (CROSS) that more precisely predicts the impacts of soil cations than the SAR calculation. This was later modified ($CROSS_{opt}$) by Oster et al. (2106). CROSS adds potassium to the SAR calculation and modifies the relative impacts of individual ions.

$$CROSS_{opt} = \frac{(Na + 0.335K)}{\sqrt{\frac{(Ca + 0.0758Mg)}{2}}}$$

Soil particle flocculation is promoted not only by a high proportion of effective flocculating cations, but also by a high concentration of ions in general, which is denoted by a high salt content. Soil salt levels are measured and expressed as Electrical Conductivity (EC) in units of deciSiemens per meter (dS/m). High EC indicates the presence of large quantities of salt ions. Soil flocculation is promoted in high EC soils.

To fully understand soil aggregation or dispersion (lack of aggregation), we must simultaneously consider both soil sodicity and soil salinity. Figure 1 shows the relative effects of ESP (on the vertical axis) and salinity level expressed as $mmol_c$ of salts (on the horizontal axis) on soil aggregate stability as reflected in water infiltration rate. If soil ESP is low, meaning that the Na concentration is relatively low, then the soil likely has stable aggregates and accepts water readily. On the other hand, aggregates in soil with high levels of salinity can remain stable even in soil with a high sodium levels. Those soils with a combination of low sodium and low salinity are most subject to loss of aggregation, or dispersion, which can result in declining permeability. Ultimately, both sodicity and salinity profoundly affect extent and stability of soil aggregates. However, high levels of soil salinity that improve flocculation may not provide a good environment for growth of salt-sensitive plants because the level of salinity needed to flocculate sodic soils may be too high for optimum plant growth. Conditions that promote good soil physical properties may not always promote plant growth.

Sodium-impacted soils typically have pH levels higher than other soils. Whereas the pH of calcium carbonate containing soils is generally no higher than approximately 8.5, the presence of sodium carbonate minerals can raise soil pH above 9.0. The indirect effect of extremely alkaline soils is primarily related to nutrient availability limitations.

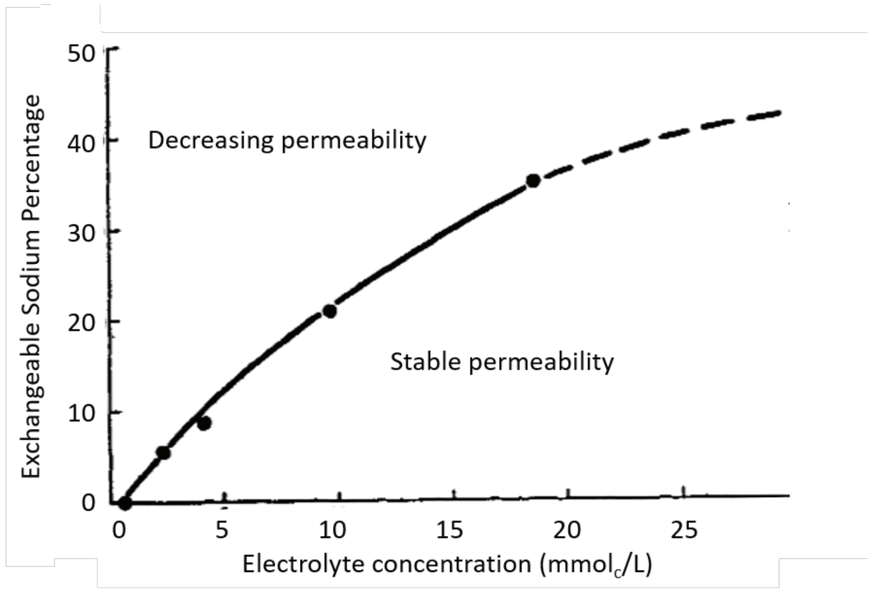

Figure 1. Effects of ESP and Electrolyte Concentration on Soil Permeability (Quirk and Schofield, 1955).

PROPERTIES OF SODIUM-AFFECTED SOILS

The most noticeable properties of sodium-impacted soils are slowed water infiltration and poor drainage. In these soils, irrigation water and rainfall soak into the soil slowly, or pond and run off the soil surface. Soil profile water will drain slowly, so salts added in irrigation water or from other sources accumulate, elevating soil salinity levels. Soil salinity may reach phytotoxic levels, resulting in reduced plant growth and crop yields. When sodium-affected soils dry, they may form surface hard crusts that can impede seedling emergence. For these reasons, it is important to measure both soil salinity and soil sodium. Additionally, thorough evaluation requires irrigation water analyses because this water is typically the major source of both soil sodium and salts in irrigates soils. Over time, characteristics of irrigated soils will reflect the properties of the irrigation water. At minimum, irrigation water analysis should include EC, SAR or CROSS, carbonate, and bicarbonate.

According to USDA classification a soil is classified as saline, meaning is contains excess salt, if the EC is greater than 4 dS/m. Soil is classified as sodic if the ESP is greater than 15% or if SAR is greater than 13. A saline-sodic soil has an EC greater than 4 dS/m and an ESP greater than 15% or an SAR greater than 13. Soil aggregation and water infiltration of sodic soil are expected to be most adversely affected in sodic soils because of their relatively high levels of sodium and low levels of salinity (low EC). Sodic soils are extremely difficult to manage and are, fortunately, rare. However, soils not classified as sodic (i.e. ESP < 15 or SAR < 13) also can be negatively affected by sodium. We can properly refer to these as sodium-affected soils even though they are not "sodic" according to USDA specifications. The precise ESP or SAR value at which soil structure is degraded is dependent on soil salinity level, as we have seen, and also soil texture and mineralogical composition. For example, a very sandy soil may contain enough large pores that water moves through the soil profile, even in the presence of large amounts of sodium.

A classification scheme presented by Sumner et al. (1998) has greater resolution than the USDA classification, and clarifies the relationship between salinity and sodicity with respect to soil structural stability (Figure 2). Note that the method of measuring sodicity and salinity are different than those typically used in the United States (they are measured in a 1:5 soil:water extract rather than in a saturated paste extract). Although the actual values are not directly transferable, the concepts and relationships are instructive as the figure shows how salinity and sodicity impact strength and stability of aggregation.

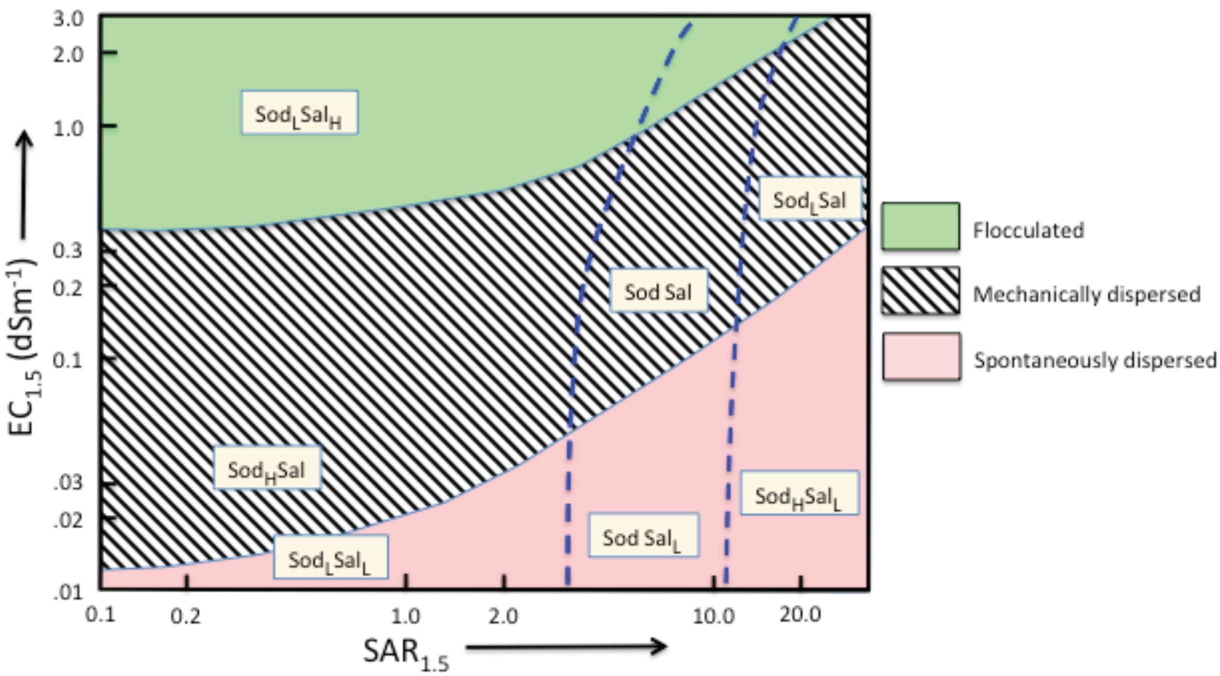

Figure 2. Proposed scheme for description of Na-affected soils in terms of physical behavior (dispersibility) and sodium (Sod) and salinity (Sal) classes (Sumner et al., 1998).

MONITORING AND MANAGEMENT

It is useful to consider sodium impact functionally by looking at how sodium affects physical properties of soil, in addition to quantitative measurements. Soil managers can monitor and track soil EC and ESP (or SAR or CROSS) to look for long-term trends. Salinity and sodicity change slowly, so it's important to conduct routine soil sampling and analysis and to track changes occurring over multiple years that can indicate increasing salinity or sodicity. Changes that may identify declining soil aggregate stability also can be detected by watching for slowing water infiltration rates over time.

Excess soil sodium can be addressed by increasing the amount of soluble soil calcium. Elevated soluble calcium mitigates the negative effects of sodium by encouraging flocculation of clay particles, and stabilizing soil structure. There are two alternatives for increasing soluble soil calcium: solubilize calcium already present in the soil, or add supplemental calcium.

The first option, solubilizing existing soil calcium, can work only if the soil contains calcium carbonate ($CaCO_3$) minerals, soils known as calcareous. Soil carbonates are identified on soil test reports as the level of "free lime." One also can test for the presence of carbonates by putting a drop of dilute acid on them and observing whether or not the soil effervesces or bubbles as the carbonate reacts with the acid to produce carbon dioxide gas (Figure 3). In soils with "medium" or "high" or "very high" free lime or reacting vigorously when combined with acid, an acid can be applied to dissolve soil calcium carbonate. As the acid dissolves calcium carbonate the released calcium reacts with soil clays, acting as a flocculant. The most commonly used acid is sulfuric acid

(H_2SO_4), although other acids can perform the same function. Sulfurous acid (H_2SO_3) can be produced on-site in agricultural fields by combustion of elemental sulfur in a "sulfur burner." Additionally, acid-forming materials such as elemental sulfur can be used. Elemental sulfur is converted to sulfuric acid by sulfur-oxidizing soil bacteria, producing sulfuric acid. Sulfur conversion to sulfuric acid is a biological process, and requires several weeks to months to take place, depending on soil conditions. Acids and acid-forming materials will only be effective in calcareous soils.

Figure 3. Test for the presence of soil carbonates by adding a drop of acid. Calcareous soils will produce carbon dioxide bubbles.

Alternatively, calcium-bearing minerals can be amended to soil as a source of soluble calcium. Gypsum ($CaSO_4 \cdot 2H_2O$) is the most common. Closely related anhydrite ($CaSO_4$) is also used. Chemically, these two minerals are very similar, the difference being that calcium sulfate anhydrite does not contain water. Consequently, calcium sulfate anhydrite contains more calcium on a weight basis than gypsum (anhydrite contains 29.4% Ca; gypsum 23.2% Ca). Both of these minerals are mined, and then ground into a powder for use as soil additives. Additionally, by-product gypsum materials, waste products of phosphate fertilizer production (phospho-gypsum) or from power plant stack scrubbers (flue gas desulfurization gypsum), are also used.

Calcium carbonate or limestone is another calcium mineral used as a soil amendment and is referred to as lime or agricultural lime. The main use of lime is to raise soil pH (to reduce acidity). It's not an appropriate source of calcium in high pH arid-region soils because it is only soluble in acidic soils.

SUMMARY

Dissolved or exchangeable sodium can degrade soil physical properties by affecting soil flocculation/dispersion. Soil cations vary in their ability to flocculate soils, and sodium is the weakest flocculator of the common soil cations. Irrigation water is the primary source of salts and sodium in irrigated soils. High levels of sodium and, to a lesser degree potassium, in conjunction with low levels of calcium and magnesium, weakens and degrades soil structure. This can impede water movement into and within the soil profile and result in accumulation of soil salts.

Irrigation water and soil sodium should be monitored, and mitigating strategies adopted if sodium inputs threaten soil structural stability. Available soil treatments include various methods of solubilizing existing soil carbonate minerals or adding soluble calcium forms.

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Managing Soils for CO_2 Drawdown: Boon or Boondoggle?

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ABSTRACT

Consensus is growing that meeting the goal of a two degree or less global warming will not only require aggressive greenhouse gas emission reductions across all sectors of the global economy, but also active measures to remove CO_2 from the atmosphere. Among the broader suite of CO_2 removal (CDR) strategies, soil C sink approaches have been deemed as being among the most ready for early deployment and having the greatest net environmental benefits. A variety of existing management practices are known to have the capacity to increase soil C stocks on most agricultural lands, including improved crop rotations, cover crops, reduced tillage intensity, conversion of marginal cropland to perennial grasses, improved grazing systems and organic amendments. New 'frontier technologies' which are still in the research phase, if successfully developed and implemented, could provide additional capacity for increasing soil C storage. Among these potential technologies are enhanced root phenotypes for annual crops, perennialized grain crops and biochar applications. The technical potentials for soil C sequestration these CDR approaches are significant and if fully implemented could sequester up to 3 Pg CO_2 yr^{-1} with existing technologies and up to 8 Pg CO_2 yr^{-1} if these new frontier technologies were widely implemented. However, achieving such levels of CO_2 removals via soil management is subject to a variety of constraints. Among these constraints are: the need for efficient, low-cost quantification and tracking systems for these dispersed, non-point soil C sinks; incentive policies to engage the millions of individual land manager involved; leakage effects associated with any land use/land cover changes; sink losses, either inadvertent or intentional; indirect impacts on other radiative forcing factors (e.g., non CO_2 gases, albedo). Critically, strategies for soil C sequestration at scale will need to be compatible with, and hopefully synergistic with, meeting the rapidly increasing global demands for food and fiber, while reducing the overall environment footprint of agriculture.

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Use of Biological Soil Tests to Assess Soil Health and Productivity

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ABSTRACT

Crops require sufficient nitrogen (N) to attain maximum yield potential. The intrinsic N supplying potential of soils is both directly and indirectly related to soil health. Soil health can reliably be predicted with existing soil tests, however, the ability to predict soil N availability, an important proxy for soil health, remains problematic due to a lack of a robust soil tests. As a result, fertilizer recommendations are often made without an accurate assessment of the amount of N that can be potentially made available through mineralization. This information gap has led to fertilizer recommendations that may lead to excessive fertilizer N inputs and decrease fertilizer N use efficiency. Excessive N input may also decrease yield potential of certain crops in addition to negatively affecting the environment. This omission of soil N mineralization potential is exacerbated in soils managed to promote soil health through the application of organic waste amendments and the use of cover crops and crop rotation. The close coupling of the C and N cycles theoretically should allow for biologically based estimation of long-term N mineralization using short-term cumulative CO_2 evolution, as shown in some previous studies. Biologically based tests allow for an estimation of available soil N by incubating soil samples at temperatures and moisture contents that facilitate N mineralization, providing a proxy to estimate N mineralization potential. A variety of biologically based soil tests, both lab-based and in situ, have been used to estimate growing season N mineralization. This has been demonstrated in dairy-amended soils, which showed a correlation between 24-hour CO_2 production and 28-day N mineralization. Other studies have shown a correlation between 72-hour CO_2 and 28-day N mineralization in unamended soils. However, the sensitivity of mineralizable C to changes in management did not differ among incubation intervals of 6, 24, and 72 h. While these procedural effects may influence inter-laboratory variability, there was also a considerable amount of analytical variability associated with mineralizable C measurements within a laboratory that is highly dependent on soil type. Generally, better correlations can be made in soils with higher organic matter content or consistent additions of organic based fertilizers. Mineralizable C had twofold to 20-fold greater inter-laboratory variability than other commonly used soil tests, leading to a high degree of uncertainty associated with the interpretation of results. Overall, regardless of soil management, soil respiration based tests to estimate growing season soil N mineralization are variable and their use requires more testing to develop relationships to accurately predict in season soil N mineralization and soil health status.

Soil Diversity and Agricultural Adaptation Across Micronesia

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ABSTRACT

Micronesia, a sub-region of Oceania, comprises approximately 2,100 small islands belonging to five sovereign nations scattered across 2.9 million square miles of the Western Pacific. A majority of the islands are low-lying, sandy coral atolls, but high volcanic islands and raised limestone islands are major population centers in the region. Palau, in the west, was first settled by seafaring peoples as early as 4000-4500 BP and the colonization of Marshall Islands at the eastern edge of the region was between 2000 - 3000 BP. While the low-lying atolls show little soil development, the high islands show remarkable soil diversity despite a small land area. The accumulation and maintenance of soil organic is the primary source of fertility and resilience of these soils, especially in the sandy Entisols of the atolls and the highly weathered, oxidic soils of the wet high islands. Prior to European contact, island populations across the region met their food, fiber and fuel needs for many generations through the development of biodiverse agroforest production systems well-suited to the different soils and landscapes. The agroforest systems are characterized by high species diversity and richness, and the food crops are nutrient dense supplying a balance of essential minerals, vitamins and starches. Rapid political, social and economic change, driven by globalization and modernization, threatens the traditional fabric of these fragile island cultures with potentially dire environmental and social consequences. However, a strategic coupling of traditional practices and appropriate technology adaptation provides alternatives to navigate an increasingly uncertain future.

Wastewater Reuse in the Arid West: Increased Water Supplies and New Paradigms for Nutrient Management

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ABSTRACT

Irrigated agriculture in the western United States is one of the most productive systems in the world. However, in recent years the security of water supplies for agriculture have come into question. Currently states that use Colorado River water are in the process of formalizing drought contingency plans to prevent reservoirs along the Colorado River from going dry. Competition for water with the agricultural sector include both urban and environmental uses. Treated municipal effluent represents a potentially stable water supply for irrigation. In addition to meeting ET needs, treated municipal effluent can provide nutrients for agriculture. Understanding nutrient content in treated effluent that will be used for irrigation is important in formulating an overall neutral management plan. In addition, opportunities for increasing nutrient availability while decreasing energy requirements at treatment plants may offer a more sustainable system in the future. Treatment processes and regulatory constraints will be discussed to provide alternate paths forward that will provide opportunities for irrigated agriculture.

Biological and Chemical Drivers of Nutrient Dynamics in the Rhizosphere: Applications for Crop Management

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ABSTRACT

The rhizosphere (soil volume around plant roots) is a "hot spot" of plant-microbe-soil interactions, and biological and chemical dynamics in this region play a large role in plant access and uptake of nutrients. Crop plants can influence these dynamics in the rhizosphere to facilitate availability and uptake of nutrients, and can form symbiotic or antagonistic relationships with rhizosphere soil microbes, who either facilitate or compete with plants for nutrient uptake. Symbiotic interactions between plants and microbes include mycorrhizal (fungi) and *Rhizobia* (bacteria) associations with crop plants, and there is evidence that these symbioses are particularly important for legumes like field pea and alfalfa. Mycorrhizae associate with a wide range of crop plants but are particularly important for small grains and legumes, and can facilitate water, phosphorus, and iron uptake in crop plants. There is evidence that fostering larger microbial communities can increase leguminous crop yields. For example, pea biomass yields were increased by 2800 kg DM ha^{-1} for every one unit increase in fungal abundance, and by over 4900 kg DM ha^{-1} for every one unit increase in bacterial abundance, in the rhizosphere, in a study in eastern Washington. Microbial activity may also contribute to beneficial effects on crop yields either directly or through associations with other crops in rotation. For example, considerable yield benefits have been observed in grain crops following alfalfa, and while these yield benefits have often been attributed to residual nitrogen fertility, soil nitrogen levels do not fully account for yield gains. Soil microbial activity in the alfalfa rhizosphere may be enhancing nutrient cycling and mycorrhizal inoculum levels that carry over to benefit following crops in rotation. In an alfalfa-tomato rotation in California, researchers observed a 40% yield boost in tomatoes following alfalfa, compared to following maize, and found 46% greater microbial biomarkers and 70% greater arbuscular mycorrhizal fungi biomarkers in the preceding alfalfa rhizosphere, compared to the maize rhizosphere. Research is ongoing to link these rhizosphere biomarkers with rhizosphere characteristics in the following cash crop. In conclusion, management practices likely affect these plant-microbial relationships, and knowledge of these dynamics will inform how to manage organic materials like composts and manure, chemical inputs, and crop rotation.

Paying Attention to Root Traits for the Effective Use of Water and Nutrients

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ABSTRACT

Roots are the main organ for water and nutrient uptake, and more research on root responses to their surrounding environment would help develop novel management strategies to increase agricultural sustainability. Increasing the effective use of resources to reduce environmental impact as we meet the increasing demands for food, fiber and fuel is a priority. Root systems have a key role on this effort. In this session, we will explore how roots respond to abiotic stress, and how root acclimation may affect crop productivity as the root functionality is altered due to morphological, anatomical and physiological changes. New techniques that exploit genotypes with desirable root systems (e.g., rootstocks) are an alternative for certain crops, and can also help us understand the importance of roots towards a more effective use of nutrients and water. This presentation aims to motivate an increased and concerted effort to improve nutrient and water management from a plant perspective, starting from the roots.

Rhizosphere Processes Impact Potassium Nutrition

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Utilizing the 4Rs to Mitigate Ammonia Toxicity in Roots

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ABSTRACT

The banding of nutrients below the seed row is a common practice in dryland agricultural settings. However, banding below the seed row has been shown to hamper stand establishment and damage seedling root growth in a number of studies. The research presented here uses a novel and inexpensive imaging technique to assess the rate and source management options for reducing root damage when banding N fertilizers below the seed at planting. Survival analysis was conducted on canola roots growing into bands of urea, AS, and UAN and LD50s were estimated. Wheat roots were visually assessed for damage when exposed to bands of urea and DAP. In all instances urea was shown to be the most toxic source of nitrogen (N). Care should be taken when banding N fertilizers to account for source and rate in order to prevent root damage.

INTRODUCTION

While not the recommended practice, banding N fertilizers directly below the seed is a practice used in dryland agriculture cropping systems featuring oilseeds, legumes, and small grains. Legumes do not require N applications due to biological nitrogen fixation. However, both oilseeds and small grains require large quantities of N for achieving high yields. Fertilizer banding at planting is a method commonly used in dryland systems. Fertilizer banding at planting has been shown to damage and modify root system architecture in many field crops (Dowling 1998,). Rate and source have been shown to be important management factors for ensuring maximum seedling root system growth when timing (at planting) and place (directly below the seed) are held constant (Passioura and Wetselaar, 1972,Angus et al., 2014).).

Even in the absence of varied placement and timing there are a variety of combinations of rate and source which may be utilized. Developing methods for rapidly assessing the impact of rate and source on root system growth has utility in developing recommendations for fieldmen and farmers. A unique method for assessing the impact of fertilizers on root growth is the use of modified office scanners to track root growth overtime (Pan et al. 2016). Such methods can be used to develop guidelines for safe rates and sources at which root damage will not occur.

The primary goals of the research presented here where 1. to develop methods for rapidly assessing rate by source interactions of fertilizer banded below the fertilizer band and 2. to develop guidelines for fieldmen and farmers who currently make recommendations for or apply N fertilizers to oilseeds and small grains.

MATERIALS AND METHODS

Previous research has demonstrated the utility of modified office scanners for assessing the impacts fertilizer bands on root health (Pan et al. 2016). The study presented here used Epson

V37 office scanners and soil boxes filled with a Palouse Silt Loam to examine the effects of fertilizer rate and source on canola and wheat on root system architecture. Prior to filling the rhizoboxes with soil the soil was air dried and passed through a 2 mm sieve. The soil was then wetted to 25% gravimetric water content, allowed to equilibrate for 24 hrs. Seeds were placed directly on the glass face of the scanner 1” below the soil surface and fertilizer bands were placed 2” below the seed row. Images were collected every 24 hours using VueScan automatic scanning software.

Images were visually compared for symptoms of root browning, root hair dieback and root shrinkage for wheat and canola. Tap root depth and lateral branching were quantified and analyzed for the canola root systems. The quantified from the canola root data was used to develop LD50s and ED50s for tap root survival, tap root depth, and a zone of non-proliferation surrounding the fertilizer band.

For the experimental design canola was exposed to three sources urea, ammonium sulfate, and urea ammonium nitrate (UAN) where selected for assessment. The rate was varied from 0-40 mg N cm-1. The 0 mg N cm-1 was used as a control and the 40 mg N cm-1 was used as an above normal field rate application. For replication the experiment was run 4 times. The experimental design for the wheat experiment followed a slightly different design with 4 replications of urea and di-ammonium phosphate being run at once. The rates were determined by the partial salt index and ranged from the equivalence of 0-120 mg $NaNO_3^-$/cm for both DAP and urea. However these experiments were considered comparable as each of them was replicated 4 times.

RESULTS AND DISCUSSION

In the canola experiment visual comparisons of root growth from the images clearly demonstrated decreasing tap root length as N rates increased for all three N sources. While the trend was similar in all treatments it appeared that the severity of the trend differed depending on the source. The visual rankings of the trends appeared to be harshest in urea followed by AS and UAN. The visual assessment of tap root survival supported the data analysis conducted on the tap root survival data which resulted LD50s of 4.7, 9.7, and 20.6 mg N cm^{-1} for urea, AS, and UAN respectively (Figure 2). In order to make these LD50s applicable for fieldmen and growers estimates were converted to lbs N/A, and are shown in table 1 for a variety of row spacings.

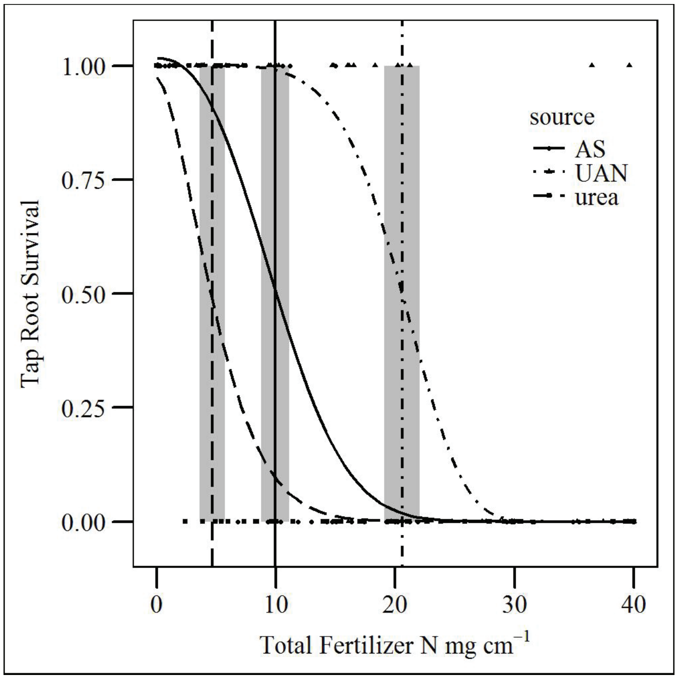

Figure 1: Dose response curves for canola tap root survival when exposed to banded urea, AS, and UAN. Vertical lines indicate the estimates of the LD50 for canola tap roots.

Table 1: LD50s of canola tap root survival exposed urea, AS, and UAN

		Row Spacing (in)		
		6	12	18
Source	LD50 (mg N/cm)	Rate (lbs N/A)		
urea	4.7	27	14	9
AS	9.7	57	28	19
UAN	20.6	120	60	40

While measurements were not collected characterizing wheat root damage, a visual assessment of the images showed a similar trend of increasing damage due to increasing fertilizer rates in both urea and DAP. A comparison of urea to DAP urea appeared to cause much more damage and an increased zone of non-proliferation (Figure 3 and Figure 4). The consistent results between the increasing range of damage above the fertilizer band for urea in both the canola and wheat experiments lends itself to the interpretation that toxicity is spreading further from banded than the other sources of N. It has been hypothesized that the reason for the dieback at greater distances from the urea band than the other fertilizer sources is due to ammonia movement within the soil profile (Pan et al. 2016). The results presented here corroborate the ammonia hypothesis, and suggest further work should be done measuring the ammonia concentrations in the soil column.

Figure 2: Wheat roots growing into urea band. Urea rate decreases from left to right.

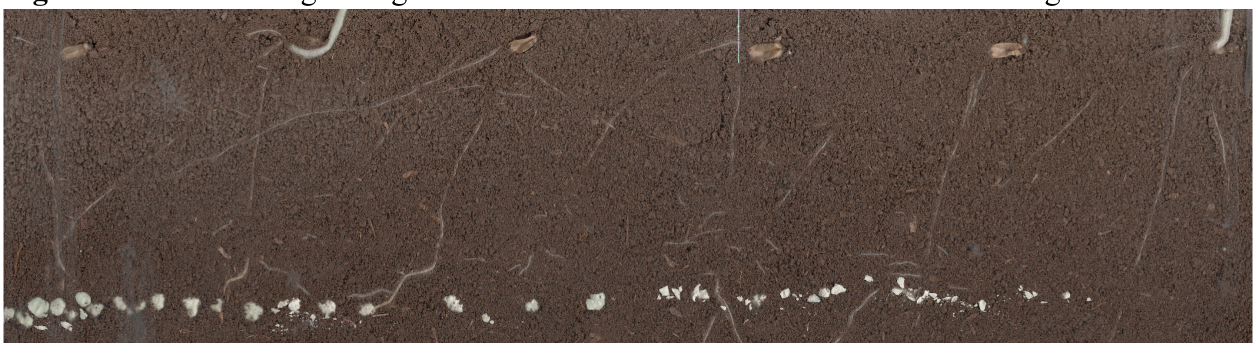

Figure 3: Wheat roots growing into DAP band. DAP rate decreases from left to right.

SUMMARY

For both wheat and canola urea was shown to do more damage to root growth and development than alternative sources of N. For canola the lethal dose in lbs/A for different row spacings can be seen in table 1. No LD50s have been calculated for wheat in relation to urea and DAP, but it is clear from the images that urea has a more adverse effect on wheat root system growth than DAP at the same exact salt index. These results indicate that salt index is not the driving culprit in root dieback when considering the banding of ammoniacal-N fertilizers. It is likely that the toxicity documented in these images is due to ammonia movement within the soils. When utilizing N fertilizer bands rate and source should be carefully considered as relates to the potential for ammonia release and root health.

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Belowground Ecological Interactions For Improved Plant Health, Nutrition And Environmental Quality In Agricultural Production

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ABSTRACT

Plant roots are in constant interaction with the myriad of organisms that inhabit the soil. Microbe-root associations are important for a plant's successful establishment in an environment as they directly or indirectly support nutrient cycling, nutrient uptake and defense from abiotic and biotic stressors. Therefore, managing these interactions offers a great opportunity for improving the efficiency and sustainability of agricultural production by improving plant nutrient uptake, reducing nutrient losses to the environment and reducing the input of agrochemicals. However, relying on these ecological interactions requires a thorough knowledge of (i) the relevance of plant-microbe interactions for supporting plant growth and environmental quality and (ii) the main drivers of these interactions. Strawberry (*Fragaria x ananassa*) cropping systems have relied heavily on the powerful soil fumigant methyl bromide for the reduction of potentially devastating soil-borne pathogens prior to plant establishment. The ban on methyl bromide fumigation, and lack of viable chemical alternatives, has fostered robust breeding efforts aimed at improving strawberry cultivar tolerance to high pathogen loads in the soil. To date, several cultivars have been identified that are tolerant to some of the major soil-borne fungal diseases, all of them presenting a wide variety of aboveground traits, such as biomass yields and nutrient uptake efficiency. In this study we assessed the relationship between the structure of the prokaryotic community in the rhizosphere of strawberry cultivars and plant biomass, nutrient uptake and tolerance to the soil-borne pathogens *Verticillium dahliae* and *Macrophomina phaseolina*. Microbial community structure was evaluated using high-throughput sequencing of DNA isolated from the bulk and rhizosphere soil of ten strawberry cultivars infected with and displaying varying degrees of tolerance to the two pathogens under field conditions. Clear differences between the prokaryotic structure of the strawberry rhizosphere and the adjacent soil confirmed the existence of a distinctive strawberry rhizosphere microbiome. In addition, significant differences in prokaryotic communities between cultivars were found; however, tolerance to either disease was not found to be a significant factor driving the composition of the rhizosphere microbiome. Other plant traits such as biomass and nutrient uptake helped to explain the differences in strawberry rhizosphere microbiome. Research is currently being conducted to study the potential role of root endophytes on plant nutrient uptake and disease tolerance. Understanding the role of rhizosphere prokaryotic community in modulating nutrient acquisition and disease resistance and incorporating this knowledge into modern breeding programs could lead to reduced dependence on fertilizer inputs, chemical controls and novel biocontrol strategies.

Improving Nutrient Use Efficiency in Irrigated Areas of Western Agriculture

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ABSTRACT

Much of Western US crop production requires irrigation for optimum performance. Irrigated cropping systems often include high-value crops grown with intensive nutrient management. Irrigation management is integral with nutrient management, especially for nitrogen. The predominant form of plant-available nitrogen in soils is nitrate, which is highly mobile and greatly affected by irrigation management. Irrigation, therefore, adds complexity to already intensive management and introduces challenges such as potential for loss of mobile nutrients with water and/or of immobile nutrients with irrigation induced erosion and sediment loss. Offsetting these special challenges are opportunities to use irrigation systems to deliver nutrients with irrigation water. Irrigation provides unique opportunities to deliver nutrients in a growing crop in better synchronization with crop demand than conventional mechanical applications. This technique, call fertigation, can save costs and improve nutrient-use efficiency by better timing of nutrients, but is highly dependent on the nature and efficiency of the irrigation and its management. Center-pivot and drip irrigation are well suited to delivering nutrients uniformly and timely, and are increasing in popularity. Furrow and flood irrigation, still popular in many areas of the west, creates unique nutrient-management challenges because of relatively non-uniform water delivery and end-of-field runoff. Studies have frequently shown deep percolation of water and nitrogen at heads of fields with insufficient water applied at field ends. Furrow and flood irrigation may also create greater irrigation-induced erosion than sprinkler and drip irrigation. This irrigation method is not particularly well suited to deliver nutrients with the irrigation water because of the challenges described above and so requires other nutrient best management practices (BMPs). Combining nutrient BMPs with irrigation BMPs is essential to achieving the greatest nutrient efficiency required for maximum net return and protection of soil, air and water resources. Improved irrigation-scheduling techniques and better equipment for more accurately and uniformly delivering water and nutrients are available. Coupling these technologies with best-available 4R nutrient stewardship practices can assure sound nutrient management in these complex systems.

Efficient Irrigation and Nutrient Use Efficiency for Vegetable Crops

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Nutrient Management and Improved Efficiency of Drip Irrigated Processing Potatoes

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ABSTRACT

Water availability may be the single greatest limiting factor for potato production in irrigated areas of the PNW and other parts of the world. Arid climates with warm temperatures during the day and cooler, drier nights produce some of the world's largest potato yields with some the best processing quality. However this comes with a challenge and that is water use efficiency. While for many years there is an abundance or adequate water it will not always be the case. These concerns have led to an increasing awareness of water usage and its impact on potato production for processing. It is also interesting to note that there may be a seemingly abundance of water, water management is also one of the greatest challenges to production practices which can lead to over-use as well as negative impacts on yield and quality for potato processing. Drip irrigation has been utilized successfully on many crops around the world. However the use of drip irrigation on potatoes used for processing into consumer potato products creates a whole new set of challenges. Foreign material in processed potato products can create very devastating consequences for growers and processors. The objective of this evaluation of drip irrigation on processing potatoes was to determine the efficiency of irrigation practices on process potato quality factors and nutrient efficiency. Another objective was to determine if drip grown processing potatoes can be grown with an expectation that no foreign material (i.e. drip tape and accompanying plastic parts) would be inadvertently delivered with the potatoes to a processing plant.

Irrigated Cereal Response to Nitrogen Applications to Improve Efficiencies for Yield and Protein

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ABSTRACT

High yielding and quality barley (*hordeum vulgare* L.) is critical for producing malt. Research trials investigating the impact of final irrigation timing cutoffs [i.e., late boot, soft dough, and soft dough + 7 days (SD7)] and nitrogen (N) rates (0 to 150 lb N/ac) at the Kimberly Research and Extension were conducted during the 2015 growing season. Our study measured yield and quality factors as well as N uptake and partitioning. Cutoff of irrigation at the boot stage severely stressed plants as soil moisture was insufficient to finish out the crop reducing yield, protein, and plumps to unacceptable levels, indicating the need for proper irrigation. Scheduling the final irrigation for soft dough, where the soil profile was full of moisture, resulted in a nearly 20% reduction in water usage where no reductions in yield or quality occurred at optimal N rates. This is a key factor as water curtailments are proposed for Idaho and properly timed irrigation will ensure high yields/quality and minimal lodging while reducing the total water usage of the crop. Additionally, results indicated that excessive N applications are unlikely to increase yield goals and thus, proper N applications will ensure adequate N for the plant that reduces the potential for negative agronomic and environmental effects By optimizing the nitrogen and water provided to the crop, barley growers can ensure they are only using the amount of water and fertilizer resources needed to maximize returns while maintaining quality specifications.

INTRODUCTION

Research trials investigating the impact of final irrigation timing cutoffs [i.e., late boot, soft dough, and soft dough + 7 days (SD7)] at the Kimberly Research and Extension were conducted during the 2015 growing season. Nitrogen at rates of 0 to 150 lb N/ac were applied under three irrigation cutoff levels. The objective of this study was to determine the effect of these treatment combinations on malt barley grain yield and quality responses as well as plant nitrogen accumulation.

MATERIALS AND METHODS

Plot Management

Plots were planted on April 21, 2015 using a small plot planter where plots were 7 rows wide with 7-inch row spacing. Plants emerged on April 30, 2015 and University of Idaho Extension recommendations were used for herbicide and insect control. An application of Palisades EC (i.e., 14 oz/ac) was applied to reduce lodging potential in the study. Plot ends were trimmed to a uniform length prior to harvest to remove the sections where tissue sampling occurred, and a single row binder was used to remove rows 1 and 7 to minimize border effect. The plots were harvested on Aug 4, 2015.

Composite soil samples were taken from the study early in the spring during the field selection process and analyzed to characterize the soil fertility status (Table 1). Irrigations were applied to meet evapotranspiration (ET) demand until the scheduled cutoff [i.e., late boot, soft dough, and soft dough + 7 days (SD7)]. Plants were harvested from a 3-foot row section at the boot, soft dough, SD7, and harvest timings where the plants were partitioned into stems/shoots (i.e., plant tissue) and grain from the soft dough stage forward. Prior to harvest, plant height was measured in the study from all plots. Grain yield was measured using a small-plot combine where grain yield and moisture were determined using a HarvestMaster grain weight system. Following harvest, grain quality characteristics were measured including percentage protein, test weight, and percentage plumps.

Statistical Analysis

Analysis was conducted based on the split-plot study design with higher level factors were included as appropriate. The highest order treatment interaction or main effects for each treatment level are reported and where appropriate means were separated by Fisher's protected LSD at the $p< 0.05$ level.

RESULTS

Irrigation was applied weekly where the cutoff at boot (Figure 1) resulted in an estimated shortage of 1.7 inches of water compared to the 13.6 inches that was estimated to be needed for the crop. When the final irrigation occurred at soft dough, rainfall, irrigation and stored soil water could meet the crop need. When final irrigation occurred at SD7, rainfall and irrigation were adequate to meet crop need, without the use of stored soil water. Overall, yields were on the lower end of those expected for Moravian 69, which is likely due to the later planting (April, 21) and the warm weather patterns that were observed during critical periods of growth during the 2015 growing season. Yield, test weight, protein, and plumps all resulted in a significant difference in the Irrigation X Nitrogen interaction ($p< 0.05$). Yield reductions, in line with soil moisture and irrigation management data, were observed when irrigation was cutoff at the boot timing as compared to soft dough and SD7 where numerical reductions ($p> 0.05$) were measured under the boot cutoff as nitrogen rate increased (Table 2; Neibling et al., 2017). At the soft dough and SD7 cutoff, N additions increased yield to a plateau where the yield from the 0 lb N/ac dough cutoff (99 lb/ac) was less than the larger N application rates.

A nearly 20% reduction in water used for irrigation was measured when irrigation was cutoff at soft dough as compared to SD7 where no major yield or quality gains were observed due to the final irrigation. The study location was appropriate for a N response trial as N rate increased yield where N applications of 50 lb N/ac were sufficient to maximize yield, as no differences were measured between the 50 to 150 lb N/ac rate at any irrigation level. This rate was somewhat less than that predicted by the early season N sampling (80 lb N/ac) and indicates that excessive N applications are unlikely to increase yield goals and thus, proper N applications will ensure adequate N for the plant that reduces the potential for negative agronomic and environmental effects. Continued research to determine optimal N levels for malt barley yield and quality will help ensure sustainable production practices are being used by barley producers.

While yield goals are important, malt barley production is uniquely tied to grain quality factors (AMBA, 2014). Test weight was less when irrigation was cutoff at the boot timing; however, test weights were within an acceptable range at the soft dough and SD7 cutoffs where they did not differ and ranged from 49 to 50 lb/bu. Protein levels in the boot cutoff were excessively high when supplemental nitrogen was added, ranging from 16.1 to 18% where the 0 lb N/ac resulted in a protein level of 12.5%. Proteins at the soft dough and SD7 ranged from 11.9 to 13.8% where supplemental N was applied and were 11.3 and 11.1 % when 0 lb N/ac was applied at soft dough and SD7. Plumps were reduced dramatically when irrigation was cutoff at the boot stage resulting in 40 to 60 percentage point reductions. The range of plumps for the dough and SD7 was 80 to 87, where no differences were measured. The similar results on barley grain quality reductions were observed by Qureshi and Neibling (2009). Plant height only varied based on supplemental N application level ($P < 0.05$) where the 0 N/ac rate resulted in a shorter plant height of 24.6 in as compared to the other N levels which did not differ and averaged 26.1 in. As irrigation was only cut at boot and later stages, the stature of the plant was already determined prior to the reduction in water late in the season.

Nitrogen uptake averaged across irrigation cutoff timing ($p < 0.05$) indicated a general trend of increasing N uptake from planting until soft dough and then nitrogen uptake either remained the same or decreased until maturity (Table 3). From the boot stage until maturity, in general nitrogen uptake increased from the 0 to 100 lb N/ac rates and the 100 and 150 lb N/ac rate did not differ but had greater N uptake than the 0 lb N/ac rate and some of the 50 lb N/ac samplings (Table 3; Neibling et al., 2017). In addition to total N uptake during the season, partitioning of plant and spike portions was conducted at the dough, SD7, and harvest timings (Figure 1). Nitrogen uptake of the spike generally increased as N rate increased. Also, total N uptake generally decreased from dough until harvest within a N rate, and N was translocated from the plant straw to the grain during these time periods as noted by the increase in the ratio of plant versus spike N. Little work has been conducted to determine the N uptake and partitioning characteristics of malt barley plants, particularly under various cutoff timings, that can be used as tools in determining N needs of the plant.

CONCLUSIONS

The results from this study provide new information on the influence of N applications under various irrigation cutoff points. This study will play an important role in developing sustainable barley production practices that can be utilized under ever changing resource allocation scenarios. By optimizing the N and water provided to the crop, barley growers can ensure their practices are sustainable as they are only using the amount of water and fertilizer resources needed to maximize returns while maintaining quality specifications. These results indicate that water savings can occur by scheduling the final irrigation at soft dough, where the soil profile water is full, as sufficient water was available to the plant to complete growth.

TABLES

Table 1. Early season soil test data for the study field at the Kimberly Research and Extension Center in Kimberly, ID during the 2015 growing season.

Depth (in)	Soil pH	Lime (%)	NH_4-N	NO_3-N	P
			---------mg/kg---------		
0-12	8.0	2.0	3.1	1.9	17
12-24	8.2	11.2	9.0	9.0	-

Table 2. Yield, test weight, protein, and plumps data from the irrigation by applied nitrogen study at the Kimberly Research and Extension Center in Kimberly, ID during the 2015 growing season.

Growth Stage at sampling	lb N/ac	Yield	Test Weight	Protein	Plumps
		bu/ac	lb/bu	%	%
Boot	0	71	46	12.5	41
	50	68	44	16.1	37
	100	62	43	17.9	28
	150	61	42	18.0	24
Dough	0	99	50	11.3	84
	50	118	50	13.3	81
	100	115	50	13.5	82
	150	116	50	13.8	81
Soft Dough + 7	0	102	50	11.1	87
	50	120	49	11.9	84
	100	113	50	13.5	80
	150	112	49	13.7	83
LSD at same Irrigation level ($p < 0.05$)		9	2	1.3	7
LSD at different Irrigation level ($p < 0.05$)		19	3	1.6	22

Table 3. Total nitrogen uptake (g/m^2) in barley plants averaged across irrigation cutoff timing for the irrigation by nitrogen study at the Kimberly Research and Extension Center in Kimberly, ID during the 2015 growing season.

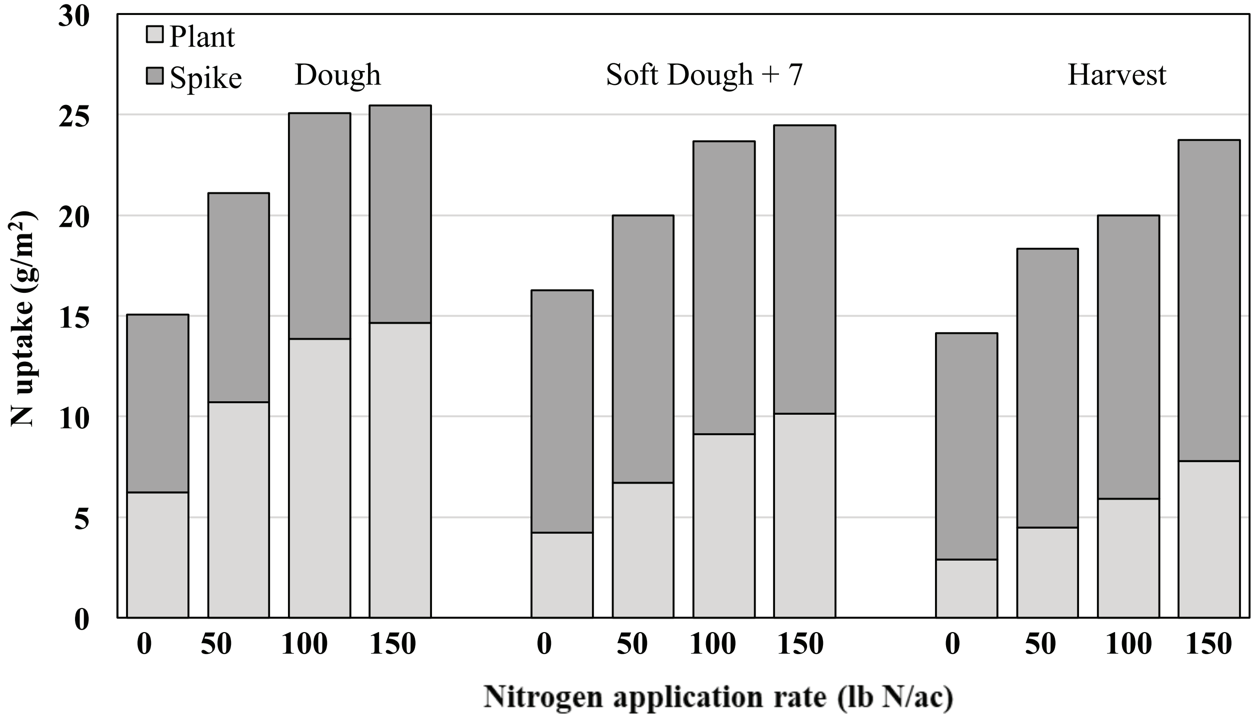
Irrigation Cutoff Timing	Nitrogen Application Rate (lb N/ac)			
	0	50	100	150
	Nitrogen uptake (g/m^2)			
F4/5	1.8	2.1	2.6	2.7
Boot	9.1	16.6	17.4	17.6
Dough	15.1	21.1	25.1	25.4
Soft Dough + 7	16.3	20.0	23.7	24.5
Maturity	13.8	18.4	20.0	23.8

LSD at same N level equals 2.6 g/m^2

LSD at different N levels equals 2.8 g/m^2

FIGURES

Figure 1. Total nitrogen uptake and partitioning data (i.e., plant or spike) from the irrigation by applied nitrogen study (sample timings are listed above the bar graphs) at the Kimberly Research and Extension Center in Kimberly, ID during the 2015 growing season.



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Phosphorus Efficiencies of Liquid P Fertilizers as Evidenced by P Adsorption Isotherms of Western Calcareous Soils

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ABSTRACT

The high levels of free lime or calcium carbonate ($CaCO_3$) in arid Western U.S.A. soils reacts with phosphorus (P) fertilizers to form Ca-P minerals that are not available to plants through P fixation. Enhanced efficiency P fertilizers may potential decrease P fixation. The objective of this study was to identify P fixations levels associated with several enhanced efficiency P fertilizers on a basic soil (pH 8.03) over a 1-, 3-, and 7-day time period, and to use that data to adjust P fertilizer recommendations for the enhanced efficiency P fertilizers. Fertilizer treatments included; a control, 6-24-6 NPK, 6-24-6 w/Nutriband®, 6-24-6 w/Avail®, 6-24-6 w/Nexia®, 4-15-5 w/OneUP® (a combination of 6-24-6, 2-Oxoglutaramate, and humic acid). Adsorption isotherms were performed by creating a solution of 1-5, 8, 12,16, 20, and 30 mg P-fertilizer kg^{-1} for each fertilizer. Freundlich and Langmuir models were used to describe P adsorption and fertilizer-P availability. The 6-24-6 w/Avail adsorption isotherms visually showed less adsorption of P suggesting Avail is preventing some P fixation in basic soils. The 4-15-5 w/OneUP showed the lowest adsorption rates and had significantly lower values than the other fertilizers. Adsorption isotherms for the 6-24-6 w/Nexia visually showed much lower P fixation in basic soils. Models for predicting plant available-P when applying 224 kg P_2O_5 ha^{-1} using the Freundlich and Langmuir P adsorption isotherms showed 4-15-5 w/OneUP had the highest plant available-P (90 and 113 kg P_2O_5 ha^{-1}, Freundlich and Langmuir models respectively). The Freundlich modeled predicted plant available-P when applying 224 kg P_2O_5/ha was higher for 6-24-6 w/Nexia and 6-24-6 w/Nutriband (73 and 64 kg P_2O_5 ha^{-1}, respectively) than the 6-24-6 NPK and 6-24-6 w/Avail (46 and 56 kg P_2O_5 ha^{-1}, respectively). The 4-15-5 w/OneUP appeared to be the most effective in reducing P fixation, but 6-24-6 w/Nexia may also be effective in reducing P fixation in basic soils. The data suggests that enhanced efficiency P fertilizer amendments can be used to reduce P fertilizer rates.

INTRODUCTION

Soils in Southeast Idaho are high in $CaCO_3$, and the Ca reacts with P to precipitate out Ca-P secondary minerals that are not available to plants (known as P fixation). The fertilizer industry has developed new technologies that might reduce P fixation and improve P fertilizer use efficiency. These enhanced efficiency P technologies include fertilizers with a high percentage of polyphosphate, organic compounds (fulvic and humic acid), and the high CEC maleic–itaconic copolymer (Avail) applied to the fertilizer. Some data has shown that these technologies have increased P use efficiency by decreasing fixation, which suggest a need for lower P fertilizer requirements when using these technologies. Fertilizer requirements for enhanced efficiency P fertilizers could be adjusted based on P adsorption isotherms. The more efficient use of P enhanced efficiency fertilizer would help to eliminate the over application of P by producers and furthermore reduce P runoff into watersheds.

An approach for adjusting P fertilizer with enhanced efficiency P amendments is determining the amount of P adsorbed or fixed in the soil using P adsorption isotherms (Fox and Kamprath, 1970). Phosphorus adsorption isotherms measure the amount of P adsorbed to soil particle surfaces by adding a known amount of soluble P to the soil and measuring the amount of P remaining in solution following an incubation period. The amount of adsorbed or fixed P is determined as the difference in the amount of P added and the amount of P remaining in solution (equilibrium P concentration) over a range of added P amounts (Goldberg, 2245). These data can be fit to P adsorption isotherm models for determining a soil's capacity to adsorb P or fix P (Fox and Kamprath, 1970; Anghinoni et al., 1996; and Shafqat and Pierzynski, 2013). Additionally, P adsorption isotherms models can be used to measure a soils' adsorption strength ('K' factor) and the maximum capacity to adsorb P (S_{max}; Goldberg, 2245). The Freundlich and Langmuir isotherms models have been commonly used in agriculture to predict P fixation for different soils and adjust P fertilizer rates (Fox and Kamprath, 1970). Typically, the Freundlich model is preferred over the Langmuir when measuring low equilibrium P concentrations that are representative of the levels of P fertilization in an agricultural setting, but both models have proven to be effective (Havlin et al., 2014 and Shafqat and Pierzynski, 2013). Phosphorus adsorption isotherms could be used to determine the ability of enhanced efficiency P fertilizer amendments to prevent adsorption or fixation of applied phosphorus fertilizer.

The objective of this study was to determine and compare different enhanced P efficiency amendments on a 6-24-6 liquid fertilizer to understand the adsorption of P to calcareous soil (Pocatello silt variant loam) and the relative availability of the P fertilizer for plant uptake at 1-, 3-, and 7-day increments following fertilizer application.

MATERIALS AND METHODS

The calcareous soil that was used for this study was a Pocatello silt variant loam with pH level of 8.03 and 6.0% free lime. The statistical design was a randomized complete block design with six replications of each P fertilizer amendment and fertilizer concentration treatment. Phosphorus adsorption methods were a modification from Fox and Kamprath (1970) and Anghinoni et al. (1996). Fertilizer treatments included; a control, 6-24-6 NPK, 6-24-6 w/Nutriband®, 6-24-6 w/Avail®, 6-24-6 w/Nexia®, 4-15-5 w/OneUP® (note: 4-15-5 is a combination of 6-24-6, 2-Oxoglutaramate, and humic acid). Fertilizer concentration treatments for determining P adsorption were 1-5, 8, 12, 16, 20, and 30 mg P-fertilizer kg^{-1} for each fertilizer (Fig. 1). The fertilizer concentration solutions were added to 1.0 g of soil and samples were shaken on an oscillating shaker table at 224 rpm. The 1-day samples were shaken for the entire 24 hr period, and the 3-day and 7-day samples were only shaken for 8 hr d^{-1}.

Immediately following shaking, polyphosphate in each sample was hydrolyzed to orthophosphate by adding 1.0 ml of 11N H_2SO_4 to the samples and heating to 120˚C and 138 kPa in an autoclave for 30 min. Soluble hydrolysable (polyphosphate + orthophosphate) P was determined using the Murphy Riley Method and a spectrophotometer at 880 nm (Fig. 1). Adsorbed P was determined as soluble hydrolysable-P minus the amount of P added to the soil sample.

Freundlich and Langmuir adsorption isotherm models were fit to the data using (adsorbed P, Y = mg P mg^{-1} soil) and hydrolysable-P concentration of the solution (equilibrium P concentration, X = mg P mL^{-1} solution). Linear models were used to determine the constants of the equations for fitting the Freundlich and Langmuir.

Constant (K) values of the Freundlich equation model was obtained by the following equation:

$$\log Y = (1/n \log X) + (\log K)$$

where: **1/n** is the slope and log **K** is the Y intercept.

Constants S_{max} (maximum adsorption) and K (related binding energy) of the Langmuir model where determined by the following equation:

$$X/Y = (1/b) + (1/Kb)$$

where: **1/b** is the slope and **1/Kb** is the Y intercept.

Available fertilizer P was determined using the Freundlich and Langmuir models when fertilizer is broadcast applied at rates of 56, 112, 156, and 224 kg P_2O_5 ha^{-1} (50, 100, 150, and 200 lbs P_2O_5 ac^{-1}) and incorporated into the top 15 cm (6 in) of soil.

Statistical analyses were performed using an ANOVA in SPSS software (ver. 24), and difference among treatment means were determined using a Tukey-HSD mean separation test with an $\alpha = 0.05$.

RESULTS AND DISCUSSION

Phosphorus Fertilizer Adsorption Isotherms

Freundlich and Langmuir P adsorption isotherms (Fig. 1-5) were visual compared to assess adsorption rates. Visual observations of the adsorption isotherms for day-1 and -3 showed similar trends of higher P adsorption among 6-24-6 NPK, 6-24-6 w/Avail, and 6-24-6 w/Nutriband fertilizers (Fig. 1, 2 ,4). Whereas, the adsorption isotherms for 6-24-6 w/Nexia and the 4-15-5 w/OneUP showed similar low P adsorption trends (Fig. 3 and 5). At the day 7 observations, the 6-24-6 NPK and 6-24-6 w/Nutriband continued to show similar trends of high P fixation (Fig. 1 and 4). The day 7 adsorption isotherm for 6-24-6 w/Avail appeared to show less P adsorption than the 6-24-6 NPK and 6-24-6 w/Nutriband (Fig. 1, 2, and 4). The day 7 adsorption isotherms for the 6-24-6 w/Nexia and 4-15-5 w/OneUP fertilizers continued to visually show much lower P fixation than the other fertilizers and amendments (Fig. 3 and 5). These data suggest the microbial inoculants in Nexia and the 2.6% humic acid in OneUP may be reducing P fixation of the 6-24-6 fertilizer. The similarity in the adsorption isotherms among the 6-24-6 NPK, 6-24-6 w/Avail, and 6-24-6 w/Nutriband suggest that the Avail and Nutriband amendments have little influence on reducing P fixation.

Comparison of Freundlich and Langmuir K Values

The Freundlich and Langmuir K values indicate soil adsorption strength with higher values indicating higher sorption of P in the soil. A comparison of Freundlich K values by fertilizer type showed that 6-24-6 and 6-24-6 w/Avail had the highest mean K values (2.11 and 1.99 mg kg^{-1} P, respectively; Table 1). The 6-24-6 w/Nutriband had a lower mean Freundlich K value (1.76 mg kg^{-1} P) than the control and Avail treatments, but higher than the Nexia and OneUP amendments. The 6-24-6 w/Nexia and 4-15-5 w/OneUP fertilizers had the lowest mean Freundlich K values (1.29 and 0.95 mg kg^{-1} P, respectively; Table 1).

Langmuir K mean values did not follow the same trends among the fertilizer amendment treatments as the Freundlich K values. The 6-24-6 w/Nexia had the highest Langmuir K mean value, and 6-24-6 w/Nutriband had the lowest (Table 1). Langmuir K values were not different for the 6-24-6 NPK, 6-24-6 w/Avail, and the 4-15-5 w/OneUP treatments (Table 1). The Freundlich mean K values suggest that the Nexia and OneUP fertilizer amendments have a lower P sorption strength resulting in decreased P adsorption and an increase in available P. The Langmuir K mean values were inconsistent and did not show any definite trends of P adsorption.

An analysis of Freundlich K values over the 1-, 3-, and 7-day incubation period showed that the 6-24-6 w/Avail and 6-24-6 w/Nutriband had lower Freundlich K values than the 6-24-6 NPK fertilizer for day-1 (Table 1). These results suggest the Avail and Nutriband products may be providing some reduction of P fixation of P fertilizers immediately following application. The 6-24-6 w/Nexia showed an increase of Freundlich K values over time (1.18 mg kg^{-1} P on day-1, 1.29 mg kg^{-1} P on day-3, and 1.41 mg kg^{-1} P on day-3; Table 1). The 6-24-6 w/Nexia Freundlich K values suggest that the Nexia product may be losing some effectiveness to prevent P fixation over time. The 4-15-5 w/OneUP had the lowest Freundlich K values for all sampling days, additionally, Freundlich K values for 4-15-5 w/OneUP were not different among dates (Table 1). The OneUP product showed the greatest potential for reducing P fixation of fertilizer P based on Freundlich K values, but 6-24-6 w/Nexia also showed good potential for reducing P fixation.

Comparison of Langmuir S_{max}

The Langmuir S_{max} model parameter is an indicator of total P adsorption capacity of the soil. The Langmuir S_{max} can be used to determine the ability of an enhanced efficiency fertilizer amendments to prevent and reduce total P fixation. The 4-15-5 w/OneUP and 6-24-6 w/Nexia fertilizers showed the lowest mean S_{max} values (4.8 and 6.4 mg kg^{-1}). The S_{max} values for 6-24-6 NPK (10.6 mg kg^{-}1) and 6-24-6 w/Avail (11.3 mg kg^{-1}) were higher than the OneUP and Nexia amended fertilizers (Table 1), but lower values than 6-24-6 w/Nutriband treatment (13.1 mg kg^{-1}). The S_{max} mean values suggest that the OneUP and Nexia fertilizer amendments are reducing the total amount of P fixation resulting in more plant available phosphorus. The high S_{max} value for the 6-24-6 w/Nutriband suggests that the zinc (Zn) from the Zn-complex in the Nutriband may be fixing some of the phosphorus. An assessment of S_{max} values over time (1-, 3-, and 7-day incubations periods) by treatment showed that S_{max} values increased with time for the Nexia, Nutriband, and OneUP fertilizer amendments. For the Nexia and OneUP amended 6-24-6 fertilizers, the increasing S_{max} values over time suggest that the Nexia's and OneUP's ability to prevent fixation is reduced over time. The higher S_{max} values for the 6-24-6 w/Nutriband is likely the result of a Zn-P interactions.

Freundlich and Langmuir Models for Predicting P Availability by Fertilizer

The Freundlich and Langmuir models were used to predict soluble plant available P following a broadcast and incorporated P fertilizer application by fitting the data to a model of applied P fertilizer versus predicted plant available P (Fig. 6 and 7). A comparison of the Freundlich and Langmuir fitted models for predicting P availability showed that the 4-15-5 w/OneUP had the highest plant available P following fertilizer application (Table 2 and 3). The 6-24-6 w/Nexia and 6-24-6 w/Nutriband had higher predicted available P values than the 6-24-6 NPK and 6-24-6 Avail for the both the Freundlich and the Langmuir prediction models (Table 2 and 3).

For illustrative purpose, available P was predicted using the Freundlich and Langmuir models when 56 and 224 kg P_2O_5 ha^{-1} (50 and 200 lbs P_2O_5 ac^{-1}) was applied (Figure 8) rates between these two rates showed a similar trend. The 4-15-5 w/OneUP had the highest amount of predicted plant available P with 14 and 27 kg P_2O_5 ha^{-1} (13 and 24 lbs P_2O_5 ac^{-1}) of available P for the Freundlich and Langmuir models, respectively, when 56 kg P_2O_5 ha^{-1} was applied and 90 and 113 kg P_2O_5 ha^{-1} (101 lbs P_2O_5 ac^{-1}) of available P respectively, when 224 kg P_2O_5 ha^{-1} was applied (Table 3 and Fig. 8). The 6-24-6 w/Nexia had the second highest amount of predicted available P followed by 6-24-6 w/Nutriband (Fig. 8 and Table 3). As compared to 4-15-5 w/OneUP and 6-24-6 w/Nexia, the 6-24-6 NPK and 6-24-6 w/Avail had much lower predicted plant available P at both fertilizer application rates (Table 3).

SUMMARY

The P adsorption isotherms models fitted to the different enhanced efficiency P fertilizer amendments showed that the organic-based Nexia and OneUP were effective in reducing P fixation and increasing plant available P (40 – 50% P use efficiency). The highly charged maleic–itaconic copolymer in Avail and the micronutrients in Nutriband showed some potential to reduce P fixation (20 – 35% P use efficiency) as compared to 6-24-6 NPK (fertilizer with no amendments; 3 – 25% P use efficiency). Enhanced efficiency P fertilizer amendments can be used to increase the effectiveness of P fertilizers while reducing overall application rates with the resulting benefit of less P loss into surface waters.

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Table 1. A comparison of Freundlich K, Langmuir K, and Langmuir S_{max} model parameters. Lower-case letter denote difference in rows, and upper-case letters denote differences in columns $\alpha = 0.05$.

Day	6-24-6 NPK	6-24-6 w/Avail	K_2SO_4	6-24-6 w/Nexia	6-24-6 w/Nutriband	4-15-5 w/OneUP
	Freundlich K					
	-- $mg\ kg^{-1}$ --					
1	2.84 c B	2.04 b AB	4.93 d	1.18 a A	0.99 a A	0.89 a A
3	2.17 d A	2.18 d B		1.29 b AB	1.69 c B	0.96 a A
7	2.05 cd A	1.76 c A		1.41 b B	2.08 d C	1.01 a A
Mean	2.11 d	1.99 d		1.29 b	1.76 c	0.95 a
	Langmuir K					
	-- $L\ mg^{-1}$ --					
1	0.33 a B	0.22 a A	0.38 ab	0.68 b A	0.13 a A	0.45 ab B
3	0.39 a B	0.25 a A		0.55 a A	0.18 a A	0.19 a A
7	0.22 a A	0.18 a A		0.26 a A	0.15 a A	0.28 a AB
Mean	0.31 ab	0.22 ab		0.56 b	0.16 a	0.31 ab
	Langmuir S_{max}					
	-- $mg\ kg^{-1}$ --					
1	11.8 b B	11.3 b A	24.6 c	4.0 a A	9.7 b A	2.7 a A
3	8.8 abc A	11.4 c A		6.2 a AB	11.1 bc A	7.1 abc B
7	12.3 b B	11.2 b A		9.0 b B	16.3 c B	4.8 a AB
Mean	10.6 b	11.3 bc		6.4 a	13.1 c	4.8 a

Table 2. A comparison of P availability predictive models for fertilizer application using the Freundlich and Langmuir P adsorption isotherms. Letter denote statistical difference among models at an $\alpha = 0.05$.

Fertilizer	Freundlich Model		Langmuir Model	
6-24-6 NPK	$0.0005x^2 + 0.111x$	a	$5 \times 10^{-4}x^2 + 0.254x$	a
6-24-6 w/Avail	$0.0005x^2 + 0.131x$	a	$6 \times 10^{-4}x^2 + 0.303x$	ab
6-24-6 w/Nexia	$0.0007x^2 + 0.184x$	b	$0.0002x^2 + 0.331x$	b
6-24-6 w/Nutriband	$0.0004x^2 + 0.201x$	b	$8 \times 10^{-5}x^2 + 0.333x$	b
4-15-5 w/OneUP	$0.0009x^2 + 0.224x$	c	$0.0002x^2 + 0.471x$	c

Table 3. The amount available P following fertilizer application of 56 and 224 kg P_2O_5 ha^{-1} (50 and 200 lbs P_2O_5 ac^{-1}) as predicted by the Freundlich and Langmuir P adsorption isotherm models. Letters denote statistical difference among fertilizer amendments using a Tukey-HSD mean separation test with an $\alpha = 0.05$.

Fertilizer	Freundlich Model		Langmuir Model	
Applied rate	56 kg ha^{-1}	224 kg ha^{-1}	56 kg ha^{-1}	224 kg ha^{-1}
	------------------ kg ha^{-1} ------------------			
6-24-6 NPK	7 a	46 a	15 a	59 a
6-24-6 w/Avail	8 a	56 a	17 ab	71 ab
6-24-6 w/Nexia	11 b	73 b	19 b	82 c
6-24-6 w/Nutriband	11 b	64 b	19 b	78 bc
4-15-5 w/OneUP	13 b	90 c	27 c	113 d

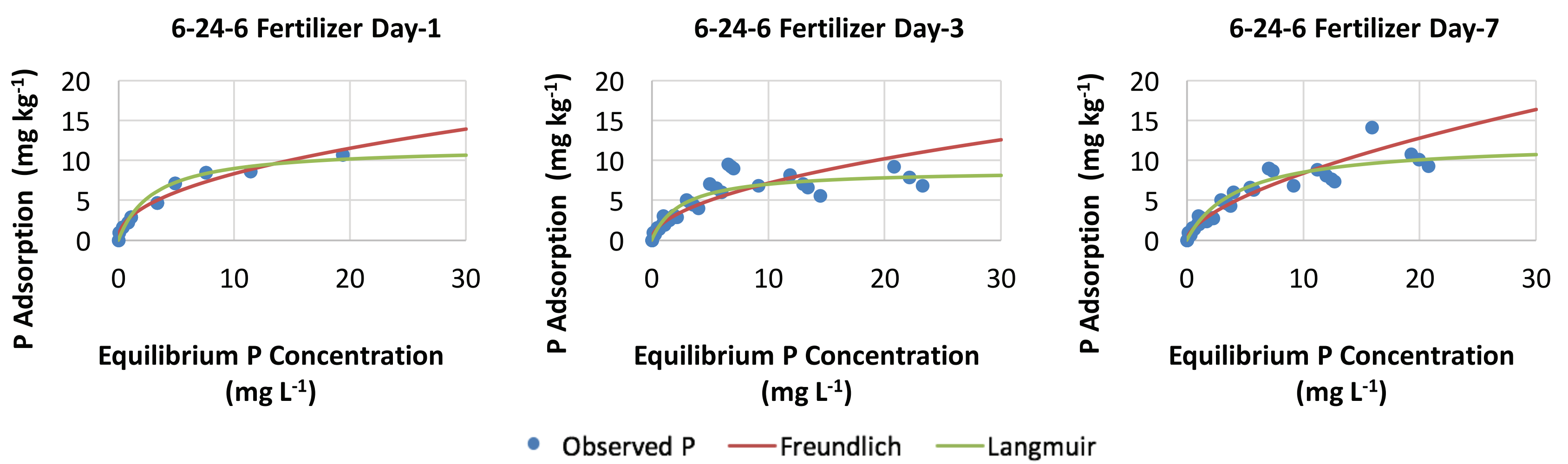

Figure 1. Phosphorus adsorption isotherms (equilibrium P concentrations vs. P adsorption) of 6-24-6 fertilizer for 1-, 3-, and 7-day incubation period.

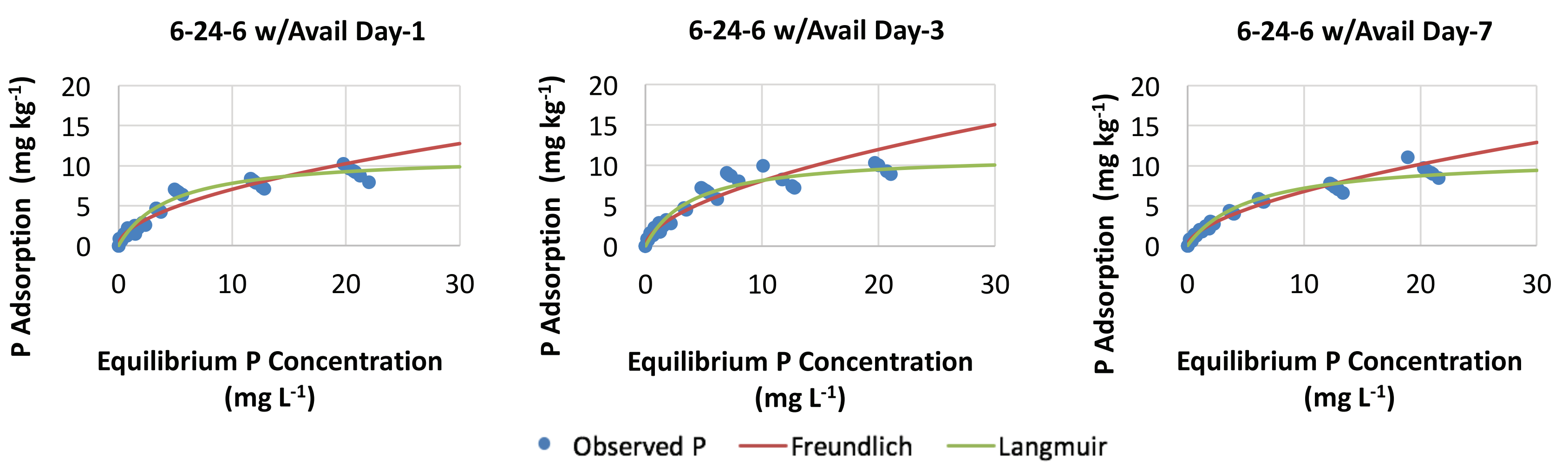

Figure 2. Phosphorus adsorption isotherms (equilibrium P concentrations vs. P adsorption) of 6-24-6 w/Avail for 1-, 3-, and 7-day incubation period.

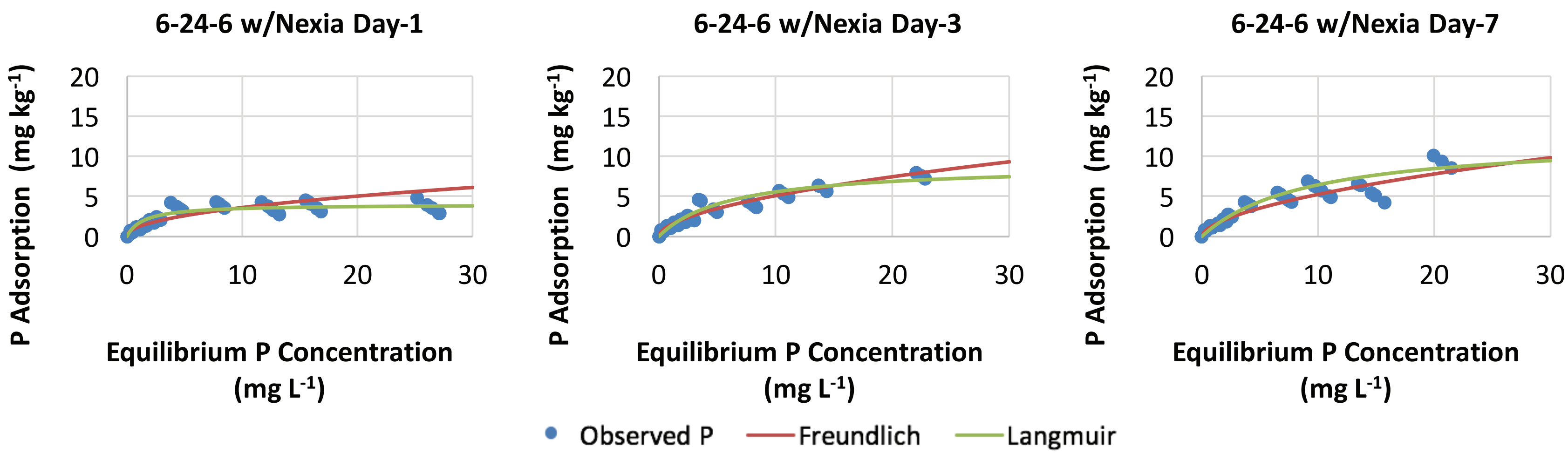

Figure 3. Phosphorus adsorption isotherms (equilibrium P concentrations vs. P adsorption) of 6-24-6 w/Nexia for 1, 3, and 7-day incubation period.

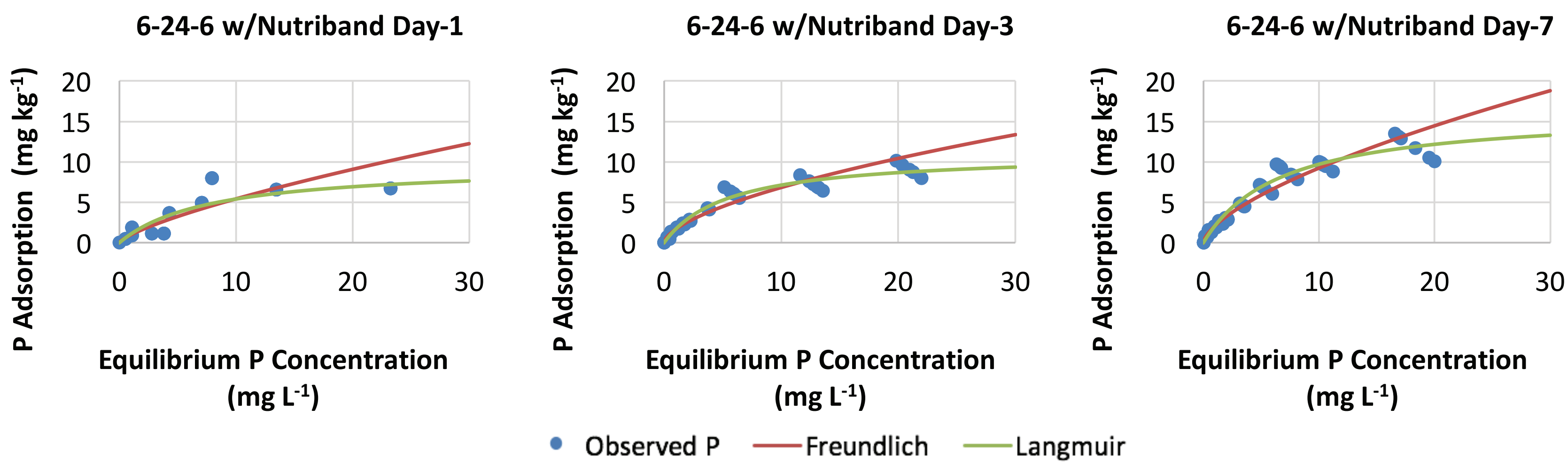

Figure 4. Phosphorus adsorption isotherms (equilibrium P concentrations vs. P adsorption) of 6-24-6 w/Nutriband for 1-, 3-, and 7-day incubation period.

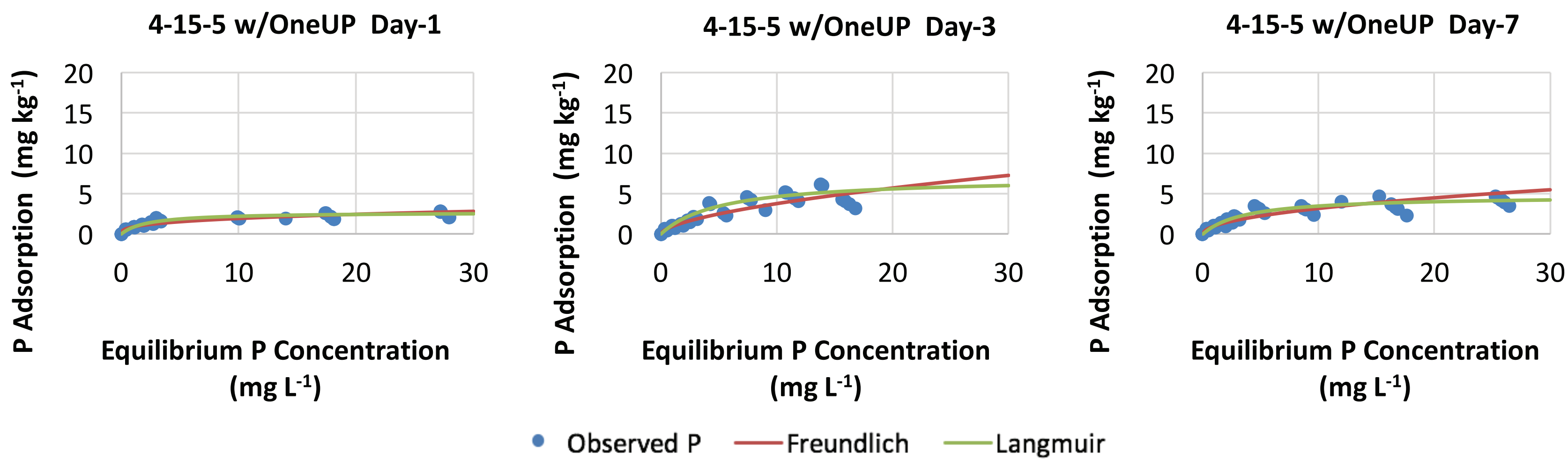

Figure 5. Phosphorus adsorption isotherms (equilibrium P concentrations vs. P adsorption) of 4-15-5 w/OneUP for 1-, 3-, and 7-day incubation period.

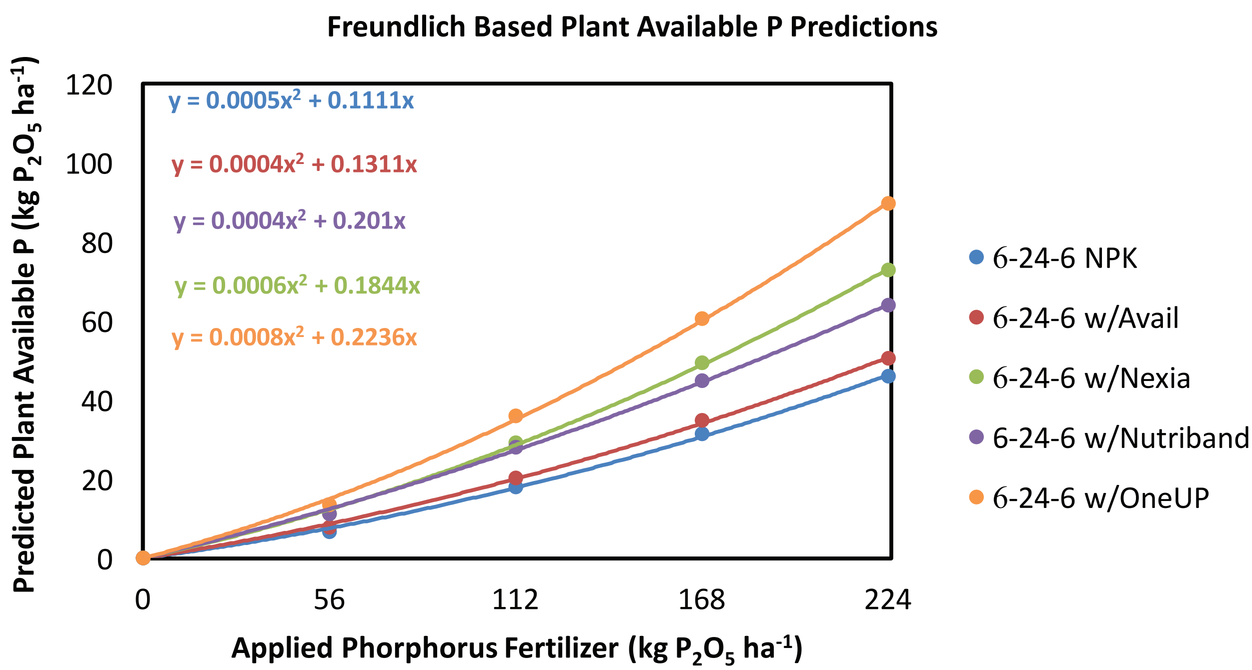

Figure 6. Applied phosphorus versus predicted plant available P using the Freundlich adsorption isotherm model.

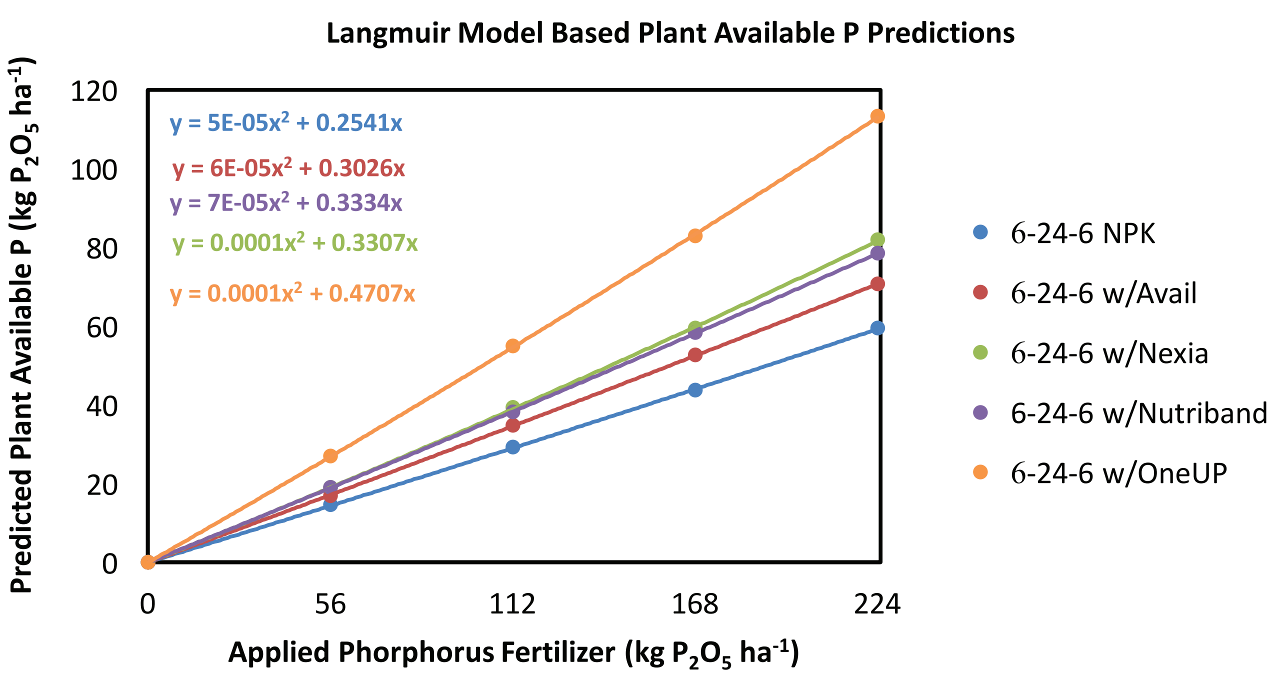

Figure 7. Applied phosphorus versus predicted plant available P using the Langmuir adsorption isotherm model.

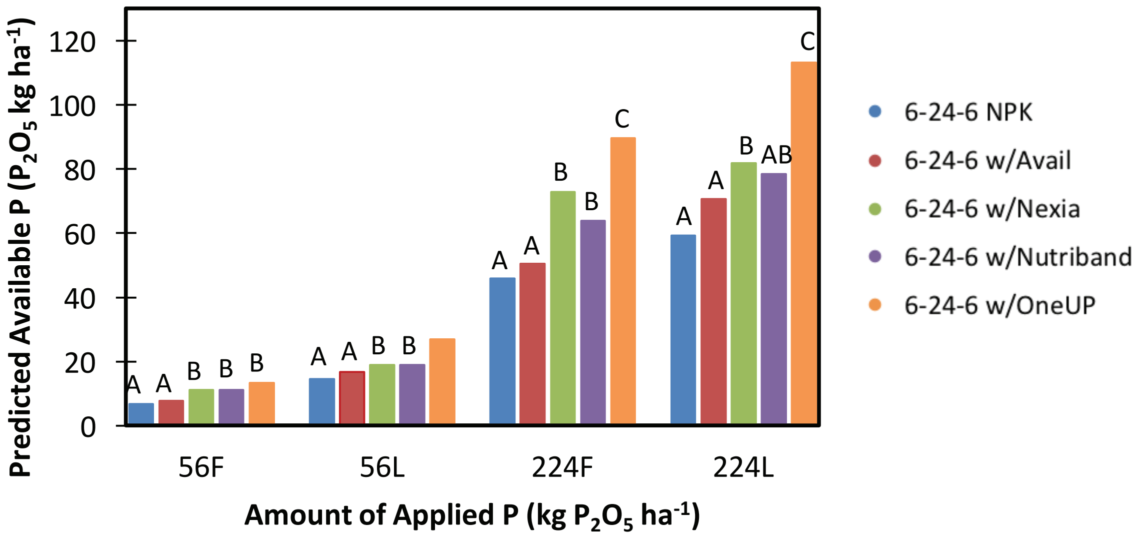

Figure 8. Plant available P_2O_5 as predicted by the Freundlich (F) and Langmuir (L) models for each fertilizer type over a 7-day incubation period for 56 and 224 kg ha^{-1} fertilizer rates. Letters denote difference among fertilizers using Tukey-HSD means separation at an $\alpha = 0.05$.

Approaches to Nutrient Recommendations

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ABSTRACT

Scientific based crop nitrogen (N) fertilizer recommendations are vital to guide N management within the agricultural sector. Accurate recommendations can maximize producer economic returns and minimize losses to the environment. Obtaining accurate recommendations is a dynamic process that requires constant research to update recommendations (within current scientific knowledge) and to better understand soil N cycle processes (develop new scientific knowledge) that can further improve recommendations. This presentation will focus on fertilizer management approaches. Several examples will be presented showing why changes have been made to specific region/crop-based recommendations based on new scientific knowledge.

If you have questions, please email me at: david.tarkalson@ars.usda.gov. The presentation with audio will also be published on the WERA 103 Western U.S. Soil Fertility YouTube channel: www.youtube.com/channel/UCq8g9TDqZwe23oymFlqi2Bw

13th Western Nutrient Management CONFERENCE

Poster Presentations

Aggregate Size, C, N and P Dynamics in Different Dryland Organic Wheat Soils

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ABSTRACT

Utah is one of the largest producers of dryland organic wheat in the US. Previous research indicates that a single application of compost can mitigate low and variable yields and improve soil properties over the long-term. Compost carryover is thought to be greater in high pH and highly calcareous soils compared with neutral, low calcareous soils. However, the mechanisms responsible are unclear. We evaluated the effect of a one-time compost addition on the formation, stability and carbon (C), nitrogen (N) and organic phosphorus (P) distribution of soil aggregates. Compost was applied at 0, 25 and 50 Mg per ha dry weight at two certified organic sites, Snowville (SN) and Blue Creek (BC), in a wheat-fallow rotation. The soil pH at SN is slightly alkaline with low organic matter (OM), while at BC, pH is neutral with greater OM and soil fertility. At SN compost significantly increased soil aggregation and aggregate stability while at BC no significant effect was observed. At SN the < 250-µm sized aggregates decreased while the 250 – 1-µm sized aggregates increased. Compost had significant effects on aggregate C, N and P at BC while at SN it increased C and P but not N. The C/P ratio within the aggregates at BC was narrower than SN while the C/N and N/P ratio were in the same range. Compost effects on soil structure likely regulate the varying effect of compost on the dynamics of OM and soil nutrients. Also, the differences in C, N and P stoichiometry is likely to mediate soil nutrient turnover and availability with time.

Our results indicate that protection of P in soil aggregates may be responsible for the long-term compost carryover. In soils with lower moisture distribution patterns of P was altered. The proportion of P was highest in the small macroaggregates (1-0.25). Cross-site variability in compost effect.

P2

Integrating Cover Crops and Livestock into Irrigated Cropping Systems

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ABSTRACT

Intensive annual cropping consisting of barley-sugar beet rotations in irrigated systems could benefit from integration of cover crops and livestock. This research is being conducted on the University of Wyoming Research Station in Powell, WY, and on six farms in the surrounding area. This area has a short growing season and integrating cover crops into the cropping system is difficult. This study examines the implementation of cover crops after mid-summer barley harvest and the subsequent grazing/haying of these cover crops after peak production. Soil health indicators will be measured for these grazed/hayed cover crops and for unharvested cover crops, followed by a comparison of the two. The research will provide producers with more information on how to promote establishment of and what the soil quality benefits are with cover crops in this system. The on-farm sites will help promote adoption and also provide producers with firsthand knowledge of how integrating livestock and cover crops can help on their specific farms or areas.

Polymer Coated Urea and Urea Blends on Potato

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ABSTRACT

Potato (*Solanum tuberosum* L.) is a globally important crop with significant economic and environmental impacts. Nitrogen (N) has a large impact in both instances. Polymer coated urea (PCU) is a N source with the ability of improving production and the environment. Environmentally Smart Nitrogen (ESN) is a PCU that may reduce the need for continual N application throughout the season. The objective of this research was to evaluate the impacts on potato tuber yield and quality with uncoated and polymer coated urea blends applied pre-emergence with or without in-season urea fertilization. Potatoes were grown at four separate field sites over four years (2015-2018). Treatments included all combinations of three pre-emergent N sources (urea at 50%, PCU at 50%, or PCU at 75%) with three in-season N treatments (0, 50, or 100%). The pre-emergent rates were applied at cultivation and based on estimated seasonal N need. The in-season rates and timing were based on petiole analysis. All fertilized treatments improved yield and tuber size as compared to the control. The interaction between pre-emergent and in-season fertilization was significant for all major yield categories. For urea applied at pre-emergence, increasing rates of in-season fertilization generally increased yields for US No. 1, marketable, and total yields. All PCU combinations, even at no or reduced in-season applied N, produced yields statistically similar to the grower standard practice of applying half of the N pre-emergence and then applying the balance during the season based on petiole NO_3-N analysis. Among the treatments with statistically superior yields, only the PCU at 50% with no in-season N and all of the PCU at 75% treatments also resulted in superior tuber size. Thus, the PCU treatments, especially with no or lower in-season N, were overall superior to the grower standard practice. These data support other findings that N in the coated urea is protected from loss and, thus, is more efficient. The PCU used in these trials (ESN) provided no detrimental yield impacts and achieved similar or better results with less N applied.

INTRODUCTION

Potato is an important food source providing several essential nutrients, vitamins, and amino acids needed by animals, including humans. It is the 14th highest crop in acres harvested at 60 million (24 million hectares) and 4th in value at $123 trillion US dollars (Food and Agricultural Organization of the United Nations, 2019).

Plants also need nutrients to be healthy. Arguably, the most important plant nutrient is nitrogen (N). It is essential for all living organisms. Nitrogen affects shoot/root biomass, tuber yield, size, shape, other quality factors, and impacts pest tolerance. (Taysom, 2015). Efficient N management is essential to a potato crop fertilization program. Potato needs an even supply of N throughout the entire growing season. There cannot be an excess or deficiency of N, as the potato is relatively more sensitive than most other crop species. Excess N delays plant maturity leading to poor root development, smaller tuber sizes, and elevated sugar levels. Deficiency hurts yield, dwarfs plants, causes chlorosis, and early death. Additionally, potatoes have shallow roots, making it difficult to uptake N from the soil. To meet the varying needs of the potato plant, growers apply a portion of the N fertilizer prior to plant emergence and the balance during the season through aerial fertilization or injection into irrigation water (fertigation) to provide a steady supply. Generally, petiole analysis is used to determine the timing and rate of N to apply in-season.

Ecosystems are also sensitive to excessive N (Hopkins et al., 2008). Excess N can result in a buildup of nitrate (NO_3^-) in groundwater. Background levels of NO_3^- in drinking water is common and not a concern, but excesses can result in methemoglobinemia in mammalian infants. Mammalian adults can handle higher levels of NO_3^- in their drinking water, but there is little known about long term effects—with various concerns about possible, unsubstantiated risks.

Additionally, overland N runoff to surface water can lead to algal blooms, which can be directly toxic to organisms and can contribute to the eutrophication related deaths of aquatic organisms. Eutrophication is a serious concern in several western bodies of water, such as Utah Lake, as well as many other regions, including areas of the Gulf of Mexico and the Great Lakes.

Excess N also adds to atmospheric pollution through nitrous oxide (N_2O) emission and ammonia (NH_3) volatilization (LeMonte et al., 2016, 2018). N_2O is a greenhouse gas ~300 more potent than carbon dioxide (CO_2), with concerns surrounding impacts on the climate and sensitive ecosystems. Nitrous oxide also weakens the ozone layer essential for protection of organisms from the sun's rays.

NH_3 gas is termed "reactive N". It does not stay resident in the atmosphere nearly if N_2O but, rather, is readily deposited on land and water bodies. In addition to contributing to surface water quality problems, this deposition can negatively impact nutrient cycling in sensitive ecosystems. An example of this is in high alpine areas where excess N can significantly alter the species composition, with resultant impacts on soil erosion potential and forage quality. Another example is in lands that have suffered wildfires. Excess N results in excessive shoot growth at the expense of roots, with negative impacts on the survivability of plants (especially when water is limiting) essential for remediation of the land.

Furthermore, the creation and use of fertilizer uses considerable resources, of which a great deal is wasted when N is lost to the environment instead of being utilized by plants. The negative environmental impacts from N pollution of the global potato industry are concerning and need to be addressed proactively. To improve these effects, research into the potato and how to grow it by more environmentally effective means is needed.

The losses of N to the environment can be mitigated with the use of enhanced efficiency fertilizers, such as polymer coated urea (PCU; Hopkins et al., 2008; Taysom, 2015; LeMonte et al., 2016, 2018). PCU is a dry, control release fertilizer that has been developed using a coating which surrounds individual granules of fertilizer. These fertilizers are used to allow for the delivery of N over extended periods, with the benefit of reducing risk of loss to the environment. The PCU products have shown a significant decrease in leaching, NH_3 volatilization, and N_2O gas emissions (Hopkins et al., 2008; Taysom, 2015; LeMonte et al. (2016, 2018).

Environmentally Smart Nitrogen (ESN; Nutrien, Loveland, CO, USA) is a PCU with a patented process engineered to control N release based on soil temperatures. ESN was created in consideration of the need to radically reform traditional fertilizer application. It can reduce the time and resource expense of continual N application throughout the growing season or the need and risk of applying all the N at the beginning of the season.

The polymer coating of ESN operates as a membrane. The polymer coat allows for the adsorption of relatively small molecules such as water but slows the release of relatively larger molecules such as urea [$CO(NH_2)_2$], ammonium (NH_4^+), and NO_3^- molecules from exiting until the desired time. Nitrogen release rates increase with increasing soil temperatures in an S-shaped curve. This release pattern is slow at first, increases dramatically after a few days, and then tapers off towards the end—with about a 60-75 d release timing when tilled into the soil. The N release rate from ESN tends to match the associated plant growth and N uptake demand for annual row crops. During periods of cold soil temperature, plant roots are not growing and simultaneously ESN is not releasing N. As the soil warms, root and shoot growth increase with consummate increases in N need as the ESN is simultaneously increasing its rate of N release. Independent research on a range of agronomic crops, including potato (*Solanum tuberosum* L.; Taysom, 2015) and Kentucky bluegrass (*Poa pratensis* L.; LeMonte et al., 2016, 2018) shows that PCU is effective and safe for use. It is compatible with other fertilizers in prescription blends and safe to transport, handle, and store.

The objective of this research is to evaluate the impacts on potato tuber yield and quality with uncoated and polymer coated urea blends applied pre-emergence with or without in-season fertilization with urea.

MATERIALS AND METHODS

Treatments (Table 1) were arranged in a Randomized Complete Block Design with 6 replicated measuring six 36-inch-wide by 40-foot length rows. Initial fertilizer treatments were applied immediately prior to emergence with hilling/cultivation as reservoir tillage incorporating the fertilizer into the soil within 1-3 d after application. Treatments included uncoated and/or PCU (ESN). The fertilizer rates for pre-emergence applications were determined based on soil analysis and University of Idaho fertilizer recommendations (http://cals.uidaho.edu/edcomm/pdf/BUL/BUL0840.pdf) using typical yield goals. The in-season fertilizer treatments were estimated prior to the season, but actual rates and timing were adjusted based on petiole analysis for those receiving the highest rates for that particular source/rate applied at cultivation (treatments 4, 7, and 10). Additionally, some treatments (3, 6, and 9) included a half rate and others none (1, 2, 5, 8, and 11) of the in-season applied urea. All fertilizer was hand spread uniformly across plots using dry, granular products.

Predicted N need for each site were very similar in 2015-2017 and, thus, treatments were identical. The yield potential and the in-season petiole NO_3-N values were different in 2018 and, thus, rates adjusted accordingly, and the treatment ID's are shown as percentages rather than actual rates, which are found in Table 1.

The calcareous soils used were mostly uniform with minimal slope across the plot areas in commercial production fields. Prior to planting, the soil was sampled and analyzed by the Brigham Young University—Environmental Analytical Laboratory (BYU-EAL, Provo, UT; see http://eal.byu.edu for methods used). The soils generally had low cation exchange capacity (CEC) and organic matter (OM) and moderate to high fertility levels. Factors that might impact N nutrition included OM (1-2%), NH_4-N (1-5 ppm), and NO_3-N (3-7 ppm for 2015-2017 and 27 ppm for 2018). Moderate, but not excessive, concentrations of NO_3^--N were found in the irrigation water. The soils had excellent infiltration and drainage and no impactful pesticide residues.

Table 1. Nitrogen fertilizer treatments for polymer coated urea (PCU) potato study with three pre-emergent treatments (urea-50%, PCU-50%, or PCU-75%) with all combinations of three in-season treatments (0, 50, or 100%). The percentages for pre-emergent treatments were based on the anticipated seasonal N need (eg. 50% = half of the total amount expected to be needed for the crop). The percentages for the in-season treatments are based on a full rate as determined by petiole analysis (eg. 50% = half of the recommended rate based on the petioles analyzed the week prior). In-season applications were done twice. The rates in 2015-2017 were identical, but higher rates were needed in 2018 based on soil test and yield potential of the site.

		Total N Applied		Pre-Emergence		In-Season			
				May		July		August	
	Treatments	2015-2017	2018	2015-2017	2018	2015-2017	2018	2015-2017	2018
		lb N/ac							
1	Control	0							
2	urea-50%PE-0%IS	105	150	105	150	0			
3	urea-50%PE-50%IS	158	200	105	150	30	30	23	20
4	urea-50%PE-100%IS	210	250	105	150	60	60	45	40
5	PCU-50%PE-0%IS	105	150	105	150	0			
6	PCU-50%PE-50%IS	158	200	105	150	30	30	23	20
7	PCU-50%PE-100%IS	210	250	105	150	60	60	45	40
8	PCU-75%PE-0%IS	158	225	158	225	0			
9	PCU-75%PE-50%IS	184	250	158	225	15	15	11	10
10	PCU-75%PE-100%IS	210	275	158	225	30	30	22	20

Russet Burbank potato was planted (dates ranged from April 25 to May 8) at 20-22 cwt/ac. The Idaho locations were near: Rexburg (2015-2016), Aberdeen (2017), and Fort Hall (2018), Idaho, USA. The crop was raised according to best management practices—including nutrient, soil, water, pest, and crop management. Wheat (*Triticum* spp) was the previous crop in each year. Weather was mostly typical each year. The crops were never seriously water stressed with the aid of irrigation. Petiole samples were taken across replications for each treatment (avoiding damaging plants and soil in the area of each plot to be harvested) weekly beginning about the end of June through the middle of August and submitted for analysis (BYU-EAL, Provo, UT; see htttp://eal.byu.edu for methods used). The crop canopy was defoliated with Reglone® or sulfuric acid each year about 21 d prior to harvest to help set the tuber skins. Tubers were harvested (dates ranged from September 14 to October 5) via mechanical digging of the middle 20 feet of the center two rows of each plot. Tubers were counted, weighed and hand graded for separation into US No. 1, US No. 2 and culls (malformed and undersized). Tubers (16 per plot) were evaluated for internal defects and specific gravity.

Statistical analysis was performed by Analysis of Variance (ANOVA), with differences between means determined by Tukey-Kramer method using SAS software (SAS 9.3, Cary, North Carolina, USA). A $P = 0.10$

RESULTS AND DISCUSSIONS

All fertilized treatments significantly increased yields vs control ($P < 0.001$) for US No. 1, marketable, and total yields with average responses of 63, 72, and 63 cwt/ac increases, respectively. Tuber size was similarly impacted with an average increase of 1.1 ounces per tuber ($P < 0.001$).

The interaction between pre-emergent and in-season fertilization was significant for all major yield categories. For urea applied at pre-emergence, increasing rates of in-season fertilization generally increased yields for both US No. 1 (Fig. 1) and total (Fig. 2). Results were similar for marketable tubers (data not shown). All PCU combinations, even at no or reduced in-season applied N, produced yields statistically similar to the grower standard practice of applying half of the N pre-emergence and then applying the balance during the season based on petiole NO_3-N analysis. Thus, equivalent yields were achieved with up to half as much applied total N when using PCU pre-emergence (Figs. 1-2). This supports the concept that the N in the coated urea is protected from loss and, thus, is more efficient. There is a distinct advantage for savings in terms of both time and cost of fertilizer and labor when in-season applications are able to be omitted without any detriments to yield or tuber quality. There is also a distinct environmental advantage when using a protected N source and less overall N fertilizer.

There were also significant differences among fertilizer treatments for tuber size (Fig. 3). Tuber size is a complicated process impacted by several factors, including overall yield, nutrition, stems per plant, number of tubers, etc. In addition to a direct impact on tuber size, N nutrition can impact various physiological parameters that influence tuber size. This complexity is reflected in this data with likely explanations provided below.

Not surprising, the most N deficient treatment (urea-50% at pre-emergence with no in-season N applied) had relatively small tubers (Fig. 3). Adding a modest amount (50% of the full rate) of in-season N resulted in significantly increased tuber size. But the effect was reversed, in part, with the full in-season rate (100%). This is likely due to a significant increase in tuber numbers and overall biomass for each plant (data not shown), which resulted in greater overall yield (Figs. 1-2), but with smaller tubers.

The PCU applied at 50% pre-emergence had relatively large tubers, but it also suffered a negative impact on tuber size with in-season N applications (Fig. 3). The PCU at 75% pre-emergence did not have major size impacts with in-season N fertilization—realizing the overall in-season rate applied with this treatment was relatively low. The bottom-line is that among the treatments with statistically superior yields, only the PCU at 50% with no in-season N and all of the PCU at 75% treatments also resulted in superior tuber size.

Potato growers often have production incentives with those they contract with to buy their tubers. Two of the most common are quality and size. Growers are often paid a premium for US

No. 1 tubers, as well as for larger size tubers. Depending on individual contract parameters, these data suggest that growers could have high yields and large average tuber sizes when applying reduced rates of PCU pre-emergence with no or little in-season N.

The results in this trial largely corroborate those in other potato trials with PCU, as reviewed by Taysom (2015). In these trials, yields and tuber quality were maintained or increased with PCU over uncoated urea. In no cases were the yields or tuber quality significantly diminished. Often, as also observed in these data, potato yields and tuber quality were maintained over a wider plateau of N rates, including no application of in-season N. The PCU provides the flexibility to combine with traditional fertigation practices with less total N applied and fewer in-season applications. Thus, PCU provides potential financial and environmental benefits with less risk.

It would be important to note that it is essential that the PCU is of high quality and from a reliable source. The PCU used in these studies, ESN, has been widely evaluated and is seemingly reliable if it is handled and applied properly.

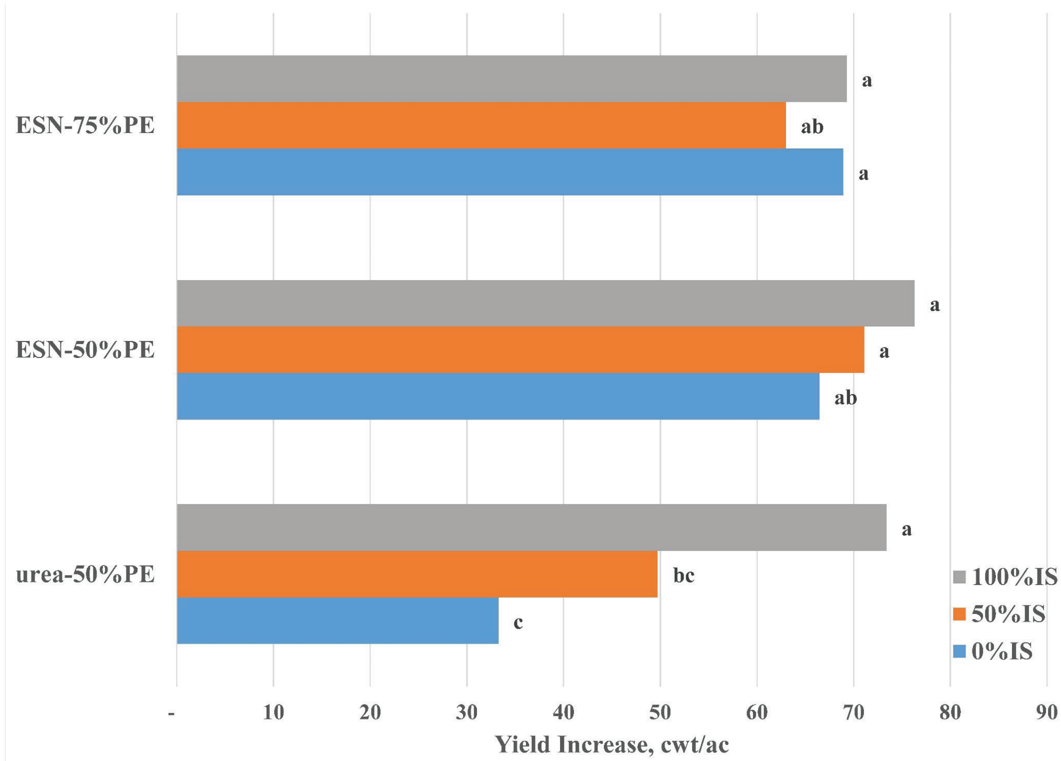

Fig. 1. Average US No. 1 Russet Burbank potato tuber yield increases relative to the untreated controls for nitrogen (N) fertilizer studies conducted in Idaho 2015-2018. Fertilizer was applied pre-emergence (PE) with at either 50 or 75% of predicted N need with polymer coated urea (ESN) or uncoated urea. Each of these were further treated with 0, 50, or 100% of in-season N fertilizer (as predicted through petiole NO_3-N analysis). Values sharing the same letter at the end of the data bar are not statistically different from one another. $P = 0.10$.

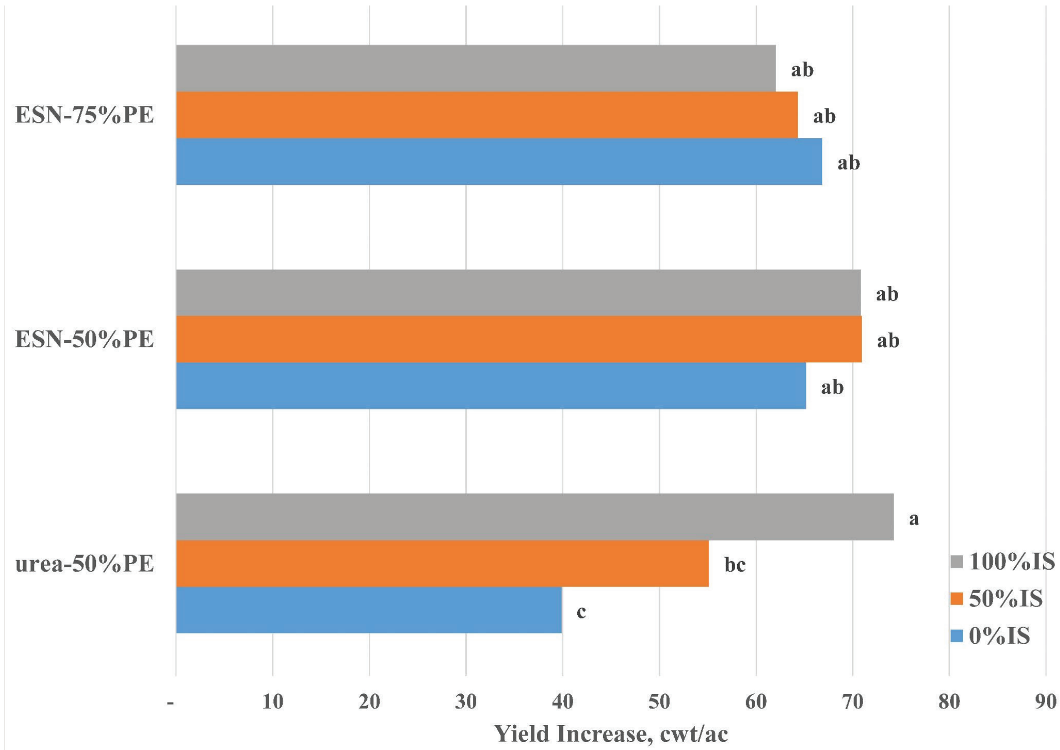

Fig. 2. Average Russet Burbank potato tuber yield increases relative to the untreated controls for nitrogen (N) fertilizer studies conducted in Idaho 2015-2018. Fertilizer was applied pre-emergence (PE) with at either 50 or 75% of predicted N need with polymer coated urea (ESN) or uncoated urea. Each of these were further treated with 0, 50, or 100% of in-season N fertilizer (as predicted through petiole NO_3-N analysis). Values sharing the same letter at the end of the data bar are not statistically different from one another. $P = 0.10$.

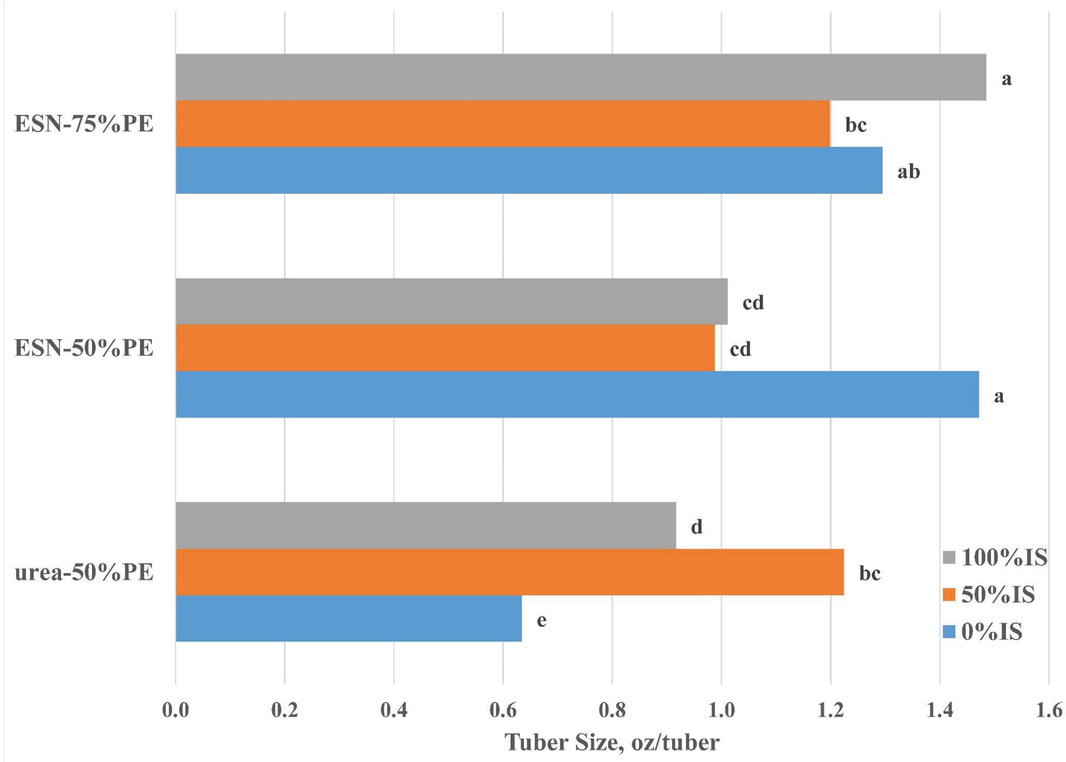

Fig. 3. Average Russet Burbank potato tuber size increases relative to the untreated controls for nitrogen (N) fertilizer studies conducted in Idaho 2015-2018. Fertilizer was applied pre-emergence (PE) with at either 50 or 75% of predicted N need with polymer coated urea (ESN) or uncoated urea. Each of these were further treated with 0, 50, or 100% of in-season N fertilizer (as predicted through petiole NO_3-N analysis). Values sharing the same letter at the end of the data bar are not statistically different from one another. $P = 0.10$.

SUMMARY

All fertilized treatments significantly increased yields over the control for tuber size and US No. 1, marketable, and total yields. For urea applied at pre-emergence, increasing rates of in-season fertilization generally increased yields. All PCU combinations, even at no or reduced in-season applied N, produced yields statistically similar to the grower standard practice of applying half of the N pre-emergence and then applying the balance during the season based on petiole NO_3-N analysis. Among the treatments with statistically superior yields, only the PCU at 50% with no in-season N and all of the PCU at 75% treatments also resulted in superior tuber size. Thus, the PCU treatments, especially with no or lower in-season N, were overall superior to the grower standard practice. These data support other findings that N in the coated urea is protected from loss and, thus, is more efficient. The PCU used in this study, Environmentally Smart Nitrogen (ESN), was an effective enhanced efficiency fertilizer source in these trials. Similar yields with better tuber size was achieved with significantly less N applied.

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Polymer Coated Urea Impact on Barley Yield and Protein

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ABSTRACT

Polymer coated urea (PCU) is an enhanced efficiency nitrogen (N) fertilizer shown to regulate N release over a season benefiting production and reducing nutrient pollution. The purpose of this study was testing the effect of uncoated and coated urea blends on irrigated barley yield and protein. The study consisted of three N rates applied as all urea or a 50-50 blend of PCU and urea. As expected, N rates increased yields and protein. In general, urea resulted in increased yields with increasing N rates. Similar was observed with the blend, but the yield increase peaked at the middle rate, with this treatment being statistically greater than all other sources and rates. In fact, yields decreased significantly with this blend at the highest rate—suggesting that excessive N late in the season harmed yields. Although protein increased slightly with N fertilization, there were no differences across N rate or source. These results show that the PCU used in this trial, Environmentally Smart Nitrogen (ESN), is an effective N source for barley. As it is an enhanced efficiency product, it is logical, and supported by data, to reduce the rate compared to standard practice with urea. Using ESN results in no negative impacts on grain protein regardless of N rate.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is a major cereal grain grown in temperate climates worldwide. It ranks fifth globally among crops with 51 million hectares (126 million acres) harvested annually with a gross value of 30 billion U.S. dollars (Food and Agricultural Organization of the United Nations, 2019; averaged over 2007-2016). Most barley is used for food/malt purposes, while the remainder is allotted to animal feed (Agricultural Marketing Resource Center, 2018).

Barley, like any plant, requires specific nutrients to thrive. Arguably, the most important nutrient is nitrogen (N). Among its essential functions in plants, it is imperative for photosynthesis. Nitrogen is a vital component of chlorophyll, which is a key compound used in photosynthesis—aiding in the conversion of sunlight energy into chemical energy stored in sugars. It also aids in the production of proteins found in nucleic acids and other plant parts.

Nitrogen affects shoot/root biomass, yield, grain protein concentration, kernel plumpness, other quality factors, as well as impacting pest tolerance. Efficient N management is essential to barley crop fertilization. The crop needs an even supply of N throughout the growing season until the plant begins to cease uptake and switches to reproductive mode. An excess or deficiency of N should be avoided. Excess N results in grain loss from lodging and/or excessively high protein levels. High protein is generally desirable for livestock feed, but can be detrimental for malting barley. On the other hand, deficiency results in dwarfed plants, reduced leaf area index, chlorosis, grain yield and protein reductions, and, if severe, premature death.

Ecosystems are also sensitive to excessive N (Hopkins et al., 2008), resulting in excess nitrate (NO_3^-) in groundwater. Background levels of NO_3^- in drinking water is common and not a concern, but excesses can result in methemoglobinemia in mammalian infants. Mammalian adults can handle relatively high levels of NO_3^- in their drinking water, but there is little known about long term effects—with various concerns about possible, unsubstantiated risks.

Additionally, overland N runoff to water bodies can lead to algal blooms. These can be directly toxic to organisms and contribute to the eutrophication related deaths of aquatic organisms. Eutrophication is a serious concern in several western bodies of water, such as Utah Lake, Lake Tahoe, and many other regions, including areas of the Gulf of Mexico and the Great Lakes. Some of this is contributed by nutrient enrichment from fertilizers.

Excess N also adds to atmospheric pollution through nitrous oxide (N_2O) emission and ammonia (NH_3) volatilization (LeMonte et al., 2016, 2018). N_2O is a greenhouse gas ~300 more potent than carbon dioxide (CO_2), with concerns surrounding impacts on the climate and sensitive ecosystems. Nitrous oxide also weakens the ozone layer essential for protection of organisms from the sun's rays. Li et al. (2016) evaluated N_2O emissions in a barley cropping system and concluded that emission from ESN fertilized barley was 15% lower than urea across all site-years. They suggest that ESN could play a role in reducing N_2O emissions, but the reduction will depend on rainfall events and crop N utilization.

NH_3 gas is termed "reactive N." It does not stay resident in the atmosphere nearly as long as N_2O but, rather, is readily deposited on land and water bodies. In addition to contributing to surface water quality problems, this deposition can negatively impact nutrient cycling in sensitive ecosystems. An example of this is in high alpine areas where excess N can significantly alter the species composition, with resultant impacts on soil erosion potential and forage quality. Another example is in lands that have suffered wildfires. Excess N results in excessive shoot growth at the expense of roots, with negative impacts on the survivability of plants, especially in water limiting conditions, essential for remediation of the land.

Furthermore, the creation and use of fertilizer takes a considerable amount of resources, of which a great deal is wasted when N is lost to the environment instead of being utilized by plants. The negative environmental impacts from N pollution of the global barley industry are concerning, clear, and significantly detrimental and need to be addressed proactively. Researching how to grow barley by more environmentally effective means is needed.

The losses of N to the environment can be mitigated with the use of enhanced efficiency fertilizers, such as polymer coated urea (PCU; Hopkins et al., 2008; LeMonte et al., 2016, 2018). PCU is a dry, control release fertilizer developed using a coating on fertilizer granules. These fertilizers deliver N over extended periods, reducing loss to the environment. PCU products show a significant decrease in leaching, NH_3 volatilization, and N_2O gas emissions (Hopkins et al., 2008; LeMonte et al., 2016, 2018).

Environmentally Smart Nitrogen (ESN; Nutrien, Loveland, CO, USA) is PCU with a patented process engineered to control N release based on soil temperatures. ESN radically reforms traditional fertilizer application, replacing the time and resource expensive practice of continual application of N throughout the growing season or the high risk practice of applying all of the N at the beginning of the season. ESN potentially solves the environmental issues, while providing ample N for crop production.

The polymer coating of ESN protects the N granule and operates as a membrane, which allows relatively small-size water (H_2O) molecules to enter through pores in the membranes. The membrane slows the release of N from the relatively large size urea [$CO(NH_2)_2$], ammonium

(NH_4^+), and NO_3^- molecules. Nitrogen release rates increase with increasing soil temperatures in an S-shaped curve. This release pattern is slow at first, increases dramatically after a few days, and then tapers off towards the end—with about a 60-75 d release timing when tilled into the soil. This pattern tends to match associated plant growth and N uptake demand for many annual crops. If the soil is cold, plant roots are not growing and thus the ESN is not releasing N. As it warms and root growth increases, with a corresponding increase in demand for N, the PCU releases it—potentially meeting all of the N needs of the plant with a reduced window of loss susceptibility.

Independent research on a range of agronomic crops, including potato (*Solanum tuberosum* L.; Taysom, 2015) and Kentucky bluegrass (*Poa pratensis* L.; LeMonte et al., 2016, 2018) shows that PCU is effective and safe for use. It is compatible with other fertilizers in prescription blends and safe to transport, handle, and store.

The objective of this research is evaluating the impacts on barley yield and quality with uncoated and polymer coated urea blends.

MATERIALS AND METHODS

Treatments were arranged in a Randomized Complete Block Design (RCBD) with six replications in plots ranging in size in various years from 200-400 ft^2. Treatments consisted of applying three rates (76, 100, or 124 lb N/ac) applied either as urea or as an equal blend of ESN and urea. Treatments were applied with broadcast, hand-held spreaders pre-plant. Treatments were disked into the soil with 1-2 days following application.

Malt barley varieties were planted between the last week of April through the first week of May each year near Rexburg (2015), Teton (2016 and 2017), and Menan (2018); ID, USA. The soils were mostly uniform silt or sandy loams with modest fertility levels, and excellent infiltration and drainage. The soil was sampled prior to planting and analyzed the Brigham Young University—Environmental Analytical Laboratory (BYU-EAL, Provo, UT). In general, barley emerged the middle of May with visual differences apparent with fertilized and unfertilized treatments in mid-June

There were no impactful pesticide residues in the soil from previous crops (fallow in 2015, barley in 2016 and 2017, and forage grass in 2018). The crop was scouted weekly for disease and insect pressure. Pest pressure was minimal, with no notable outbreaks of any pathogens, viruses, or insects. Pesticides were applied per label and applications were considered successful as weed pressure was minimized and under control. Lodging was typically observed, especially in the high N plots, about 30 days before harvest. The crop did not suffer from serious moisture stress with the aid of irrigation. Weather was mostly typical for the area.

Composite flag leaf samples were taken and submitted for analysis (Environmental Analytical Laboratory, Brigham Young University, Provo, UT; data not presented herein). Canopy health was evaluated by Normalized Difference Vegetation Index (NDVI) using a GreenSeeker® Handheld Crop Sensor, (Trimble, Sunnyside, CA; data not presented herein) about the same time as flag leaf samples were taken. Harvest was conducted the middle to the end of August using a Haldrup research harvester (Haldrup USA. Ossian, IN) to mechanically collect grain from 5 ft x 10 ft area from the middle of each plot. The grain samples were weighed and analyzed for protein content and other quality factors.

Statistical analysis was performed by Analysis of Variance (ANOVA) with differences between means determined by the Tukey-Kramer method using R software (r-project.org) with a $P = 0.10$.

RESULTS AND DISCUSSION

The effect of year did not significantly interact with source or rate and, as such, the values are combined across the four years of this trial.

As expected, N rates generally increased yields (Fig. 1). With urea, the yields increased with increasing rates, although the highest rate was statistically equivalent to the middle rate. In contrast, the yield increase peaked at the middle rate with the PCU-urea blend, with this treatment being statistically greater than all other sources and rates. In fact, yields decreased significantly with the PCU-urea blend at the very highest rate—suggesting that excessive N late in the season harmed yields in these studies. Barley yields at higher ratios of ESN were not as effective as the 50-50 blend in these studies (data not shown). It is noteworthy that the difference between urea and PCU-urea blend trended to be higher in wet years, although the interaction between year and treatment/rate was not highly significant.

Often, increasing N rates will also increase grain protein, which occurred in this trial. Although individual treatments were not significantly different from one other for protein, an orthogonal comparison of fertilized vs. unfertilized shows a slight, but significant increase of 0.41% protein concentration in the N fertilized plots (averaged across all treatments) compared to the unfertilized control. Although there was a trend for increasing protein with increasing rates of the PCU-urea blend, this and other rates and sources were not significantly different (Fig. 2). Thus, we conclude that, based on four years of mostly consistent results, protein values were not impacted any differently for the PCU-urea blend compared to urea alone.

It is also noteworthy that differences were often, although not in every year, measured for flag leaf N, visual assessments, and NDVI—with trends tending to follow N rate (data not shown). It should also be noted that the high rate of N fertilizer often resulted in significant amounts of lodging, with no strong difference between fertilizer sources.

These results show ESN is an effective enhanced efficiency fertilizer source of N for barley, although it is seemingly important to avoid blends with too high of a percentage of ESN. Based on these data, we recommend a 50/50 blend. We also recommend avoiding excessive N rates when using an enhanced efficiency product.

SUMMARY

Based on four years of trials on irrigated barley, a 50%-50% blend of PCU (ESN) and urea significantly increased yield at a moderate rate of N. The yield increase for this treatment and rate was greater than any other treatment, including those with urea applied alone. However, the high rate with this blend resulted in yields decreasing significantly. In regards to protein, the source had no impact on concentration. In summation, these results show that ESN is an effective source of N for barley, although it is seemingly important to avoid blends with too high of a rate or too high of a percentage of ESN.

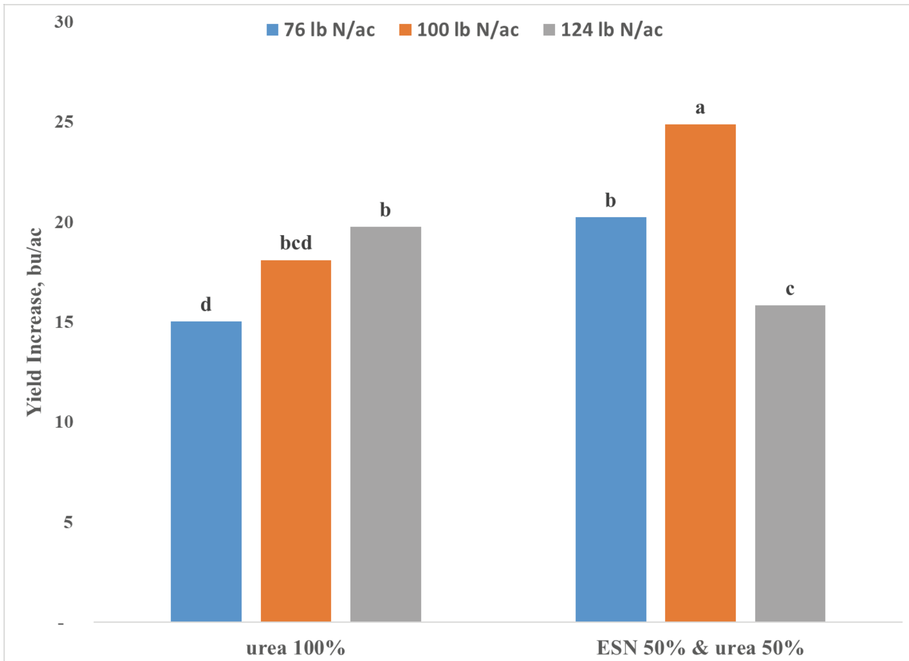

Fig. 1. Barley grain yield increases relative to an unfertilized control averaged over four years (2015-18) for a polymer coated (ESN) urea fertilizer trial in Idaho. Fertilizer was applied at three rates, with each rate applied as 100% urea or 50% ESN & 50% urea. Data bars sharing the same letter(s) are not statistically different from one another. *P* = 0.10

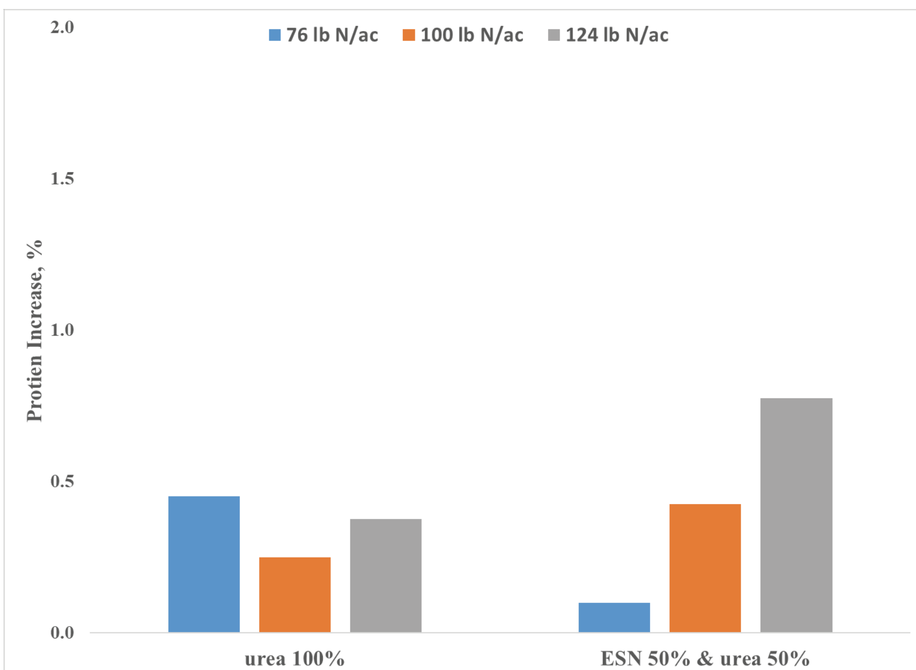

Fig. 2. Relative barley grain protein percentages averaged over four years (2015-18) for a polymer coated (ESN) urea fertilizer trial in Idaho. Fertilizer was applied at three rates, with each rate applied as 100% urea or 50% ESN & 50% urea. Values shown are the ESN treatments relative to the untreated control. No differences were statistically significant. P= 0.10.

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Struvite Phosphorous Fertilizer on Sugar Beet

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ABSTRACT

Sugar beet is very sensitive to P deficiency early in the growing season. Crystal Green is a struvite phosphorus (P) fertilizer source that may uniquely enhance uptake in sugar beet. In this study, we examine the effect of struvite applied to sugar beet and compare the results against the use of traditional monoammonium (MAP) fertilizer and a control. There was a significant increase in response to MAP over the control for both total and sugar yield. The struvite based fertilizer had an additional yield increase over MAP, with the magnitude of the response relatively greater at sites where the fertilizer was applied in a concentrated band than in those where it was broadcast applied. There were no differences in sugar percentage or impurities. The results indicate that struvite fertilizers effectively provide P and increase sugar beet yields. These results suggest that a concentrated band application may be more effective than broadcast, although more work needs to be performed with direct comparisons within the same fields.

INTRODUCTION

The chemist Andreas Marggraff (1709-1782) discovered that white and red beet roots (*Beta vulgaris* L.) contained sucrose indistinguishable from sugarcane (*Saccharum* spp.). After this discovery, several attempts were made to develop ways to extract the sucrose to develop an efficient method to industrialize the extraction. Prior to this, sugar could only be obtained from sugarcane expensively exported from tropical areas. The first successful attempt for commercial production of crystalized sucrose obtained from beets was made in California in 1870. Currently more than 33 million tons of sugar, about 35 percent of the world's production, comes from sugar beet and 65 percent is still obtained from sugarcane. In the US, about 50-55% of domestic production, which is about 143 million tons, comes from sugar beet (Harveson, 2015). Among crops, sugar beet is harvested on ~5 million hectares (12 million acres) annually with a value at ~$13 billion US dollars (FAO, 2019).

Soil fertility is an important aspect of sugar beet nutrition—with phosphorus (P) being a dominant aspect required to perform vital functions. It is part of important plant structure compounds, and it is a catalyzer of multiple biochemical reactions in plants. One significant role P plays in plant function is helping capture and conversion of the sun's energy into plant compounds. Phosphorous is part of the adenosine tri-phosphate (ATP) molecule, which is plants' energy transfer system. Phosphorous is essential for the health of plants, not just for the production of ATP but also for early root development, crop maturation, stem and stalk strength, crop quality, and resistance to plant diseases (Hopkins, 2015).

Phosphorous deficiency inhibits sugar beet growth. A P deficiency will cause stunted growth and stiff appearance. The color of a P deficient leaf will range from dark green to purple (Hopkins, 2015). However, we have never observed a purpling color in our many years of research with sugar beet. Phosphorous deficiency is often associated with soils that are high in pH and excess limestone, as well as with acidic soils (P solubility and, thus, plant availability, is greatest at near neutral pH). Less than optimal P nutrition can lead to crop losses of 10-15 percent (Hergert, 2012).

Soils chemistry of P is challenging as only a small part of the total soil P is dissolved in soil solution, which is the form it needs to be in for plant uptake. Phosphorus cannot be replenished in soil except from an external source if it is lost by run off, erosion or other means (Sanyal and De Datta, 1991). As such, there are best management practices and enhanced efficiency fertilizers developed to improve P nutrition (Ellsworth and Hopkins, 2006; Hopkins and Stephens, 2008; Hill et al., 2015; Hopkins et al., 2008, 2014, 2018; Hopkins, 2015).

Struvite is a crystal with equal molar concentrations or magnesium, ammonium, and phosphate made from excess buildup of nutrients in waste water streams as it accumulates as a cement-like substance in water treatments pipes, pumps, and valves. It is somewhat soluble under neutral conditions, but highly soluble in acidic conditions (Rahman et al., 2014). This presents a possible advantage for crops grown in acid soils with low P solubility. These characteristics make struvite an "eco-friendly" option for fertilizer (Rahman et al., 2014).

Ostara (Vancouver, British Columbia, Canada) has developed a slow release fertilizer material from struvite called Crystal Green®. Their process recovers up to 90 percent of P and 20 percent of ammonia (NH_3) from a treated wastewater stream, effectively transforming the waste stream into a renewable resource as an environmentally-friendly fertilizer (Zakrzewski, 2012).

Our objective with this study is to test the effectiveness of struvite (Crystal Green) applied as either a broadcast or a concentrated fertilizer band to sugar beet total and sugar yield, sugar concentration, and presence of impurities.

MATERIALS AND METHODS

Roundup Ready Sugarbeet varieties were planted at four locations near American Falls, ID (2016), Provo, UT (2017 and 2018), and Nampa, ID 2018 (dates ranged from April 12 to May 15). The seed was treated with a fungicide coating and planted ~0.5 inches deep. The soils were calcareous silt to sandy loams with 0-2% slopes, moderate soil fertility levels, excellent infiltration and drainage, and no impactful pesticide residues. Soil test P was low to medium (Table 1).

Plots were arranged in a Randomized Complete Block Design with six replicated blocks in plots with six rows by 40 foot length. Distance between rows was between 18-22 inches. Treatments varied each year, but included a control without any P fertilizer, MAP, and various combinations of MAP with struvite (Table 2). The concentrated band treatments were applied at planting by placing the fertilizer directly below the seed at a depth of six inches. The broadcast treatments were applied immediately prior to planting by uniformly broadcast spreading the fertilizer with a hand-held rotary spreader and then incorporated by disking to a depth of four to six inches. Nitrogen was balanced across all treatments using urea (46-0-0).

The crop was raised per best management practices – including nutrient, soil, water, pest and crop management. Glyphosate (Roundup®) herbicide was applied at label rates in the growing season for weed control. The crop was scouted weekly for disease and insect pressure—revealing minimal impact and, thus, no application of insecticides or fungicides (other than what was on the seed).

Weather was mostly typical, with a moderate amount of precipitation and near average temperatures. The crop was irrigated frequently due to the low water holding capacity of the soils and minimal precipitation. At times, the crops were water stressed due to malfunctions in the irrigation systems. Fortunately, these occurred late season when sugar beet is known to be very resilient to moisture stress.

Table 1. Select soil test values for four fertilizer field site locations

	American Falls, ID 2016	Provo, UT 2017	Provo, UT 2018	Nampa, ID 2018
	Top-Soil (0-8 inches)			
pH	7.9	7.8	8.0	8.0
Lime, %	8.2	2.1	2.1	5.4
Bicarbonate P, ppm	18	10	11	15
	Sub-Soil (8-36 inches)			
pH	8.3	8.1	8.2	8.1
Lime, %	12.4	3.4	3.5	7.0
Bicarbonate P, ppm	6	3	2	4

The crops were harvested late in the season (dates ranged from October 15 to November 10) by removing the center 20 feet of the center two rows. Beets were hand-harvested, weighed, and then analyzed for tare dirt, sugar, nitrate concentrations, and electrical conductivity by the Amalgamated Sugar Company Tare Lab (Rupert, ID).

Statistical analysis was performed by Analysis of Variance (ANOVA) with differences between means determined by Tukey-Kramer method using SAS software (SAS 9.3, Cary, NC). A *P* value of 0.10 was used to evaluate the statistical analysis.

RESULTS AND DISCUSSION

There was a significant interaction for fertilizer placement and treatments, but not a difference across years. Therefore, the data for broadcast applications in 2016 and 2018 were combined and the data for concentrated band applications in 2017 and 2018 were combined for analysis.

There was an increase in sugar yield with broadcast applied MAP fertilization compared to the control, although there was not an increase for total yield (Table 3). Similarly, there was a significant increase in sugar yield for broadcast Crystal Green over the control, but it also showed a significant increase in total yield. Although there was a trend for Crystal Green to have greater yield than MAP it was not statistically significant. There were no differences in sugar percentage or impurities (nitrates and salts as measured by electrical conductivity).

There was a significant increase in response to P fertilizer for application of Crystal Green in a concentrated band as well (Table 4). MAP fertilization resulted in significantly greater total yield over the control, although there was no difference for sugar yield. The Crystal Green fertilization had greater yields than MAP and the control. There were no differences in sugar percentage or impurities (nitrates and salts as measured by electrical conductivity).

Table 2. Phosphorus fertilizer treatment blends. Monoammonium phosphate (MAP) and/or various Crystal Green (CG) products. Nitrogen (N) was balanced in the controls with urea.

Trial	Treatment	Trt #	MAP	CGO	CGNXT	15CG-85MAP	25CG-75MAP	N, lb/ac	P_2O_5, lb/ac
2016	control	1						13	
broadcast	MAP	2	100%					13	60
	CG/MAP	3	85%	15%				13	60
	CG/MAP	4	75%	25%				13	60
	CG/MAP	5	65%	35%				13	60
	CG/MAP	6	50%	50%				13	60
2017	control	1						13	
band	MAP	2	100%					13	30
	CG/MAP	4	75%	25%				13	30
	CG/MAP	5	65%	35%				13	30
	CG/MAP	7	75%		25%			13	30
	CG/MAP	8	65%		35%			13	30
2018	control	1						11	
band	MAP	2	100%					11	30
	CG/MAP	4	75%	25%				11	30
	CG/MAP	5	65%	35%				11	30
	CG/MAP	7	75%		25%			11	30
	CG/MAP	8	65%		35%			11	30
	CG/MAP	9				100%		11	30
	CG/MAP	10					100%	11	30
2018	control	1						21	
broadcast	MAP	2	100%					21	60
	CG/MAP	4	75%	25%				21	60
	CG/MAP	5	65%	35%				21	60
	CG/MAP	7	75%		25%			21	60
	CG/MAP	8	65%		35%			21	60
	CG/MAP	9				100%		21	60
	CG/MAP	10					100%	21	60

Table 3. Sugar beet yield parameters for a phosphorus study in Idaho 2016 and 2018. Fertilizer was broadcast applied and then incorporated into the soil with tillage. Data in bold-face type is statistically significant, with values sharing the same letters being not different than one another. $P = 0.10$

	treatment	electrical conductivity	nitrate	sugar	**yield**		**sugar yield**	
		dS/m	ppm	%	**--------- ton/ac ---------**			
1	control	1.12	688	17.6	**36.7**	**b**	**6.47**	**b**
2	MAP	1.10	576	17.8	**37.8**	**ab**	**6.70**	**a**
3	Crystal Green/MAP	1.07	665	17.6	**39.5**	**a**	**6.94**	**a**

Table 4. Sugar beet yield parameters for a phosphorus study in Idaho 2017-2018. The fertilizer was applied as a concentrated band six inches below the seed. Data in bold-face type is statistically significant, with values sharing the same letters being not different than one another. $P = 0.10$

	treatment	electrical conductivity	nitrate	sugar	**yield**		**sugar yield**	
		dS/m	ppm	%	**--------- ton/ac ---------**			
1	control	0.76	218	16.9	**35.6**	**c**	**6.01**	**b**
2	MAP	0.76	267	16.9	**37.2**	**b**	**6.32**	**ab**
3	Crystal Green/MAP	0.78	198	16.8	**42.1**	**a**	**7.08**	**a**

It is noteworthy that struvite is also high in magnesium (Mg), which is not the case for MAP. However, the Mg levels of the soil and irrigation water are very high—resulting in high levels of Mg in the plant tissue (data not shown). As such, the responses observed in this study are not likely due to a Mg response.

It is apparent from these results that struvite is a more efficient source of P fertilizer than MAP. The magnitude of the response seems larger when the fertilizer is band applied, although no firm conclusions for this can be made because the trials did not occur in the same fields.

The efficiency of banding versus broadcast application is much greater at low versus high soil test P results, with about a threefold increase in uptake efficiency with banding. For maximum effect, the fertilizer needs to be placed in an area where roots are likely to be congregated. For sugar beet, placement should be directly below the seed in order to intercept the taproot dominant in the first few weeks of growth (Hopkins and Ellsworth, 2005; Ellsworth and Hopkins, 2006; Stevens et al., 2007; Hopkins et al., 2008; Hopkins and Stephens, 2008; Hopkins, 2015).

Physiologically, it is important to understand that sugar beet sets its yield potential in the first ~8 weeks. Any stress can result in a lower maximum yield potential—regardless if conditions improve later in the season. The yield potential is set by the number and thickness of the cambial rings in the taproot. Both of these can be reduced if the plant is P deficient.

Sugar beet has a unique nutrient intake system, consisting of a long taproot and lateral, filiform rootlets (Artschwager, 1926; Stevens et al., 2007; Hopkins and Stephens, 2008; Hopkins, 2015). This strong, fleshy taproot can grow to depths of five to six feet. The lateral rootlets begin to appear when the plant is six to eight weeks old (Weaver, 1926). A tap root is a long and somewhat thick root that penetrates deep down into the soil. It is the first root to appear from the seed and remains the largest, central root of the plant. The taproot allows the beet to be drought tolerant, and to store food reserves. However, nutrient availability is low because the taproot burrows so deep into the soil at the expense of lateral root growth in the topsoil at the beginning of the season. The subsoil is typically very low in P.

The probability of P deficiency is relatively high with sugar beet due to this root architecture and morphology. Sugar beet is very slow to grow initially. The root system is a very dominate taproot with minimal topsoil exploration during the first two months of growth (Fig. 1). Root growth increases during the third month, but there is still not much exploration of the fertile topsoil (Fig. 2). It is not until much later in the season when eventual exploration of the nutrient rich surface soil occurs (Fig. 3). In contrast, Fig. 4 shows the root system of potato, which effectively explores the fertile topsoil during the first two months of growth.

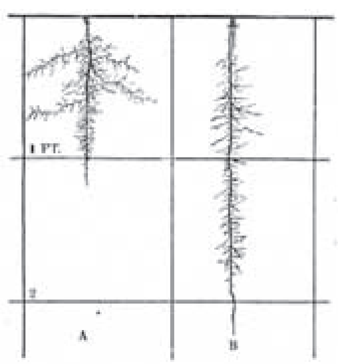

Fig. 1. Sugar beet roots at about 2 months old: *A,* dry land (practically no water available in the second foot); *B,* irrigated soil. Horizontal lines represent one foot increments in depth. (Adapted from Weaver, 1926).

Fig. 2. Sugar beet roots at about 3 months old: *A,* dry land with low water content of subsoil; *B,* fully irrigated soil. Horizontal lines represent one foot increments in depth. (Adapted from Weaver, 1926).

Fig. 3. Sugar beet roots towards at maturity: *A,* dry land; *B,* fully irrigated soil. Horizontal lines represent one foot increments in depth. (Adapted from Weaver, 1926).

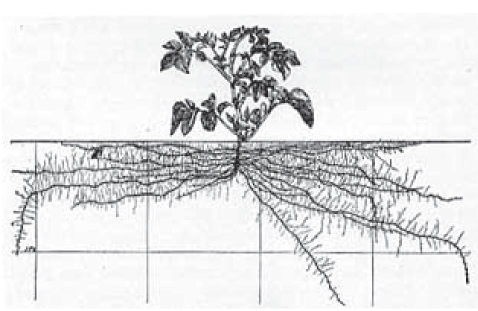

Fig. 4. Potato roots at 56 days old. Horizontal lines represent one foot increments in depth. (Adapted from Weaver, 1926).

SUMMARY

Crystal Green, a struvite-based fertilizer, generally increased total and sugar yield in sugar beet. This effect seemingly had a larger magnitude of response when the fertilizer was applied in a concentrated band directly below the seed, although further work needs to be performed to verify this assumption.

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P6

Phosphorus Rate Effects with and without AVAIL on Dryland Winter Wheat in an Eroded Calcareous Soil

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ABSTRACT

Soluble phosphorus fertilizer precipitates rapidly after application on alkaline, calcareous soils. A fertilizer additive known as AVAIL® (J.R. Simplot Company) is purported to keep applied phosphorus fertilizer more available to plants by binding soil cations, thereby reducing precipitation reactions. In a soil high in base cations, this could prove useful due to the attraction of AVAIL® with cations such as Ca^{2+}, but is fairly unstudied for dryland wheat production on alkaline, calcareous soils. The objective of this study was to evaluate the effect of low-rate fertilizer treatments with AVAIL® on dryland small grain yield on alkaline, calcareous, eroded hillslopes in a fallow-wheat crop rotation. Two experiments were conducted to determine the treatment on yield and grain quality for (1) spring broadcast application of mono-ammonium phosphate (MAP; 11-52-0) fertilizer (2017), and (2) fall banded application of MAP at planting (2018). Fertilizer treatments were the recommended rate (60 lbs/ac) or one-half the recommended rate (30 lbs/ac) for dryland small grain, with or without AVAIL® (four treatments), replicated four times in a strip-block design in 2017 and replicated 3 times in a randomized complete block design in 2018. Erosional severity was used as experimental blocks (non-eroded, slightly eroded, highly eroded, and depositional slope segments). Hillslope segmentation allowed for correlating between calcium carbonate, organic matter, and yield levels across treatments. In the broadcast study there was no statistically significant yield advantage of any treatment at any level of erosional severity, saving a grower \$20.30/acre by applying 30 lbs/acre of MAP. However, 30 lbs/acre of MAP with AVAIL® showed similar yields to 60 lbs/acre of MAP without AVAIL®, saving a grower \$6.42/acre over the standard practice.

Results from the banding study also indicate no statistically significant yield advantage of any treatment at any level of erosional severity, saving a grower \$15.37/acre by applying 30 lbs/acre of MAP. Neither treatment with AVAIL® had greater yield or profit than those without AVAIL®. Profit for the 60 lbs/acre of MAP treatment narrowly outperformed 30 lbs/acre of MAP by \$1.73/acre. This indicates that growers may be able to reduce phosphorus use under dryland growing conditions with optimal fertilizer placement.

Water and Nitrogen Interactions in Kentucky Bluegrass

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ABSTRACT

Pressure is increasing in arid regions to conserve water, especially during drought. Turfgrass is the irrigated crop of greatest acreage in the United States and is coming under scrutiny in urban ecosystems. The purpose of this study was evaluating water use by Kentucky bluegrass (*Poa pratensis* L.) under various irrigation and nitrogen (N) regimes. A study was conducted in an established stand of Kentucky bluegrass in Provo, UT, USA. The turfgrass was split equally into 27 plots (11 x 11 foot). Three moisture regimes were established at 60%, 100%, or 140% of evapotranspiration (ET) daily replacement values with three N regimes of deficient, optimal, and excessive (1.3, 2.7, and 5.3 lb/1000 ft^2, respectively). The N applications were applied in the form of 67% PCU and 33% ammonium sulfate. Remote and proximal sensors were used to collect data over the space of 21 days beginning July 23, 2018. Data on canopy temperature, normalized difference vegetation index (NDVI), and soil water were collected hourly. For the high irrigated grass, as expected, none of the N treatments experienced stress. However, in the full and low irrigation treatments, when coupled with excessive N rates, grass experienced significant drought stress as shown by canopy temperature 5 degrees F higher than optimum or deficient. The stress came from increased canopy height and growth rate due to higher nitrogen availability. This trend is not evident in the NDVI data but this is due to the truncated time frame of the study. If the study continued, NDVI may have dropped as a result of water stress caused by high nitrogen. The results suggest that water conservation might be achieved by optimizing the interaction of N and water supply. These results indicate N management influences ET in Kentucky bluegrass. Reducing N can result in water conservation, but the effects on grass health and appearance must be considered. In one case, limiting N may reduce ET of fully irrigated grass. In another case, high N may improve greeness when water supply is limited.

INTRODUCTION

Turfgrass is the irrigated crop of greatest acreage in the United States, occupying almost 2% of the total surface area (Milesi et al., 2005). As urban and suburban developments grow, turfgrass is quickly growing as the principle managed land cover. Turfgrass aids in providing healthy urban ecosystems regarding groundwater protection, erosion control, soil health, and cooling and cleaning of the air. Turfgrass improves air quality by acting as a filter, capturing smoke and dust, as well as absorbing sulfur and carbon dioxide, reducing and greenhouse gas concentrations. Carbon cycle modeling shows turfgrass sequesters up to 11.8 g C ft^{-2} $year^{-1}$ (Zirkle et al., 2011). In addition, turfgrass is used for aesthetics in landscape and recreational purposes, including sports turfgrass (Beard, 1993). Various applications provide utility to residential and public lands.

However, concerns about natural resource consumption and pollution issues have brought turfgrass under scrutiny, particularly in the arid and semi-arid regions of the western US. Drawbacks of turfgrass include natural resource consumption, both in the mining of minerals for and production of fertilizers used on turfgrass. Proper management of turfgrass requires fossil fuels for mowing and water for irrigation. There is concern about pesticide use, and various problems result from pollution of the hydrosphere and atmosphere. Fragile ecosystems surrounding turfgrass can be permanently damaged by the nutrient pollution resulting from over fertilization and irrigation of turfgrass.

Plants require water and nitrogen (N) for survival. Nitrogen is the nutrient required in highest concentrations and is vital for a plant's life cycle. Plant biogeochemical processes require N for the synthesis of chlorophyll, nucleotides for deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), and amino acids for protein and enzyme production. Plant deficiencies of N lead to dramatic effects on the health of the plant. Plant vigor and verdure, visual landscape quality, recovery from damage, and overall plant health are maintained with sufficient N (Bowman, 2002).

Along with N, water is necessary for all plant functions. Turfgrass requires a significant amount of water, a scarce resource in the arid and semi-arid regions of the west. In most locales, there is insufficient precipitation to meet water demand. Water scarcity is a pressing issue due to declining groundwater levels, increasing competition for water by municipal and industrial users, increasing frequency and severity of drought, rapid population growth, and declining water quality due to pollution and salinity (Gleeson et al., 2012). Unfortunately, turfgrass managers often over apply N fertilizers and do not properly manage irrigation, leading to many of the ecological and environmental problems mentioned above, as well as often having poor plant health.

Over fertilization can lead to an increase in water use and environmental pollution. Increased nutrients, especially N and phosphorus (P), in waterways leads to algal blooms and speeds up the natural eutrophication process. An increase in algal blooms often results in injury or death to aquatic life or organisms drinking the water. This results in decreasing biodiversity, unsightly conditions, strong odors, economic losses, and a decrease in recreational use (Fangmeier et al., 1994). Nitrate (NO_3^-) and ammonium (NH_4^+) are easily transported through soil erosion and surface runoff and, as they contaminate drinking water sources, they can cause methemoglobinemia, commonly known as blue baby syndrome. In addition to water pollution, a percentage of N fertilizers are volatilized leading to air pollution, including: photochemical smog, particulate matter, and acid rain. In addition, nitrous oxide (N_2O) is produced and contributes to greenhouse gas concentrations, with a higher warming potential than CO_2, furthering the warming effect of these gasses on the earth.

Environmental impacts caused by the production and use of N fertilizers has created the need to evaluate the use and management of turfgrass in urban ecosystems. It is imperative to apply N fertilizers at the appropriate rate and timing. As such, there have been a multitude of research evaluating proper N management (Hopkins et al., 2008), including turfgrass studies. Candogan et al. (2015) found irrigation requirements could be decreased by adjusting N fertilizer rates for a perennial ryegrass in a sub humid climate. Acceptable turfgrass color and quality can be maintained at 100% evapotranspiration (ET) replacement and 22 lbs N acre^{-1}, and at 45 lbs N acre^{-1} 75% of ET replacement is sufficient. St. Augustine Grass grown in Florida has a minimum N requirement of 175 lbs N acre^{-1}. It has been shown that a rate of 87 lbs N acre^{-1} can sustain an acceptable turfgrass grass for two years, but long-term effects were not examined. It was suggested that a more appropriate rate could be found below the current requirement (Shaddox et al., 2016).

In addition, studies have shown that the use of polymer coated urea (PCU) can be used with reduced N rates—resulting in significant reductions of N loss to the environment while maintaining functional and aesthetic landscapes (Ransom, 2014; Buss, 2016; LeMonte et al., 2016, 2018).

Similarly, there have been many studies on water management. A study was conducted by Wherley et al. (2015) to determine if recommended irrigation rates were sufficient for warm season turfgrass. They found that recommended rates were insufficient during the peak of growing season, while being in excess during the fall when the turfgrass was slowing its growth and transitioning toward dormancy. However, there have not been many studies performed examining the interaction between N rate application and irrigation rate. One such study was done to evaluate the drought stress effect on various rates of N (Carrol et al., 2015). In this study on corn (*Zea mays* L.), they found N deficiencies reduced chlorophyll concentration drastically, while irrigation deficiencies had a greater impact on canopy temperature. In an N deficient corn plant, the chlorophyll content was significantly lower than the sufficiently fertilized plant during growing season. However, 100 days after sowing, the chlorophyll content in the leaf for the deficient and sufficient N plants were equal. Similarly, the limited and sufficiently irrigated treatments did not produce a significantly different chlorophyll concentration, indicating that water conservation is possible without inhibiting the overall health of the plant and production potential.

Preliminary studies show a correlation between increased N use and irrigation requirement (Demirel, 2014: Cangogan, 2015; Shaddox et al., 2016). However, the threshold of N conservation and water conservation, before causing permanent damage to the crop, has not been determined. In a perennial ryegrass (*Lolium perenne* L.) study, Candogan et al. (2015) concluded that with proper N management in non-limited irrigation conditions, at least 25% of irrigation water could be conserved by reducing N use. In a study done by Demirel (2014), it was suggested that when managing perennial ryegrass in semi-arid conditions, 50% water deficit with excess N application can be used to achieve desired quality turfgrass. The interaction between N and irrigation has not been proven extensively and has not been done with Kentucky bluegrass (*Poa pratensis* L.).

Although there has been significant research conducted on water and N management in turfgrass, there is a need for investigation into the interactions of these important inputs. The objectives of this study are to evaluate the interactive effects of N rates and water supply to Kentucky bluegrass for biomass, height, health, and verdure.

MATERIALS AND METHODS

This study was conducted over 21 days beginning July 23, 2018 at Brigham Young University in Provo, UT, USA (40.2518º N, 111.6493º W at 4,551 feet above mean sea level) in an established stand of Kentucky Bluegrass. The grass was grown in a sandy loam 1.5 ft depth. The soil had a pH of 7.2, 1% OM, 2 ppm NO_3-N. Each plot was 11 feet square and sprinkler irrigated from each of the four corners with minimal overlap. Measurements were taken from the center of each plot with no impact from neighboring plots.

The experimental design was a full factorial, randomized complete block design (RCBD) with three replicates. There were three irrigation treatments and three N treatments. The irrigation treatments were Low (60% of average ET), Full (100%), and High (140%). The N treatments were: Deficient (1.33 lb/1000 ft^2), Optimum (2.66 lb/1000 ft^2), and Excessive (5.33 lb/1000 ft^2). The N fertilizer was broadcast by hand as 66% PCU and 33% ammonium sulfate on July 23, 2018. Proximal and remote sensors were used to collect a variety of indices, including normalized difference vegetation index(Spectral Reflectance (SRS) NDVI; METER Group STS, Pullman, WA, USA), canopy temperature (Apogee SI-421, Logan, UT, USA), soil water potential (TEROS 21, METER Group, Pullman, WA, USA), volumetric water content, electrical conductivity, soil temperature (TEROS 12, METER Group, Pullman, WA, USA), and local weather data (ATMOS 41, METER Group, Pullman, WA, USA).

Handheld instruments were also used for additional NDVI (Trimble handheld Greenseeker) and canopy temperature (FLIR E6 thermal imaging camera) measurements. Grass canopy heights were measured randomly throughout the center four feet of each plot by placing a 14 x 14 inch hardboard onto the center of the plot, pressing firmly into the canopy, and visually measuring from the top of the board to the average top of the canopy from each of the four corners of the board and averaged per plot. Turfgrass height was used as a estimation of biomass (Ransom, 2014). Statistical analysis was performed by Analysis of Variance with mean separation by the Tukey-Kramer method (SAS Inc., v. 9.0, Cary, NC, US).

RESULTS AND DISCUSSION

There was a significant interaction between N and irrigation rates for canopy temperatures (Fig. 1). Canopy temperatures (which is an indicator of stress) were maintained at low levels at all N rates for the high irrigation treatment. Temperatures were similarly low for the deficient and optimum N rates at the full irrigation treatment, but temperature spiked with excessive N. Canopy temperatures were higher at every N level when the irrigation was low—with at least ~2-4°F increase in canopy temperature. The difference was greatly exacerbated when N fertilizer was excessive and irrigation water was low—having the highest temperature of all treatments.

There was a significant interaction between N and irrigation for canopy height (Fig. 2). Generally, heights increased with increasing N rate. However, there was a significant difference between the deficient and optimum N rate for the low and full irrigation, but no difference at high irrigation. Curiously, the high irrigation countered the deficient N in terms of height—resulting in excessive mowing and clippings even when N fertilization was kept low. The opposite was observed, with no significant difference when comparing optimum and excessive N rates for the low and full irrigation treatments, but having a significant difference at the high irrigation rate.

There was a significant interaction between N and irrigation for NDVI (Fig. 3). Turfgrass canopy health, as measured by NDVI, was clearly distressed for the low and full irrigation treatments when N was deficient. However, an excess of water in the high treatment seemed to alleviate that stress on the high N deficiency treatment somewhat. This trend is also seen in the canopy temperature and height data (Figs. 1-2). Using NDVI as an indicator, the canopy was otherwise not stressed at other N/irrigation levels.

Excessive N results in increased growth of Kentucky Bluegrass. Ransom (2014) showed a strong correlation between height and biomass with excessive N. This results in a need to mow more frequently (mowing is the largest cost in turfgrass maintenance) and/or larger clipping volume. It is a best management practice to return clippings back onto the surface from which they came, but it is more likely that they will have to be bagged, removed, and deposited in landfills or elsewhere if mowing is not able to be accomplished in a timely fashion due to rain, schedules, etc.

Excessive N is also an environmental problem. In addition to direct effects on air and water quality previously discussed, applying more N than is needed is wasteful of the resources—most notably the fossil fuels used in the manufacture of most N fertilizers and in transportation. Furthermore, excess N results in shorter stunted roots (Peacock, 2015) and increased canopy temperatures (Fig. 1), which creates a greater need for more irrigation water. And, of course, conservation of water is a critical need in society. This is especially true of the semi-arid and arid regions of the Western United States.

Another important implication of this work is how to manage N fertilization in a drought. It is apparent that an optimum level of N fertilization is still desirable in drought situations. An N deficiency coupled with water stress results in poor canopy health (Fig. 3). An excess of N results in a spike in canopy temperature that will send grasses (especially cool-season species, such as Kentucky bluegrass) into stress and dormancy sooner—possibly resulting in recovery failure. Kentucky bluegrass is particularly effective at rebounding from drought induced dormancy, but even it has a limit to how much moisture stress it can handle. But, by applying an optimum amount of N (in our study this was 2.6 lb/1000 ft^2) even when under water restrictions, the turfgrass is better able to fight off stress and recover from dormancy more quickly. We have observed this frequently and plan to conduct formal research to measure the exact parameters.

We also note it is frequently observed grasses slide into dormancy when managers implement reductions in irrigation in order to conserve water. This occurs even when ET losses are being replaced with a minimum amount of irrigation. This often results in frustration and abandonment of the effort to conserve water. This (and other) data suggests it is possibly not water stress that is causing the dormancy, but rather an interaction with excessive N which results in high canopy temperatures that cool-season grasses cannot tolerate. Carefully managing both N fertilization and water are vital for effective turfgrass management while balancing managing for conservation and environmental quality.

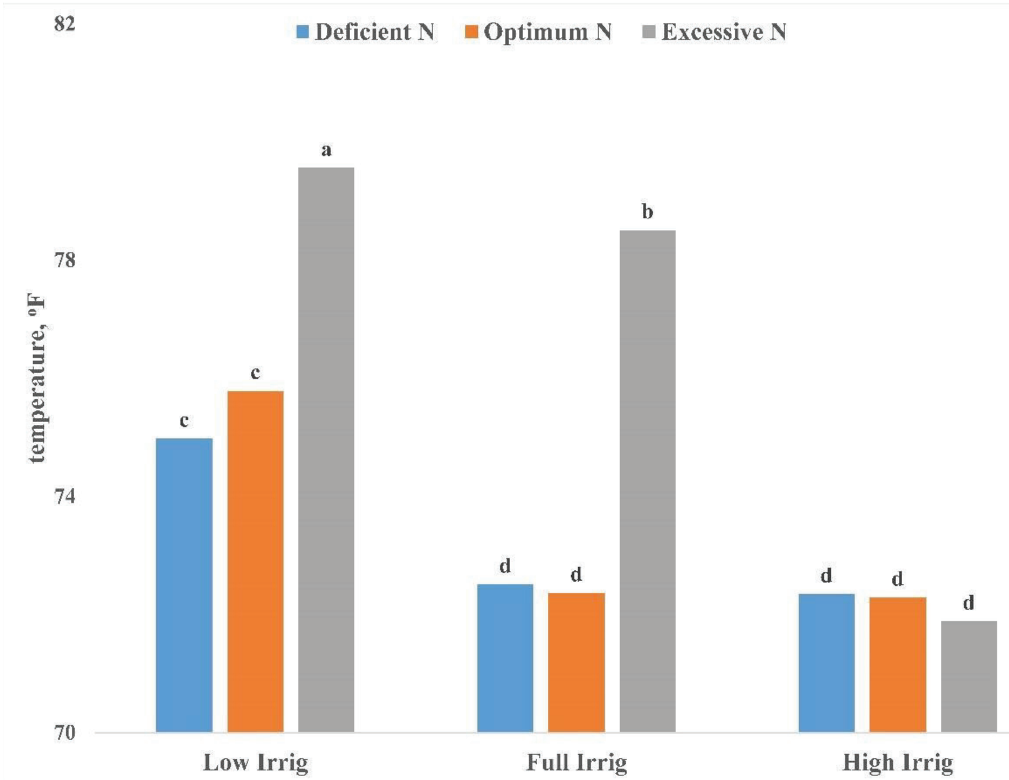

Fig. 1. Canopy temperatures for a N x water study in closely mowed Kentucky bluegrass with N treatments of Deficient, Optimum, and Excessive with all combinations of Low, Full, and High Irrigation (Full = 100% evapotranspiration replacement). Data bars sharing the same letter(s) are not statistically significant from one another. $P = 0.05$

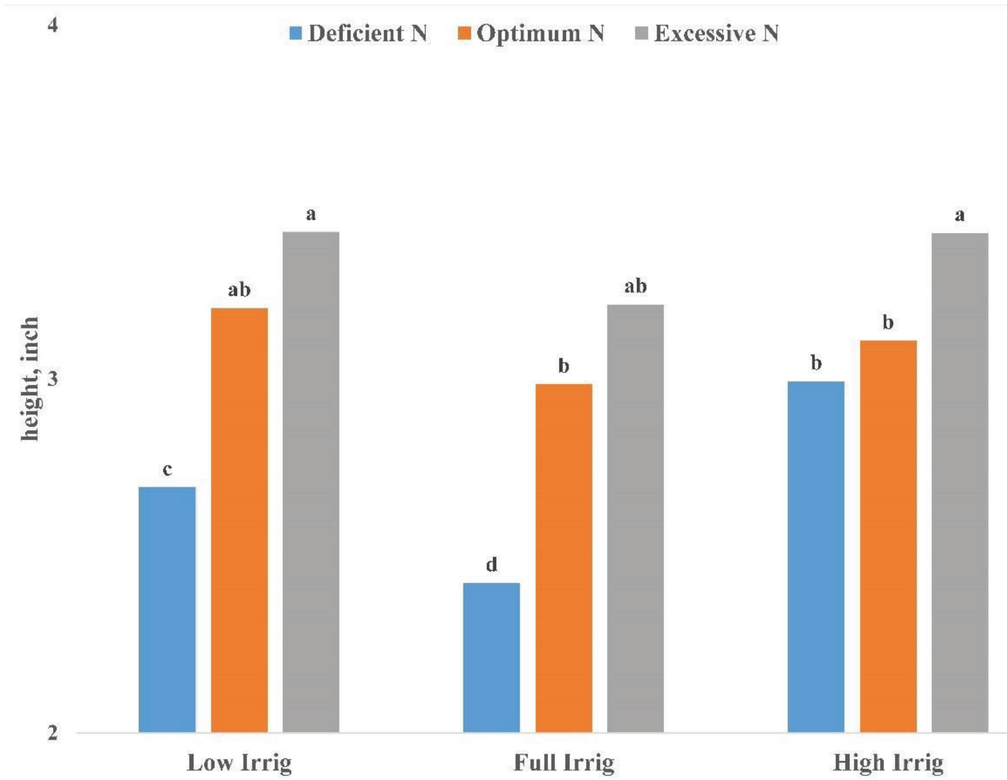

Fig. 2. Canopy heights for a N x water study in closely mowed Kentucky bluegrass with N treatments of Deficient, Optimum, and Excessive with all combinations of Low, Full, and High Irrigation (Full = 100% evapotranspiration replacement). Data bars sharing the same letter(s) are not statistically significant from one another. $P = 0.05$

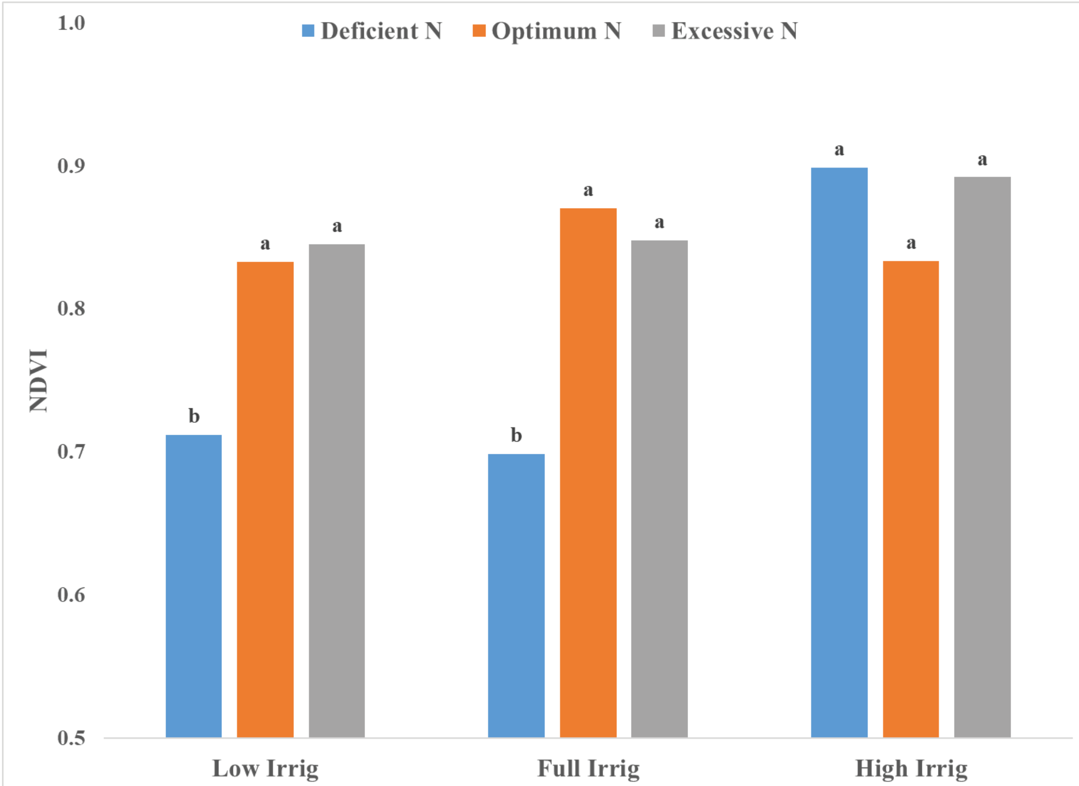

Fig. 3. Canopy normalized difference vegetation index (NDVI) for a N x water study in closely mowed Kentucky bluegrass with N treatments of Deficient, Optimum, and Excessive with all combinations of Low, Full, and High Irrigation (Full = 100% evapotranspiration replacement). Data bars sharing the same letter(s) are not statistically significant from one another. $P = 0.05$

SUMMARY

When examining all of the measured parameters in this study, it is apparent that it is vital, not surprisingly, to manage both N and water carefully. This is especially true when managing turfgrass under a water limited environment while still attempting to achieve function and aesthetics.

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P8

Cover Crops As A Source Of Plant-Available Nitrogen: Effect Of Residual Soil N And Cover Crop Species

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ABSTRACT

Fall-planted brassica and small grain cover crops have the potential to serve as catch crops by taking up residual soil nitrogen (N) in the soil. While plant species is often considered when estimating N release rates from cover crop residues, variation in residual soil N is rarely considered. The first objective of this study was to quantify the effect of N fertilizer application rate (to simulate varying residual soil N levels) on tissue N concentrations of several cover crop species, including brown mustard (*Brassica juncea* "Caliente"), tillage radish (*Raphanus sativus* L. var. *oleiformis*), and forage oats (*Avena sativa* "Charisma") The second objective was to determine the amount of Plant Available Nitrogen (PAN) available to the following crop using an aerobic incubation method. Cover crops were grown in the greenhouse in 0.2 m^2 flats with granular urea-N fertilizer rates of 0, 45, 90, and 135 kg N/ha. After 10 weeks of growth, plants were harvested, and a subsample was dried, ground, and analyzed for total N concentration via combustion analysis. Subsamples of fresh cover crop residues were aerobically incubated in Madras loam soil (0-30 cm depth) in polyethylene bags at a ratio of approximately 1:100 cover crop residue: soil. Soil in incubation bags was subsampled after 4 and 8 weeks of incubation to determine nitrate-N concentration. PAN from cover crop addition was calculated by difference from a soil-only control. The N fertilizer rate applied had a greater impact on cover crop tissue N concentration than did cover crop species. Cover crop N percentage on a dry weight basis increased linearly with increasing N fertilizer rates for all three cover crop species in the study. Mustard tissue N concentrations were 2.5, 3.3, 3.7, and 3.8% N at 0, 45, 90, and 135 kg N/ha fertilizer rates, respectively. Oat tissue N concentrations were 2.4, 3.0, 3.7, and 4.2% over the same respective N fertilizer rates. Radish tissue N concentrations were 2.2, 3.1, 3.4, and 3.9%. Across N application rates, similar tissue N concentrations were observed for all cover crop species in this study. This response was somewhat unexpected. A possible explanation may lie in the young stage of growth present at the time when cover crops were harvested. For example, stem elongation had just begun when oats were harvested for the PAN incubation experiment. PAN data from this research is currently being analyzed.

Source and Rate Interactions for Enhanced Efficiency Phosphorus Fertilizers

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ABSTRACT

Phosphorus (P) is an essential plant nutrient and plays a major role in the health and wellbeing of ecosystems. Deficient P is detrimental to plants. Excessive P is also detrimental to plants and is potentially harmful environmentally. Soil testing is an effective tool to help growers determine if fertilizer P is needed and, if so, the rate that is needed to be applied. Rates higher than the recommended amount can be detrimental to plant health and decrease yield. In addition to applying the right rate, choosing an efficient fertilizer source is an important part of P management as well. Traditional forms of P fertilizer are effective if applied at high enough rates. Enhanced Efficiency Fertilizers (EEF) allow for similar yields at lower rates compared to traditional P fertilizer sources. However, yields and/or crop quality can decrease if EEFs are applied at the normal rates for traditional P fertilizer. An example of this is an EEF (AVAIL) that is blended with traditional fertilizer. A meta-analysis of 503 field sites was conducted which showed an overall response of 2% greater yields. However, the sites with high soil test P and/or very high rates often resulted in negative responses. When only the sites with a high probability of response and with reduced rates of P, the average increase in yields was 5%. Another EEF (Carbond P) showed similar results with an overall response of 5% yield increase, but when parsing the data the high soil test sites only had an average response of 2% and the low were 7%. This data underscores the importance of soil testing to determine P rate and to reduce the rate, based on experimental results, when using an EEF.

INTRODUCTION

Soil fertility is an important aspect of plant nutrition. It is part of important plant structure compounds, and it is a catalyzer of multiple biochemical reactions in plants. One significant role P plays in plant function is helping with the capture and conversion of the sun’s energy into plant compounds. Phosphorous (P) is part of the adenosine tri-phosphate (ATP) molecule, which is part of plants’ energy transfer system. Additionally, P is part of plant structures and other biochemical roles. Deficiency of P inhibits plant growth, resulting in a stunted plant. Phosphorous deficiency is often associated with soils that are high in pH and have excess limestone, as well as with acidic soils (P solubility and, thus, plant availability, is greatest at near neutral pH).

Fertilization with P needs to be efficient in order to maximize crop yield and economic returns, while minimizing environmental risks to surface water bodies and depletion of mineral reserves. Within the discipline of soil fertility and plant nutrition, the “4R” approach to nutrient management has been advocated, which is the (1) right source, (2) right rate, (3) right timing, and (4) right placement (IPNI, 2012; Hopkins, 2015; Hopkins et al., 2018). Best management practices regarding this 4R stewardship for P have been reviewed by Hopkins (2015).

SOIL TEST PHOSPHORUS

The soil serves as a storage pool of phosphorus, typically with large reserves (Hopkins, 2015). Often, there is no crop response to P fertilizer when the labile soil P has been built up to high levels. There are several chemical tests that have been developed for predicting P need. These tests have been calibrated to correlate soil test P (STP) with likelihood of a yield and/or quality response. These scientific tests show a reasonable correlation when used on soils for which the tests are compatible.

The rate of P needed tends to be somewhat proportional to the STP value. It is important to realize that the vast majority of these rate calibration tests that have been conducted have been done so with "traditional" P fertilizers, such as monoammonium phosphate (MAP) or diammonium phosphate (DAP).

PHOSPHORUS RATE

These correlations nearly all share one common finding, which is that the response is a curve with a plateau. In other words, there is not a continued increase in yield with increasing fertilizer rate. At some point, enough P is enough, and more is not better. This is commonly referred to in the discipline of soil fertility and plant nutrition as the "law of diminishing response/ return" (Hopkins, 2015; Hopkins et al., 2018). In fact, adding excess P fertilizer has been shown to be detrimental in many studies (Hopkins, 2015; Hopkins et al., 2018).

ENHANCED EFFICIENCY FERTILIZERS

In addition to discussing rate of P fertilizer, there are many products in the fertilizer marketplace with claims of being more effective than the traditional sources. If proven true, these are classified as Enhanced Efficiency Fertilizers (EEF). Typically, this effectiveness is centered around being able to yield the same response with less fertilizer.

For example, if a STP for a certain crop calls for 200 lb P_2O_5/acre when using a traditional fertilizers (not an EEF) and the EEF is 50% more effective, one would expect the same yields whether using the full rate of traditional fertilizer or 100 lb P_2O_5/acre of the EEF. Applying more than this would not likely result in additional yield increases if the need for P had been met and there were no other modes of action for this fertilizer, such as biostimulation or efficiency of other nutrients.

There are exceptions to this rule. Most notably, nitrogen EEF products often result in yield increases beyond what is achieved with the full rate of traditional fertilizer. This increased productivity is due to timing of supply interactions of nitrogen (Hopkins et al., 2008). This generally is not the case with P fertilizers. However, it is possible to have other modes of action occurring with biostimulation etc. beyond the effect of the P alone.

INTERACTION BETWEEN RATE AND EEF SOURCE

Therefore, there is an important interaction between rate and source that is surprisingly often misunderstand by growers, agronomists, and scientists. The rate of fertilizer needs to be reduced when using EEF. And, if the STP is indicating that there is not a likely response due to very high residual STP then adding an EEF isn't likely to give a response and could damage the plants.

Example: AVAIL

An example of this is illustrated in the meta-analysis reported by Hopkins et al. (2018). The EEF evaluated was AVAIL (Verdesian Life Sciences [formerly Specialty Fertilizer Products, LLC], Visalia, CA, USA), a maleic-itaconic copolymer, is a product marketed to increase PUE through increasing P solubility.

In this analysis, 503 field sites of a variety of crops were tested in a comparison with traditional fertilizers and those with an EEF product (AVAIL) additive (Hopkins et al., 2018). Overall, the yield increase was 2% with use of the EEF. However, an examination of the data showed an alarming number of studies being conducted in scenarios where the likelihood of a P response was very low. Many were conducted on soils with very high STP (Fig. 1). And others were being conducted at very high P fertilizer rates. When eliminating these sites, the average response was ~5% (Hopkins et al., 2018).

Not surprisingly, the field trials conducted with high STP generally showed no advantage for the EEF (Fig. 1). In fact, there was a significant negative response [likely due to P-induced micronutrient deficiencies, as discussed by Hopkins (2015)] at the very highest levels. This illustrates that enough P is enough and adding more through an EEF can be harmful.

Also not surprisingly, there was no advantage when using very high rates of P in the study (Hopkins et al., 2018). As was exemplified above, when adding the full rate of P, as determined by calibrated STP studies, of 200 lb P_2O_5/acre plus the EEF wouldn't likely result in a further yield increase because the crop response was already plateaued with ample P uptake in the plant. Now, if the rate was reduced to half of this amount then one might expect that the EEF added to 100 lb P_2O_5/acre of fertilizer would yield more than the traditional fertilizer alone.

These principles are demonstrated in Fig. 1. It is apparent that there was a reasonable P response at low to moderately high STP levels (category 7; Hopkins et al., 2018). The upper range of category 7 for the four most common STP extractants (representing 89% of soil samples tested in North America) was 55, 40, 40, and 30 ppm for the Mehlich 3 (ICP), Bray P1, Mehlich 3 (colorimetric), and Olsen bicarbonate extractants, respectively (IPNI, 2011). It is noteworthy that these values are somewhat higher than the published critical values provided by most fertilizer recommendation guides (Hopkins, 2015). But, above this level the response is nil or even negative at very high STP.

Example: Carbond P

In another example, Carbond P (Land View Inc., Rupert, ID, USA) is a fertilizer with demonstrated EEF properties. This product has P bonded to various organic acids, which makes it relatively soluble and more plant available (Hopkins, 2015). Fig. 2 shows a compilation of 36 field trials showing a large response at low STP and only a minimal response at high STP. In this case, it is suspected that the response at high STP had nothing to do with P, but rather increased solubility of other nutrients (such as zinc, manganese, copper, and/or iron) or some sort of a biostimulation response (Tan, 2014; Hopkins, 2015). Although, this was not observed by Summerhays et al., (2017) that showed that the effect with both Carbond P and AVAIL was due to P response with no other benefits. These effects have been noted in other EEF products as well (Hopkins, 2015).

In Fig. 3, the effect of rate is shown, with a much smaller response when applying at the full rate, but a relatively larger response at a half rate—showing the enhanced efficiency.

SUMMARY

Phosphorus is an essential nutrient that is required for plant growth. Soil test P can give insight into the rate of P fertilizer a plant needs. Diminishing returns are the result when P fertilizer is applied in soils with a high STP. A similar situation is realized when applying high rates of Enhanced Efficiency Fertilizers (EEF). This is likely due to P-induced micronutrient deficiencies. When using an EEF, such as AVAIL or Carbond P, reduced rates of fertilizer should be used to prevent such interactions. Enhanced Efficiency Fertilizers (EEF) allow for similar yields at lower rates compared to traditional P fertilizer sources. An example of this is an EEF (AVAIL) that is blended with traditional fertilizer. A meta-analysis of 503 field sites was conducted which showed an overall response of 2% greater yields. However, the sites with high soil test P and/or very high rates often resulted in negative responses. When only the sites with a high probability of response and with reduced rates of P, the average increase in yields was 5%. Another EEF (Carbond P) showed similar results with an overall response of 5% yield increase, but when parsing the data the high soil test sites only had an average response of 2% and the low were 7%. This data underscores the importance of soil testing to determine P rate and to reduce the rate, based on experimental results, when using an EEF.

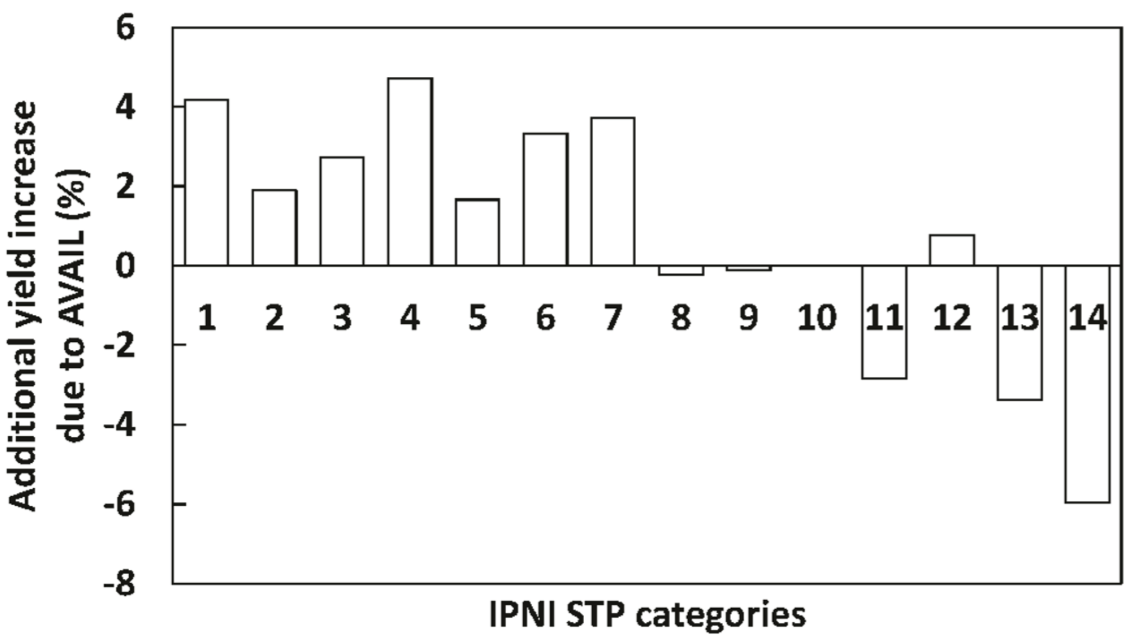

Fig. 1. Relative yield response to an enhanced efficiency phosphorus fertilizer additive (AVAIL), as compared to the same source of fertilizer applied at the same rate without AVAIL. These responses of 503 field sites are shown as a function of 14 categories of soil test (STP) ranked from very low (1) to extremely high (14) (based on the International Plant Nutrition Institute (IPNI, 2011) rankings. (Adapted from Hopkins et al., 2018.)

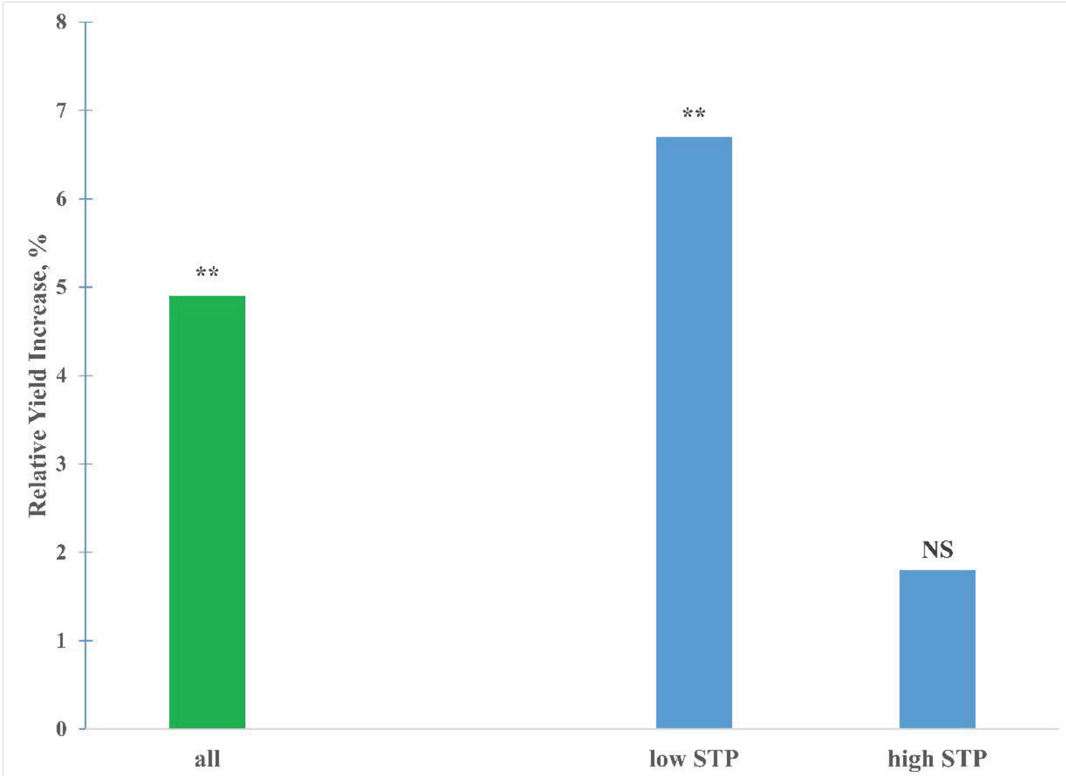

Fig. 2. Relative yield increases to an enhanced efficiency phosphorus fertilizer additive (Carbond P), as compared to a fertilizer with similar analysis, but without a blending with organic acids. The Carbond P resulted in a highly significant increase (signified by "**") over the traditional fertilizer when evaluated over all 36 sites. But, the response was even greater when only evaluating the 23 sites with low soil test P (STP). Sites with high STP were not significantly different between fertilizer sources.

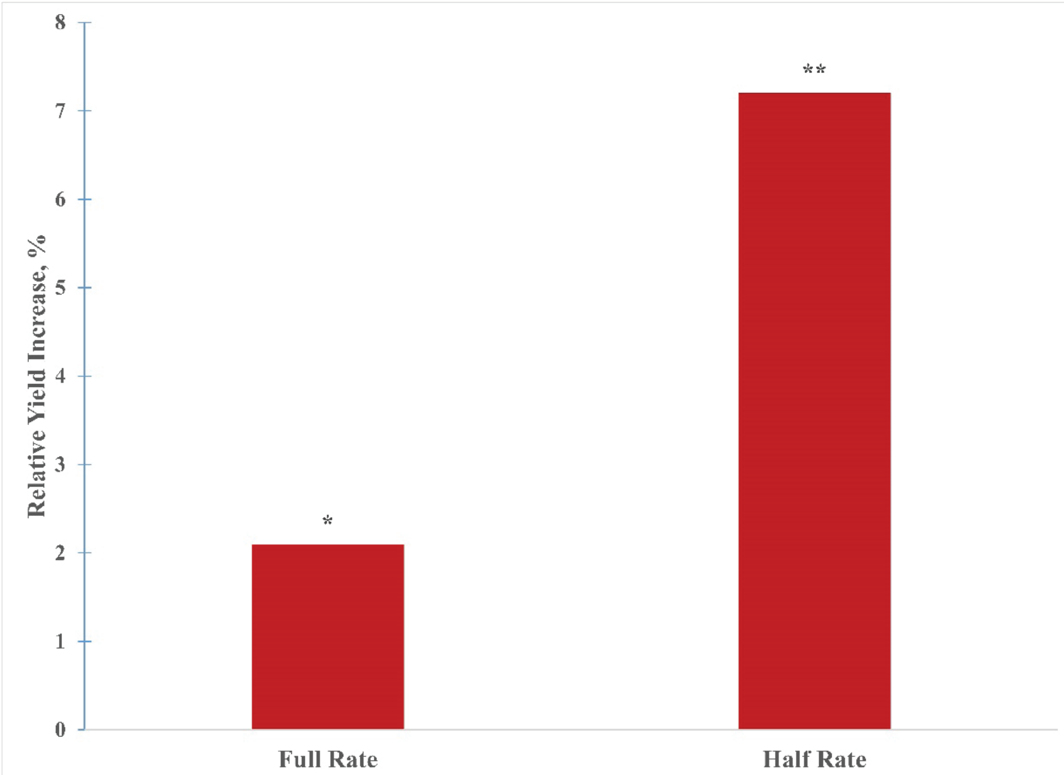

Fig. 3. Relative yield increases to an enhanced efficiency phosphorus fertilizer additive (Carbond P), as compared to a fertilizer with similar analysis, but without a blending with organic acids. The Carbond P resulted in a significant increase (signified by "*") over the traditional fertilizer when applied at the full rate, but the response was relatively larger when evaluated at a half rate.

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Nitrogen Management in Small Grains After Alfalfa

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ABSTRACT

Small grains are commonly grown following alfalfa in Utah and the Intermountain West, especially during drought years as small grains require less irrigation than corn. Several studies across the country have shown that corn following alfalfa rarely needs N fertilizer, yet relatively few have evaluated the N needs of small grains. Furthermore, research on the N needs of small grains grown as forage vs. grain are even more sparse. The objectives of this research are to quantify the N contributions of alfalfa to small grains and develop N guidelines for the first and second year following alfalfa termination, to determine the economics of alfalfa-corn vs. alfalfa-small grain rotations and whether early spring soil nitrate tests or plant chlorophyll content at flag leaf or boot stage could predict N response. Experiments were conducted on 18 field sites in Utah and Colorado in 2018. Four sites had direct comparisons of small grains harvested as grain vs. forage, while another five and nine sites were harvested as grain or forage only, respectively. At each site, four replications of six N rates ranging from 0 to 168 kg N ha-1 were applied in the early spring as ammonium nitrate. Early results indicate that N fertilizer was not needed to increase small grain yield at most sites, unless small grains followed old stands (> 9 yrs). These results will help growers better utilize N credits from alfalfa, improve their small grain yield and profit, and reduce negative implications of excessive N fertilizer applications.

Polymer Coated Urea in Kentucky Bluegrass

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ABSTRACT

Nitrogen (N) is a commonly over-applied nutrient in urban environments. This over-application has led to nutrient pollution of the atmosphere and hydrosphere. The losses of N to the environment can be mitigated with the use of enhanced efficiency fertilizers, such as polymer coated urea (PCU). Some PCU labels state that a single annual application is a best management practice. The objective of this study was to evaluate a PCU compared to monthly applications of ammonium sulfate/urea. A two-year study was initiated in April 2014. Six fertilized treatments were applied at two locations in Provo, UT. Treatments included a urea and ammonium sulfate blend split applied monthly compared to a polymer coated urea (PCU) and ammonium sulfate blend applied either once in spring, once in fall, or twice in spring and just ahead of early fall— all applied at the same rate of N at each location. Additionally, reduced rates of 50% and 75% of the two PCU application treatment were made. The single annual application treatments resulted in uneven growth and verdure with significant increases shortly after application, but a steady reduction after several weeks. The two-application PCU treatment was virtually identical in verdure and plant growth as compared to the spoon feeding of N applied monthly. The reduced rates were effective, although the 50% rate resulted in significant decreases in plant health. This study shows that one application of PCU is not ideal under the application method tested in this study, but two applications results in steady, healthy growth and, as such, is effective. Further work is needed to evaluate other timing approaches for a single annual application.

INTRODUCTION

Turfgrass is the principle managed land cover in the United States (National Turfgrass Federation, 2003; Walker, 2007). According to the combination of studies done by Milesi et al. (2005) and Runfola et al. (2014), turfgrass coverage in the U.S. is estimated to be ~27,597,470 ac. Turfgrass occupies 1.9% of the total surface area in the United States and is the leading irrigated crop in the country (Milesi et al., 2005). Turfgrass is important in that it is aesthetic, provides safe recreational surfaces, generates oxygen, and reduces air temperatures, atmospheric pollutants, erosion, water and chemicals in storm water runoff, chemicals leached to groundwater, flooding, noise pollution, and fire risk.

Turfgrass requires essential nutrients and is not able to survive without them. The most important among these, in terms of plant concentration and likelihood of deficiency, is nitrogen (N). When N is deficient, plants are stunted and chlorotic (yellow due to chlorophyll deficiency) and are more likely to succumb to various stresses. Alternatively, when N is applied in excess it also has negative results, including poor root development (which impacts water needs) and excessive growth (which results in a need to mow too frequently and/or excessive clippings). Over-application of N fertilizers also can lead to environmental quality problems.

Although turfgrass generally limits leaching to groundwater, excess N can result in a buildup of nitrate (NO_3^-) in groundwater. Background levels of NO_3^- in drinking water are common and not a concern, but excesses can result in methemoglobinemia in mammalian infants, as well as other possible uncorroborated health effects. Additionally, runoff of N (and phosphorus) overland to surface water bodies can lead to algal blooms, which can be directly toxic to organisms and can contribute to the eutrophication-related deaths of aquatic organisms. Eutrophication is a serious concern in several western bodies of water, such as Lake Tahoe and Utah Lake, as well as many in other water bodies, such as the Gulf of Mexico and the Great Lakes.

Excess N also adds to atmospheric pollution through nitrous oxide (N_2O) emission and ammonia (NH_3) volatilization. N_2O is a greenhouse gas ~300 times more potent than carbon dioxide (CO_2), with concerns surrounding impacts on the climate and sensitive ecosystems. NH_3 is termed "reactive N". It does not stay resident in the atmosphere nearly as long as N_2O but, rather, is deposited on land and water bodies. In addition to contributing to surface water quality problems, this deposition can negatively impact nutrient cycling in sensitive ecosystems. An example of this is in high alpine areas where excess N can significantly alter the species composition, with resultant impacts on soil erosion potential and forage quality. Another example is in lands that have suffered wildfires. Excess N results in excessive shoot growth at the expense of roots, with negative impacts on the survivability of plants essential for remediation of the land.

The losses of N to the environment can be mitigated with the use of enhanced efficiency fertilizers, such as polymer coated urea (PCU; Hopkins et al., 2008; LeMonte et al., 2016, 2018). PCU is a control release fertilizer that has been developed using a coating which surrounds individual granules of fertilizer. These fertilizers are used to allow for the delivery of N over extended periods with the benefit of reducing risk of loss to the environment. The PCU products have shown a significant decrease in leaching (Du et al., 2006; Guillard and Kopp, 2004; Nelson et al., 2009; Pack and Hutchinson, 2003); Pack et al., 2006; Wilson et al., 2010), NH_3 volatilization (Knight et al., 2007; Pereira et al., 2009; Rochette et al., 2009; LeMonte et al., 2016, 2018; Ransom, 2014), and N_2O gas emissions (LeMonte et al., 2016, 2018; Ransom, 2014).

There are many PCU products available. One of the common selling points is variable release timings ranging from 45 days to one year. Some PCU labels state that a single annual application is a best management practice for turfgrass. These predicted times of release are relatively accurate when PCU is tilled into the soil where temperatures are cool and buffered against dramatic change (Ransom, 2014). However, PCU is a temperature dependent release and temperatures at the soil surface can be significantly higher than compared to inside the soil or even in the air above the soil. Turfgrass surface temperatures commonly exceed 122°F. Thus, these PCU products tend to release much faster in turfgrass surface applications than is claimed by the manufacturer. Although this is true, the release occurs over 35-45 days, which is proven to be beneficial in terms of both grass growth and reduction of loss to the environment (Ransom, 2014).

The objective of this study was to determine optimal fertilization (source, timing, and rate) for PCU compared to traditional sources and practices on a cool season turfgrass (Kentucky bluegrass; *Poa pratensis* L.).

MATERIALS AND METHODS

Two irrigated field plot areas were installed in 2012 at Provo, UT (40º24'52.09"N, 111º64'17.61"W) near the BYU Life Sciences Greenhouse Complex. One field was installed with a constructed sandy loam soil and the other was installed to meet the specifications for a High Performance Sand-Based Rootzones for Athletic Fields per the American Society for Testing and Materials (ASTM) method F2396. Kentucky bluegrass (varieties P105, Bedazzled, Prosperity, and Moonlight SLT) were established as sod at both sites. Only a portion of the loam data is presented herein. The remainder of the loam data and the sand data is found at Buss (2016).

Studies were initiated in April 2014. The soils had minimal soil N with no confounding results due to previous applications. Six treatments with four blocks were applied with a randomized block control design (RBCD) with plots of 2.6 m by 1 m. A control with no added N was also included but not fully reported herein. The Grower's Standard of Practice (GSP) served as the "ideal" treatment with a steady supply of N throughout the growing season applied through equal, monthly (April-November) with a total of 2.8 lb N/1000 ft^2 (122 lb N/ac) applied on the loam at what is considered the 100% rate needed to achieve reasonable color without excessive mowing in this soil type. Three PCU full rate (100%) treatments were made with all of the fertilizer applied in the spring in April (1Ap-S), all just prior to fall in late August (1Ap-F), or a split application in April and August (2Ap; also identified as P100 in figures showing rates). Additionally, reduced rates of the split application were made with 50% (P50) and 75% (P75) of the full rate (P100). All treatments had ammonium sulfate included as part of the total N (33%) to serve as a source of sulfur and to insure that each fertilized treatment included at least some immediately available N. The other treatments were various combinations of a PCU (Agrium One Ap, Agrium Advanced Technologies, Loveland, CO, USA). The fertilizer for each treatment was spread uniformly by hand.

Height and Normalized Difference Vegetative Index (NDVI; an assessment of plant health) measurements were taken every seven days. Shoot height was averaged over three locations in each plot by measuring from the thatch layer to the tip of the grass blades. The NDVI (FieldScout TCM 500 NDVI Turf Color Meter, Spectrum Technologies, Inc., Aurora, IL, USA) measurements were also averaged over three locations in each plot. Shoot and root biomass, visual ratings, and tissue N concentration measurements were also collected, but not reported herein.

Data was checked for normality and analyzed by analysis of variance (ANOVA) with R (R project for Statistical Computing), with significance indicated at $P \leq 0.05$. Any significant means were then separated using a Tukey-Kramer test.

RESULTS AND DISCUSSION

Timing

There were interactions between treatment and dates and, thus, values for height (Fig. 1) and NDVI (Fig. 2) are shown across dates.

There were highly significant differences in shoot height (Fig. 1) and biomass (Buss, 2016) across the various treatments in this study. The biomass readings were made less often than the weekly height readings, but generally followed the same trends —with both as measures of shoot growth. Biomass is a combination of height along with shoot thickness and density.

Shoot growth for the loam soil was never significantly different for 2Ap as compared to the GSP (Fig. 1). In contrast, shoot growth was significantly greater for 1Ap-S over the GSP on three dates in spring 2014 and one date in both summer 2014 and spring 2015 (Fig. 1). These dates with statistical significance, as well in Figures 2-4, are not shown herein due to space limitations but can be found in several Tables found in Buss (2016). Height was never significantly lower for 1Ap-S than the GSP, although there was a trend for less growth in fall 2015. Similarly, although at the opposite time of year, shoot growth was significantly greater for 1Ap-F over the GSP on two dates in fall 2014 and three dates in fall 2015.

The results were similar when comparing 2Ap against 1Ap-S and 1Ap-F (Fig. 1). Shoot growth for 1Ap-S was significantly greater than 2Ap on one date in spring 2014. The effect was even greater for 1Ap-F, but only in 2015—with significantly greater shoot growth over 2Ap on five dates in the fall of that year. The lack of significance in 2014 could be due to larger magnitude of differences in the heights of the treatments in fall 2015 as compared to 2014.

As expected, there were significant shoot growth differences due to timing between the 1Ap-F and 1Ap-S. Height was significantly greater for 1Ap-F than 1Ap-S on one date in fall 2014 and six dates in fall 2015. Surprisingly, there were no differences in spring between these treatments.

Plant health, as represented by weekly NDVI measurements, for the loam soil was never significantly different for the treatment with two applications of PCU (2Ap) as compared to the monthly applications of N (GSP; Fig. 2). In contrast, NDVI was significantly greater for 1Ap-S over the GSP on three dates in spring 2014 and no differences in 2015 (Fig. 2; dates with statistical indications are shown in Tables in Buss, 2016). The NDVI readings for 1Ap-S were never significantly lower than the GSP, although there was a trend for lower NDVI readings in 2015. The NDVI for 1Ap-F was never significantly different than the GSP. The results were similar when comparing 2Ap to 1Ap-S and 1Ap-F. NDVI for 1Ap-S was significantly greater than 2Ap on two dates in the spring of 2014, but reverse was true on one date in fall of that year. There were no differences between 2Ap and 1Ap-S in 2015. The NDVI of 1Ap-F was significantly greater than 2Ap on two dates in fall of 2015, but no differences in the prior year. As expected, there were significant differences between 1Ap-S and 1Ap-F due to timing of application (Fig. 3). The NDVI was significantly greater for 1Ap-F on three dates in the fall of both years. Surprisingly, the NDVI of 1Ap-S was not significantly greater than 1Ap-F in the spring of 2015. The visual ratings had the same general trends as the NDVI readings (Buss, 2016). Results were similar for the sand location (Buss, 2016).

Rate

Shoot growth, as determined by height and biomass measurements, was never significantly different for P75 as compared to the GSP and P100 applied to loam soil (Fig. 3). The P75 mimicked the P100 and GSP treatments quite closely for a majority of both years of this study.

In contrast, the reduced rate (P50) was consistently below the GSP and P100 (Fig. 3). This rate resulted in significantly lower shoot heights than the GSP on one date in the spring and one date in the fall of 2015. The P50 was also significantly below P100 on one date in the spring and one date in the fall of 2014, as well as two dates in the spring of 2015. In the second year of the study, the differences in shoot height had greater magnitude with P50 trending much lower than the other treatments as compared to 2014. The shoot biomass results generally followed these same trends—especially in the second year with very low growth for P50 (Buss, 2016).

Plant health and verdure, as represented by weekly NDVI measurements, for the loam soil was never significantly different for any of the treatments which included PCU as compared to the GSP in both years of the study (Fig. 4). The NDVI readings for the full rate of N fertilizer applied twice with the PCU blend (P100) was significantly greater than P50 on one date in the spring of 2015, otherwise there are no other significant differences in NDVI readings between the treatments. Although not significant, there is a trend for P50 to be below all of the other treatments throughout the two year study. Although NDVI did not show a difference on ordinal day 126 when the first visual ratings of plant verdure were made in 2014, the P100 treatment had significantly higher visual 57 ratings than P50. On the following visual rating dates, there were no significant differences, which corresponds with the NDVI readings on the same dates. Similarly, the GSP had significantly greater visual ratings than P50 on the first date in 2015 although the NDVI readings for the same date were not statistically different. The second date in 2015 did not show any significance in the visual ratings or the NDVI readings for the same date. The visual ratings had the same general trends as the NDVI readings (Buss, 2016). Results were similar for the sand location (Buss, 2016).

SUMMARY

The single annual application PCU treatments resulted in uneven growth and verdure with significant increases shortly after application, but a steady reduction after several weeks. The two-application PCU treatment was virtually identical in verdure and plant growth as compared to the spoon feeding of urea applied monthly. This study shows that one application of PCU is not ideal under the application method tested in this study due to increased need for mowing, but two applications results in steady growth and, as such, is effective. The efficiency of PCU allows for a rate reduction with at least a 25% reduction from the full rate.

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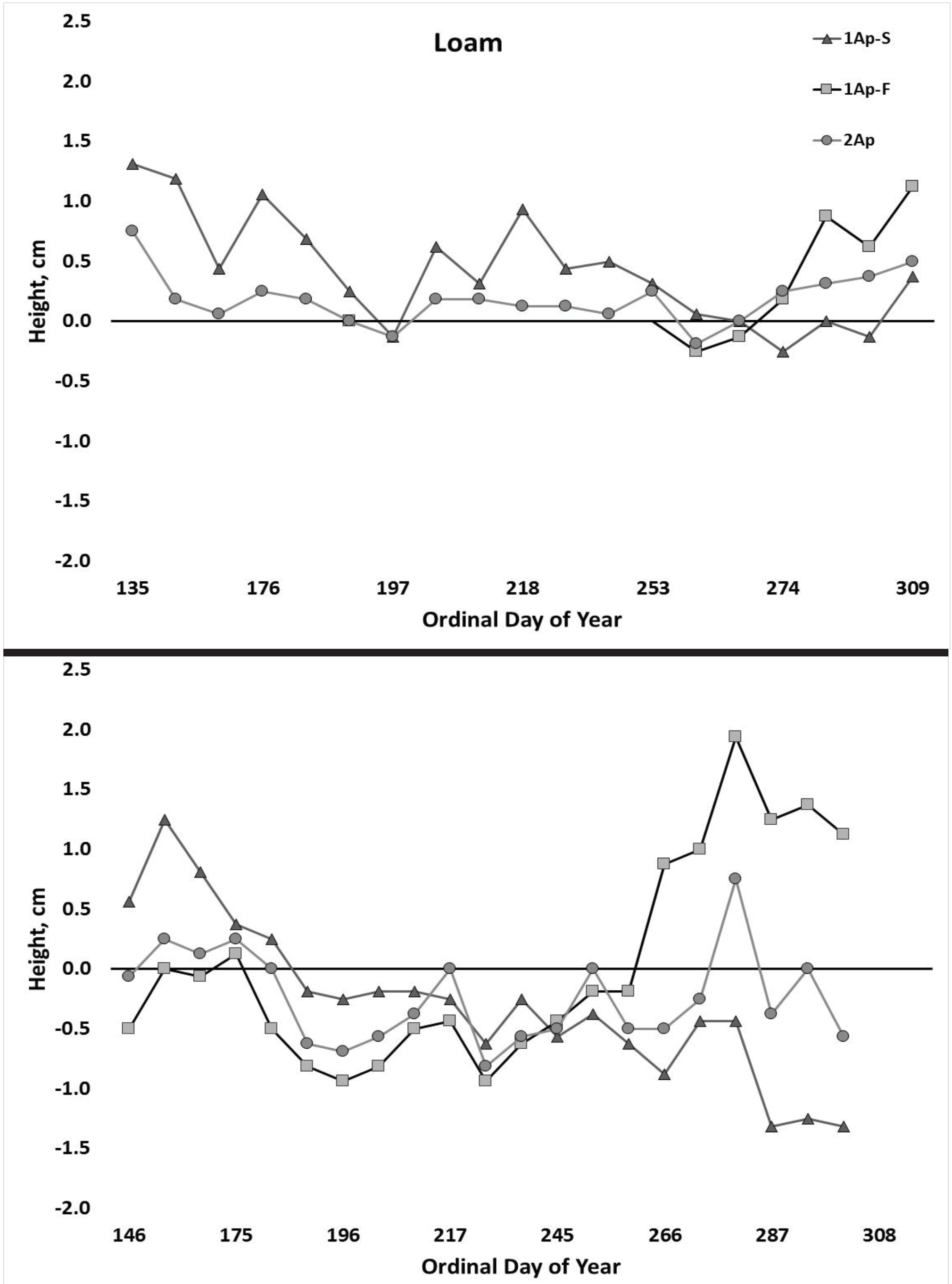

Fig. 1. Kentucky bluegrass heights over two years for a trial on loam soil. Year 2014 is on top and 2015 is on the bottom. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) or fall (1Ap-F) or a split two applications once in spring and again in fall (2Ap) all at the 100% rate. Statistics are shown in Buss (2016).

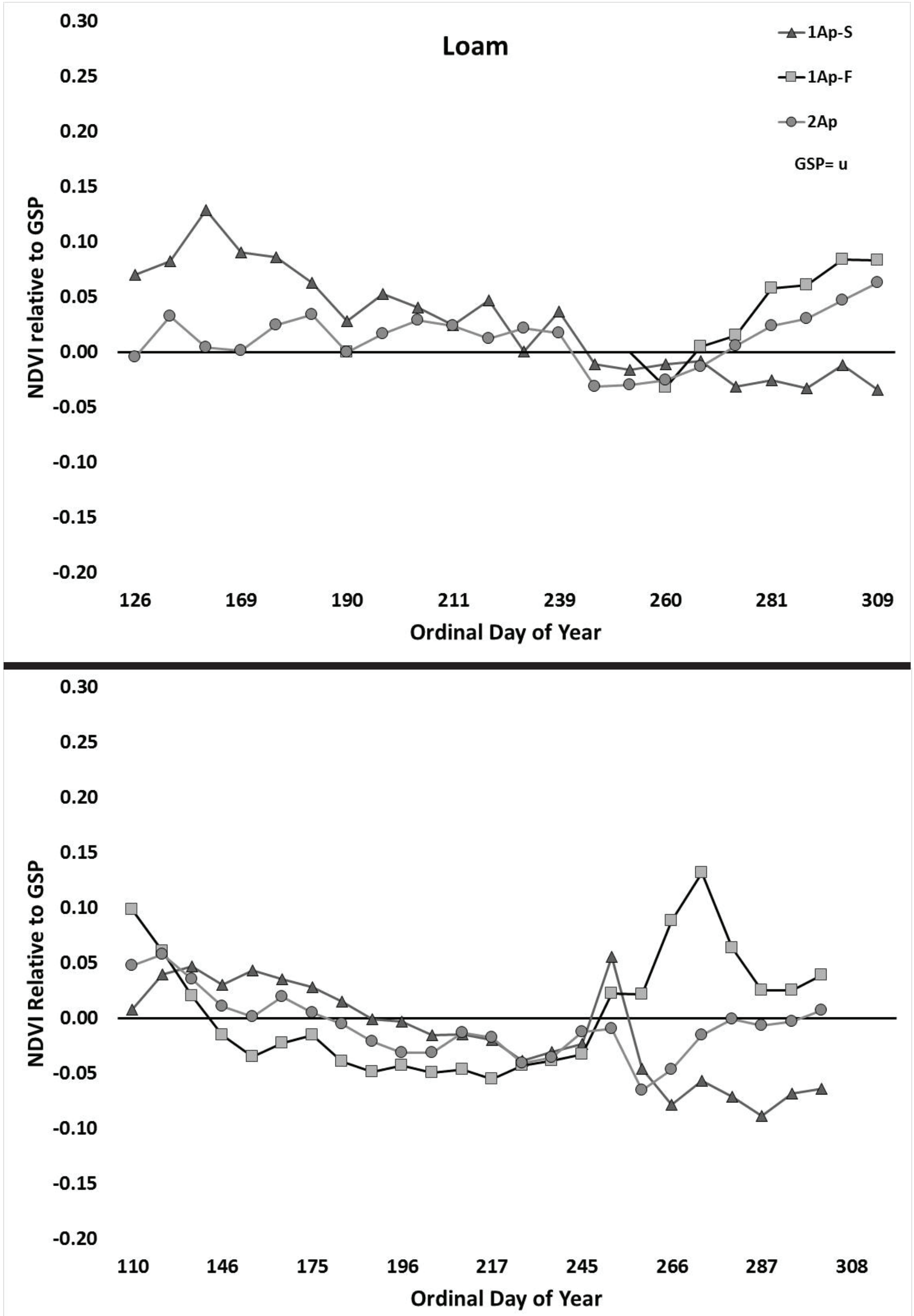

Fig. 2. Kentucky bluegrass Normalized Difference Vegetative Index (NDVI) readings over two years for a trial on loam soil. Year 2014 is on top and 2015 is on the bottom. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied once in spring (1Ap-S) or fall (1Ap-F) or a split two applications once in spring and again in fall (2Ap) all at the100% rate. Statistics are shown in Buss (2016).

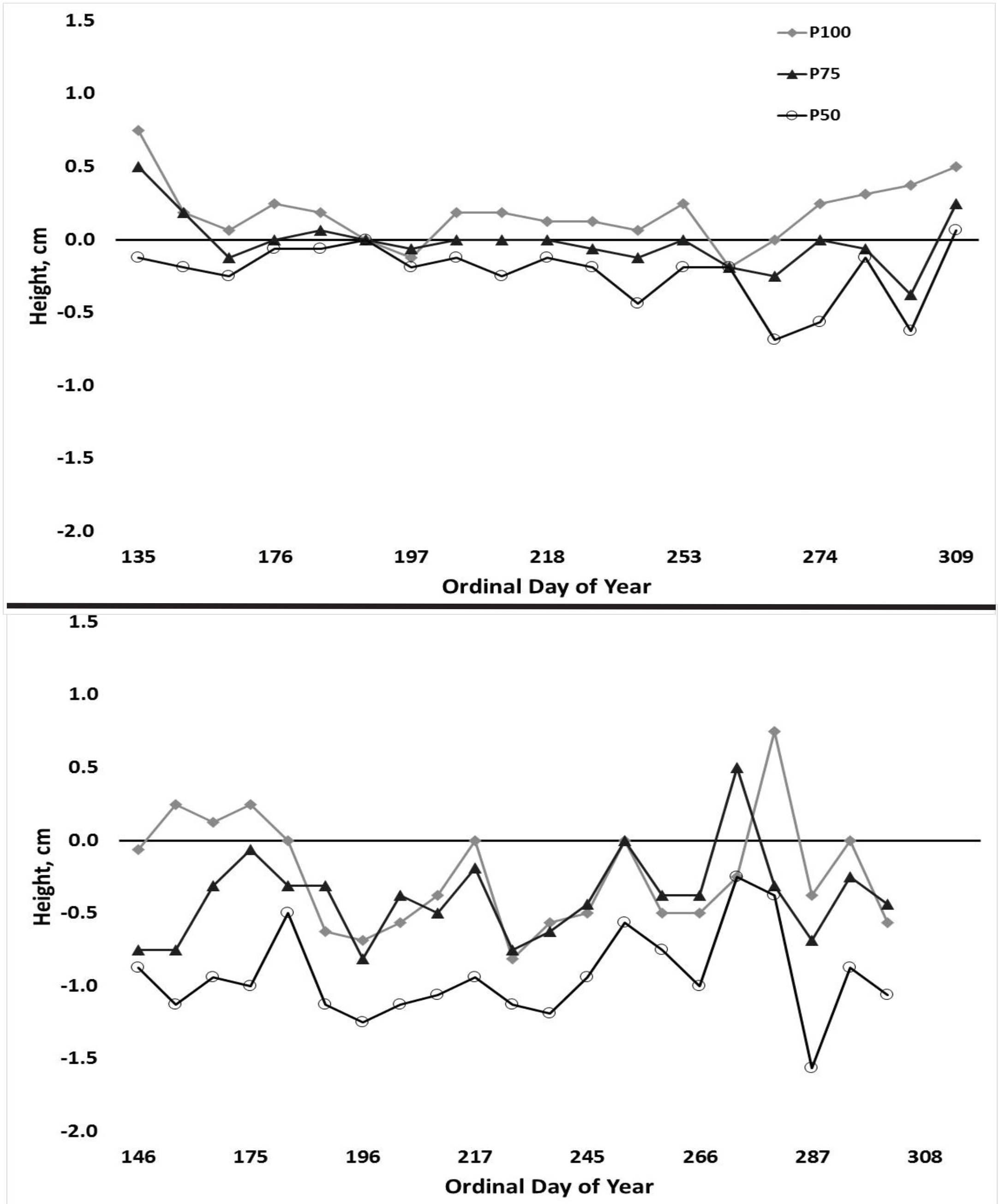

Fig. 3. Kentucky bluegrass heights over two years for a trial on loam soil. Year 2014 is on top and 2015 is on the bottom. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied at the 100% rate same as GSP (P100) and reduced rates of 50% (P50) and 75% (P75). Statistics are shown in Buss (2016).

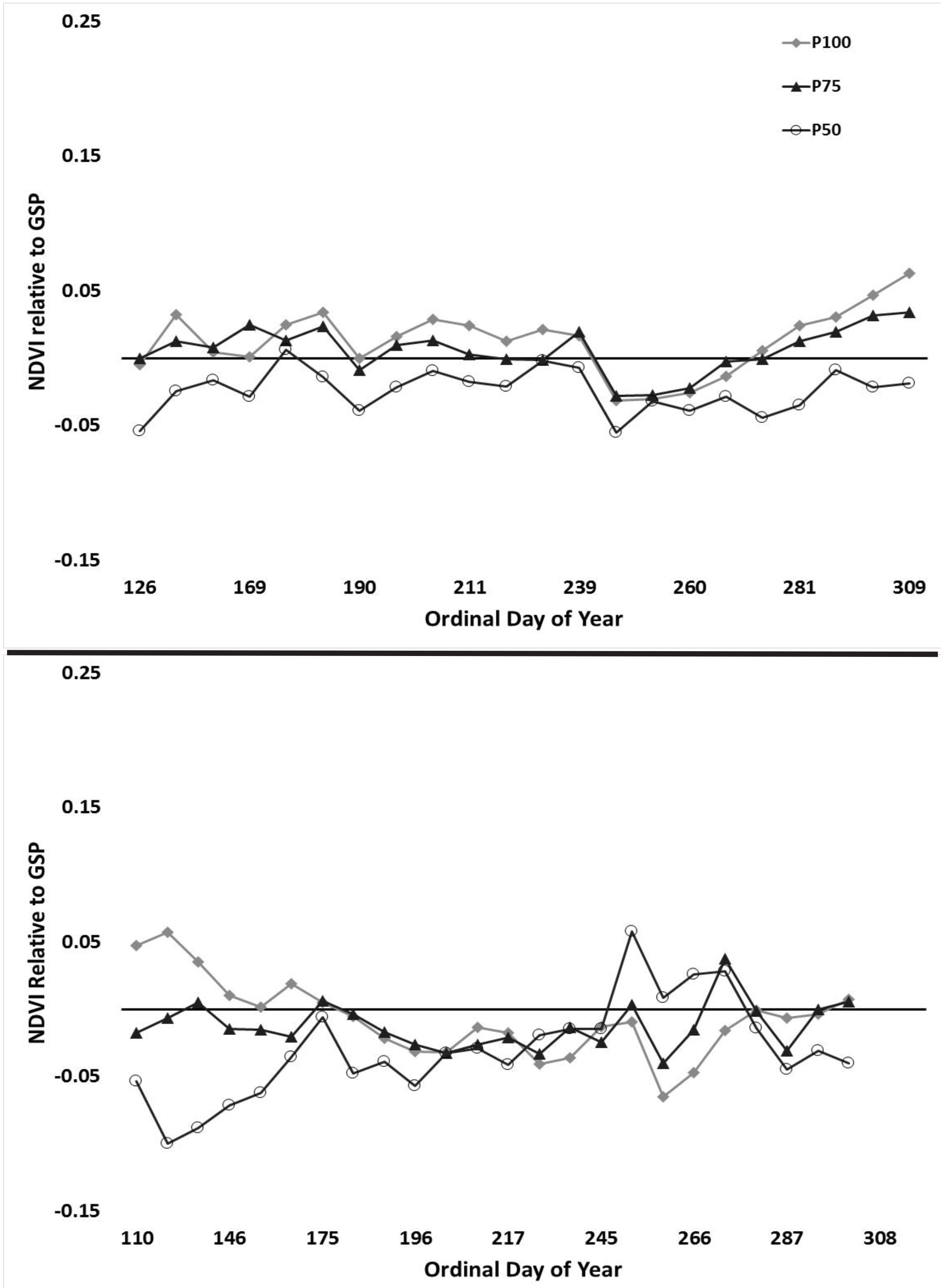

Fig. 4 Kentucky bluegrass verdure as measured by NDVI readings over two years for a trial on loam soil. Year 2014 is on top and 2015 is on the bottom. The data has been transformed with the grower's standard practice (GSP) of urea/ammonium sulfate applied monthly as the line at zero (ideal) in comparison to polymer coated urea/ammonium sulfate applied at the 100% rate same as GSP (P100) and reduced rates of 50% (P50) and 75% (P75). Statistics shown in Buss (2016).

Phosphorus Fertilizer and Hydrogel for Rangeland Seeding

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ABSTRACT
The US Air Force uses live munitions at Hill Air Force Base, a desert testing range west of Salt Lake City, Utah, USA. Resultant fire has disturbed rangeland vegetation. Revegetation of the area is impeded by low average precipitation rates of approximately 0.025 m per year, and opportunistic invasive species. Previous studies indicated hydrogel increases soil water content and the longevity of bottlebrush squirrel tail seedlings. In this glasshouse study, the effects of phosphorus (P) fertilizer, with low nitrogen (N), with hydrogel was evaluated to determine the effects on seedling establishment and longevity. Hydrogel was applied at rates equivalent to 0 or 3000 kg ha^{-1} at either surface level or a depth of 0.075 m. Phosphorus fertilizer was applied at rates equivalent to 0 or 17 kg P_2O_5 ha^{-1} and 4 kg N ha^{-1} applied at the same depths as the hydrogel. Six seeds of either bottlebrush squirreltail [*Elymus elymoides* (Raf.) Swezey] or Vavilov II [*Agropyron fragile* (Roth) Candargy] were planted in pots, as per the NRCS recommended seeding rate. All pots were watered once to saturation and monitored three days per week for gravimetric water content and seedling status. We observed that all combinations of hydrogel and fertilizer increased the longevity of emerged bottlebrush squirreltail seedlings by up to 34% relative to the control. In all treatments with hydrogel, Vavilov seedlings emerged 6-44% higher than the control. A longevity increase of 9% relative to the control was observed when hydrogel and fertilizer were combined at a depth of 0.075 m. This data shows that fertilizer used in conjunction with hydrogel has the potential to improve seedling success in rangeland applications.

INTRODUCTION

The Utah Test and Training Range (UTTR) is a military training ground located in Utah's west desert, approximately 80 miles west of Salt Lake City. (United States Air Force, 2016) It is maintained by the United States Air Force via Hill Air Force Base and used as a practice bombing and gunnery site by the US Air Force, Army and Marines.

Resultant fire from live munitions training has heavily disturbed or destroyed native rangeland vegetation. Revegetation is impeded by opportunistic invasive species and a low average precipitation rate of less than 10 inches per year, that falls mainly as rain and snow from fall to spring. Among these species is cheatgrass (*Bromus tectorum*). Native species are generally resistant to cheatgrass invasion until a disturbance, such as fire, occurs. A disturbance that removes established native plants and creates areas of exposed soil opens the window for invasion.

Cheatgrass maintains a competitive advantage over native species by virtue of being a prolific seed producing winter annual grass that germinates and establishes a root system in the fall (Zouhar, 2003). The seedlings leave dormancy in the late winter or early spring, capitalizing on available moisture and nutrients and preventing the establishment of later germinating native perennials. The grass grows abundantly and completes its life cycle by June, producing a carpet of dry fine fuel that risks ignition during the hot dry summer. This accumulation is dangerous at UTTR where live munitions can cause expansive wildfires.

Bottlebrush squirreltail *[Elymus elymoides (Raf.) Swezey]* is a native perennial bunchgrass native to the region. It has been noted for the ability to compete with unwanted weed species, like cheatgrass (Plumb, 2010). Introduced perennial grasses have also been shown to compete with cheatgrass (Davies and Johnson, 2017). Previous studies have indicated that the placement of superabsorbent hydrogel in bands below newly seeded squirreltail increases the longevity of the newly emerged seedlings in drought conditions. The purpose of this study was to determine how the combination of low nitrogen, phosphorus fertilizer in conjunction with the hydrogel affects perennial grass seedling establishment and longevity.

Previous studies have shown that hydrogel can function as a soil conditioner, making the soil able to retain more water over longer periods of time. This retained water can then nourish native seedlings when they sprout in the spring. In this study, we hoped to learn more about the interaction between hydrogel and fertilizer, as well as its effects on rangeland grasses. We hypothesized that adding fertilizer to the hydrogel would make both water and fertilizer plant available to the sprouting seedlings, promoting better growth and a better chance of survival.

MATERIALS AND METHODS

This 150-day glasshouse pot study was installed in November 2017. Different combinations of hydrogel and fertilizer depths were used, as shown in Table 1. 9x4x4 in pots were filled to a depth of 4 in with Tooele loam soil from UTTR. Hydrogel was applied evenly over the soil at a rate of 3000 kg ha^{-1} to treatments receiving it at that depth. 3 ml of fertilizer was applied in a concentrated band at the same time to treatments receiving fertilizer at that depth. The fertilizer was calculated to contain 4 N, 17 P_2O_5, 17 K_2O, 0.6 S, 0.6 Fe, 0.1 Zn, 0.1 Mn, 0.1 Cu and 0.1B (kg ha^{-1}). 3 inches of the same UTTR soil was placed on top of the soil in each pot. All pots were soaked to saturation in deionized water to allow for weed seed germination and removal, and to ensure the hydrogel had become fully saturated.

Table 1. Treatments

Treatment	Hydrogel (HG)	Fertilizer Placement
A	HG	surface
B	none	surface
C	HG	3 inch depth
D	none	3 inch depth
E	HG	none
F (control)	none	none

After 14 days the pots were removed from the water and allowed to drain to field capacity for 24 hours. Six seeds of either bottlebrush squirreltail or Vavilov II Siberian wheatgrass *[Agropyron fragile (Roth) Candargy]*, an introduced perennial grass species, were then planted in the pots at a depth of 0.5 inches (NRCS planting recommendation depth). 0.5 ml (0.1 teaspoons) of fertilizer was applied to each seed for all treatments with surface application. The pots were weighed three times per week and monitored weekly for seedling germination, length, number of blades, and death.

RESULTS AND DISCUSSION

Both emergence and longevity of each of the species were evaluated. As seen in Fig. 1, fertilizer use alone did not improve emergence in either species. No treatment improved bottlebrush squirreltail emergence. Vavilov only showed improved emergence in treatments with hydrogel.

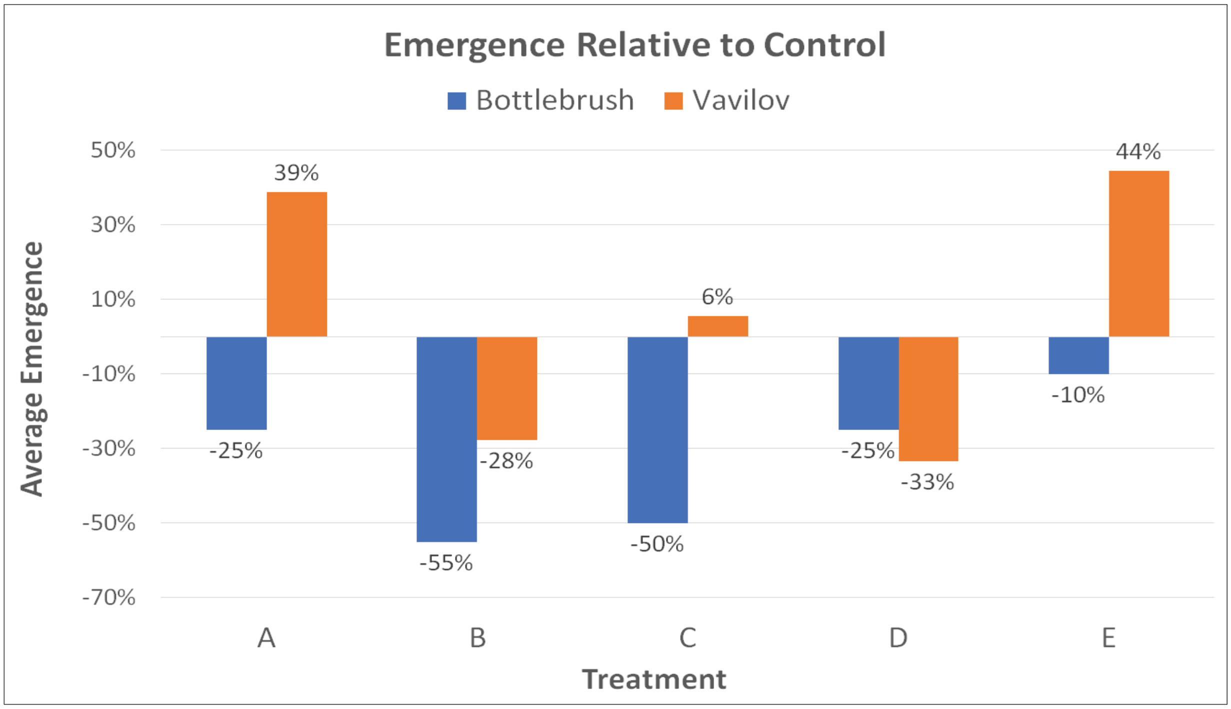

Fig. 1. Emergence relative to the untreated control. All differences were statistically significant than the control ($P = 0.10$) with the exception of Vavilov (C).

For both species, longevity was most improved in the presence of hydrogel and fertilizer at a depth of 3 inches (Figure 2.). Bottlebrush squirreltail seedlings had poor emergence, but those seedlings that did emerge showed a 9-34% increase in longevity relative to the control in nearly every treatment. Longevity was only reduced when the seeds were treated to fertilizer alone at the surface. In the presence of HG at both depths or alone at the 3-inch depth, longevity was improved. It is possible that the fertilizer inhibits the germination or growth of new seedlings. However, when deep enough for roots of older seedlings to reach it becomes a benefit to the young plants.

A positive effect on the longevity of Vavilov was only seen with a combination of hydrogel and fertilizer at a depth of 3 inches. No other treatments showed an increase in longevity relative to the control.

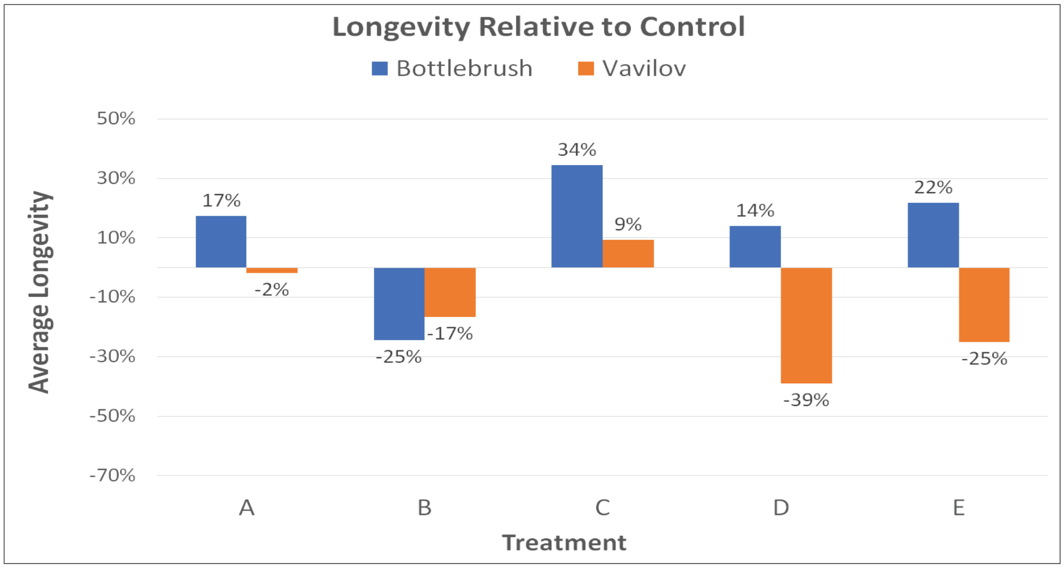

Fig. 2. Seedling longevity compared to the untreated control. All differences were statistically different than the control (*P* = 0.10) with the exception of Vavilov (A).

SUMMARY

Hydrogel has shown promise as an effective tool for rangeland rehabilitation and restoration. The combination of hydrogel and fertilizer may potentially help with the establishment of perennial grass seedlings. The addition of hydrogel and fertilizer increased bottlebrush longevity by up to 34% relative to the control. In a range setting, this increase could potentially give bottlebrush seedlings an establishment advantage over cheatgrass. Results appear to be species specific. Increased Vavilov II seedling longevity was small relative to the control and limited only to treatments with hydrogel and fertilizer at a depth of 3 inches. Further research must be done to fully determine the viability of this combination and its effects on different species. Additionally, more research must be done to determine how this combination affects already established cheatgrass.

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Boron Fertilization with Aspire® in Alfalfa and Potato

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ABSTRACT

Potassium (K) and boron (B) are essential nutrients. The spatially even distribution of applying K fertilizer is typically not a problem, but for B fertilizer application, it is a problem. This is especially difficult for crops such as alfalfa (*Medicago sativa* L.) and potato (*Solanum tuberosum* L.) due to low B rate and limited soil exploration by roots. Fertilizer with K and B fused into a single granule could result in even distribution. Trials were performed to evaluate the performance of Aspire (0-0-58-0.5B) against traditional K fertilizer (muriate of potash or MOP) in alfalfa and potato. Additionally, a comparison was made with a traditional B source (boric acid as Granubor) for the alfalfa. Three years of field trials were performed in Rexburg, ID. Potatoes fertilized with Aspire showed a increase in petiole B concentration. Boron concentration in alfalfa forage tissue did not increase for either form of B fertilizer. Boron fertilization with Aspire resulted in a significant increase in average tuber size, but no increase in yields were measured. In contrast, there were no increases in alfalfa forage quality with B fertilization, but there were significant increases in yield over the unfertilized control. The magnitude of the differences was not great (137 lb/acre), but the Aspire resulted in consistently greater yields in alfalfa compared to the Granubor. These studies show that combining K and B into one granule is an effective means of B fertilization in potato and alfalfa.

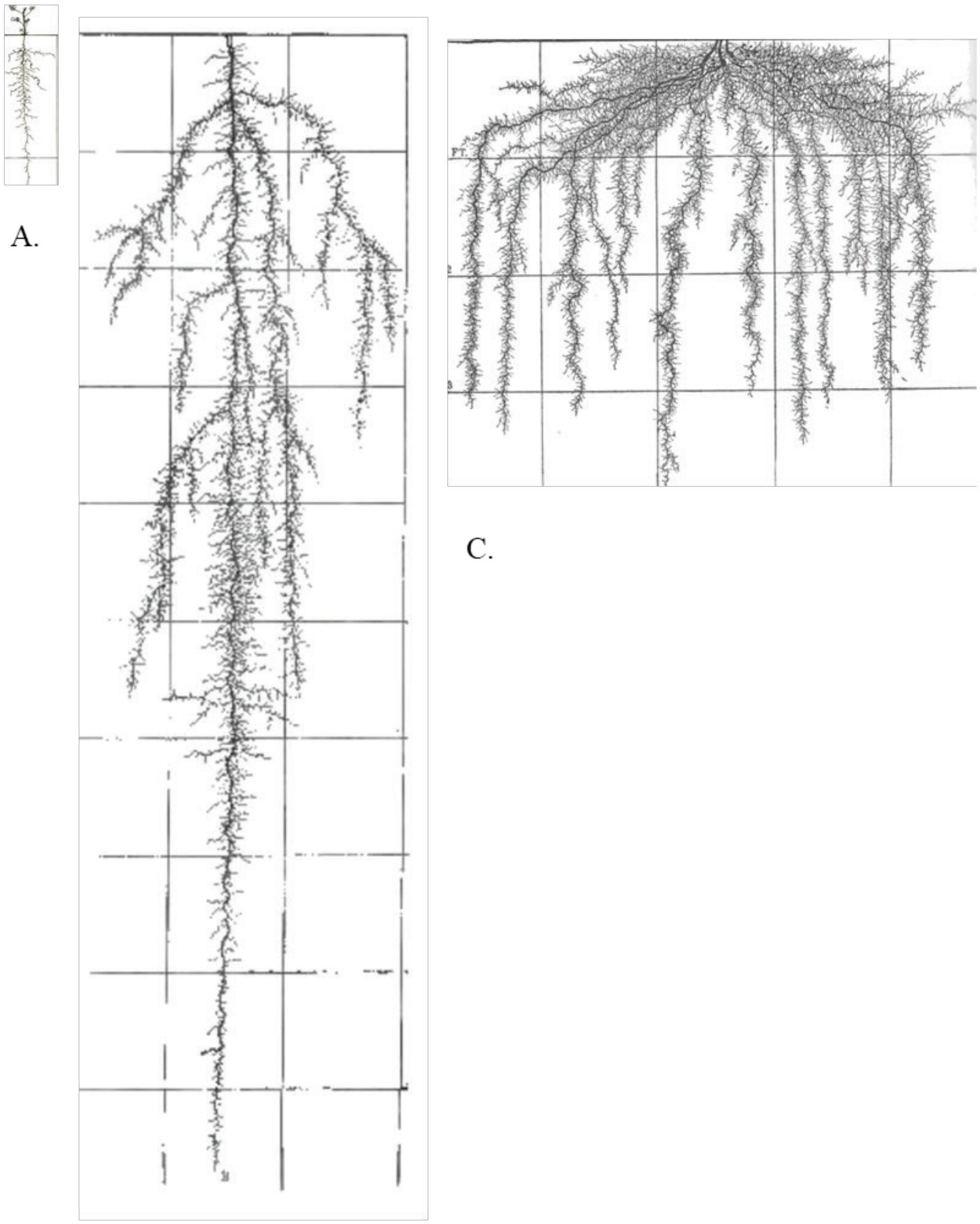
INTRODUCTION

Alfalfa (*Medicago sativa* L.) and potato (*Solanum tuberosum* L.) are economically important crops. Alfalfa is a significant crop in the US due to its ability to fix nitrogen (N_2), its growth efficiency, and its source of protein and yield (Barnes et al., 1988). Globally, potato is the 14th highest in acres harvested at 24 million and is 4th in value at \$123 trillion US dollars (FAO, 2019).

Potassium (K) and boron (B) are essential plant nutrients. The main role of K in plants is plant-water relations, while B plays a key role in cell wall health, reproductive growth, and nitrogen fixation in alfalfa.

Potassium is generally applied at high rates. Therefore, the spatial distribution of K granules is essentially uniform during fertilization. However, B distribution is often poor because it is a micronutrient used at substantially lower rates. For example, typical rates of K can be as high as ~300 lb/ac, whereas B is 1-3 lb/ac (Lissbrant, S., et al., 2009 and Undersander, D. et al., 2011).

Bulk blending of various dry fertilizers is common. For example, potassium chloride (KCl) is blended with boric acid as separate fertilizer granules. This approach lends itself to custom blends for each unique zone in a field. The disadvantage of this fertilization method is segregation of the fertilizer sources during transportation and non-uniform spatial application due to the different sizes, shapes and densities of each of the fertilizers. Additionally, even if fertilizer has a perfectly even blend that is spread uniformly, not many granules of the B are applied per plant. Some plants may have limited or no access to B because of a very narrow circumference of the root system. Crops with narrow root system circumference are alfalfa (Fig. 1), carrot, onion, strawberry, and turfgrass. It may also be a problem with plants that have inefficient rooting systems, such as potato that have a shallow root distribution with very few root hairs (Fig. 1).



B.

Fig. 1. Root morphology and architecture for alfalfa (A and B) and potato (C). Horizontal lines represent one foot increments in depth. A) Alfalfa roots at 63 days after planting. B) Alfalfa roots near the end of the first season's growth. C) Potato roots near the end of a season of growth. (Adapted from Weaver, 1926.)

A potential solution, especially for crops with a narrow root system circumference and/or inefficient root system, is the use of homogeneous granules that each have the same concentration of K and B for better distribution. Aspire (0-0-58-0.5B; The Mosaic Company, Plymouth, MN, USA) is an alternative to muriate of potash (MOP), which is potassium chloride (KCl), and sodium borate or boric acid. It is a fusion of K and B into a single granule, which improves the spatial distribution of B and insures that the same amount of nutrients are received into the soil.

The objectives of these trials were to evaluate Aspire as a source of B for potato and alfalfa.

MATERIALS AND METHODS

Three years of field trials were conducted on potato and alfalfa on the Brigham Young University-Idaho Hillside Farm in Rexburg, ID (coordinates about 43°48'32.4"N 111°46'59.4"W elevation about 4,900 feet above sea level). Treatments were applied uniformly with a rotary spreader to each plot arranged in a Randomized Complete Block Design (RCBD) with six replicated blocks.

The soil type was a Ririe silt loam. The crop was never severely moisture stressed with the aid of an irrigation system—with low B levels in the water. Soil samples were taken each spring and analyzed by the Brigham Young University—Environmental Analytical Laboratory (BYU—EAL, Provo, UT; see http://eal.byu.edu for methods used). The soil test concentrations of K and B were moderate (Table 1). Crops were raised per best management practices—including nutrient, soil, water, pest and crop management. The crops were scouted at least weekly for disease and insect pressure. Overall, pest pressure was minimal, with no notable outbreaks of any pathogens, viruses, or insects. Weather was mostly typical for the Rexburg area with a moderate amount of precipitation and near average temperatures.

Statistical analysis was performed by Analysis of Variance (ANOVA; P = 0.10) with differences between means determined by Tukey-Kramer method using SAS software (SAS 9.3, Cary, North Carolina, United States).

Table 1. Selected soil test concentrations (ppm)

		------ potato ------			-- alfalfa --	
analyte	extractant	2016	2017	2018	2016	2018
K	Olsen Bicarbonate	195	170	153	190	235
B	Saturated Paste	0.7	0.4	0.2	0.5	0.5

Potato

Russet Burbank potato was planted [previous crop was wheat (*Triticum* spp.)] at 21 cwt/ac at 6 inches deep at the beginning of May each year. Each plot consisted of four 36-inch rows by 40 feet length. The studies had varying treatments in each year. The studies had varying sources of phosphorous (not shown), which proved to not have any significant differences and, thus, are combined for orthogonal comparisons of treatments with muriate of potash compared to those with Aspire. Both K sources (MOP and Aspire) were applied at a rate of 300 lb K_2O/ac in all cases. The control was lost in 2018 and, thus, the negative and positive control data is not presented in this multi-year analysis. Rather, just the comparison between MOP and Aspire are presented. Treatments were incorporated into the soil within 24 hours after application.

Composite petiole samples (six petioles per plot combined into one sample per treatment) were taken in July and August and submitted for analysis by the BYU—EAL. Late season canopy health was evaluated by Normalized Difference Vegetation Index NDVI) using a GreenSeeker® Handheld Crop Sensor, (Trimble, Sunnyside, CA) throughout July and August.

The crops were killed with sulfuric acid foliar spray mid-September for harvest during the first week of October via mechanical crossover potato harvester. Tubers were harvested out of 20 feet of the center two rows of each plot. Tubers were counted, weighed and hand graded for separation into US No. 1, US No. 2 and culls (malformed and undersized). US No. 1 tubers were sized based on breaks at 4, 8, 12, and 16 ounces. A subsample from each plot was used to evaluate internal defects and specific gravity.

Alfalfa

A Roundup Ready® alfalfa (AmeriStand 433T RR) stand used for this trial was established in 2014. The stand was relatively full and healthy with minimal weed pressure, although there is the presence of some grass weeds (<10%). Each plot consisted of areas 40 feet long by 30 feet wide with 10 foot buffer strips along the 40-foot margin. Treatments (presented with the data below) were applied with hand-held broadcast spreaders in mid-June after the first cutting each year. The alfalfa forage was harvested three times each season about the first of June, middle of July, and end of August/first of September with a 12 foot wide commercial swather. The windrows of harvested material laid in the field for ~three days drying.

Wet yields were measured by weighing 10 ft of the windrow in the middle of each plot. Several random subsamples were taken (hand grab) from the weighed forage, with a total volume of about one gallon of sample for each plot. Gravimetric moisture content was determined by drying the samples at 140°F for 48-72 hours. Samples were ground to pass a 60 mesh screen and analyzed for various forage quality parameters via near infrared spectroscopy (NIRS, Unity Scientific, Info Star version 3.10.0, Unity Scientific, Columbia, Maryland). The remaining dry, ground samples were analyzed for mineral nutrients BYU—EAL.

RESULTS AND DISCUSSION

Potato

Fertilization with Aspire resulted in significant increases in B petiole concentrations (Table 2). Curiously, petiole nitrate-N concentrations decreased and zinc and manganese increased. Total and US No. 1 tuber sizes increased with Aspire, with no differences in the sizes of other grades (Table 3). However, there were no significant differences for the various US No. 1 size categories (data not shown). In contrast with previous studies (Hopkins et al., 2010), there were no differences for total yield, nor for any tuber grade category (Table 4). Increases in tuber growth rates and size often result in increased incidence of brown center and hollow heart, which did occur for Aspire treatments in these trials (Table 5). There were no differences for canopy NDVI or tuber solid (as measured by specific gravity).

Alfalfa

There were no significant differences for yield at any alfalfa harvest (data shown is combined across the three harvests that occurred each year), but there was a trend for Aspire to yield higher

(Table 6). An orthogonal comparison was made with this data by comparing MOP to MOP + GB to Aspire. All treatments that included both MOP + GB were averaged for the comparison. Similarly, all treatments that included Aspire were averaged and compared. There was a significant increase with B fertilization (MOP + GB) and a further yield increase with Aspire (Figure 2). There were no differences for protein or other alfalfa quality factors (Table 7).

Table 2. Potato petiole nutrient and sodium (Na) concentrations for a boron (B) trial in Idaho 2016-18. Values in bold are statistically different from one another. *P* = 0.10

	------------------------- % -------------------------					
	NO_3-N	P	K	S	Ca	Mg
MOP	**1.33**	0.0931	5.17	0.222	2.08	1.66
ASPIRE	**1.01**	0.0930	5.11	0.210	2.16	1.68
	------------------------- % -------------------------					
	Zn	Fe	**Mn**	Cu	**B**	Na
MOP	**34.6**	84.3	**31.6**	2.55	**31.2**	1,054
ASPIRE	**41.7**	87.5	**35.5**	2.88	**33.8**	1,247

Table 3. Average potato tuber sizes for various grade categories for a boron (B) trial in Idaho 2016-18. Values in bold are statistically different from one another. *P* = 0.10

	----------------------------- oz/tuber -----------------------------				
	US No. 1	US No. 2	cull < 4 oz	cull malform	**total**
MOP	**7.0**	9.0	3.2	9.4	**7.1**
ASPIRE	**7.3**	8.7	3.1	10.7	**7.4**

Table 4. Potato yields for various grade categories for a boron (B) trial in Idaho 2016-18. No differences were statistically different from one another. $P = 0.10$

	US No. 1	US No. 2	cull < 4 oz	cull malform	marketable (US No. 1 and US No. 2)	total
	-------------------------------------- cwt/ac --------------------------------------					
MOP	270	28	29	22	299	349
ASPIRE	272	27	29	25	299	353

Table 5. Potato measurements for a boron (B) trial in Idaho 2016-18. Values in bold are statistically significant from one another. $P = 0.10$

	NDVI	Brown Center, %	Hollow Heart, %	Specific Gravity
MOP	0.74	**9**	**0**	1.08
ASPIRE	0.73	**16**	**3**	1.08

Table 6. Alfalfa yield for a potassium (K) and boron (B) trial in 2016-18. Fertilizer for K was applied as Aspire or muriate of potash (MOP; KCl) for B as Aspire or Granubor (boric acid). Differences were not significant in any year or with the average. (*P* = 0.10)

Trt #	Aspire	MOP (KCl)	Aspire	Granubor	yield, ton/ac			
	--- K_2O, lb/ac ---		------- B, lb/ac -------		2016	2017	2018	average
1	0	0	0	0	6.01	6.88	7.49	6.79
2	0	200	0	0	6.17	6.97	7.67	6.93
3	0	200	0	1	6.33	6.78	7.47	6.86
4	0	200	0	2	5.92	6.44	8.28	6.88
5	0	200	0	4	5.94	7.36	7.65	6.98
6	0	200	0	6	6.51	7.03	8.02	7.19
7	200	0	1.6	0	5.90	7.47	7.81	7.06
8	200	0	1.6	0.5	5.60	6.74	8.28	6.87
9	100	100	0.8	0	6.33	7.20	8.09	7.21

Table 7. Alfalfa protein for a potassium (K) and boron (B) trial in 2016-18. Fertilizer for K was applied as Aspire or muriate of potash (MOP; KCl) and for B as Aspire or Granubor (boric acid). Differences were not significant in any year or with the average. (*P* = 0.10)

Trt #	Aspire	MOP (KCl)	Aspire	Granubor	yield, ton/ac			
	--- K_2O, lb/ac ---		------- B, lb/ac -------		2016	2017	2018	average
1	0	0	0	0	23.3	24.0	23.1	23.5
2	0	200	0	0	23.3	23.7	23.3	23.4
3	0	200	0	1	23.9	23.8	23.5	23.7
4	0	200	0	2	23.5	23.7	23.5	23.6
5	0	200	0	4	23.5	23.7	23.3	23.5
6	0	200	0	6	23.0	23.8	22.9	23.2
7	200	0	1.6	0	23.1	23.9	22.9	23.3
8	200	0	1.6	0.5	23.8	23.5	22.8	23.4
9	100	100	0.8	0	23.2	23.5	23.1	23.2

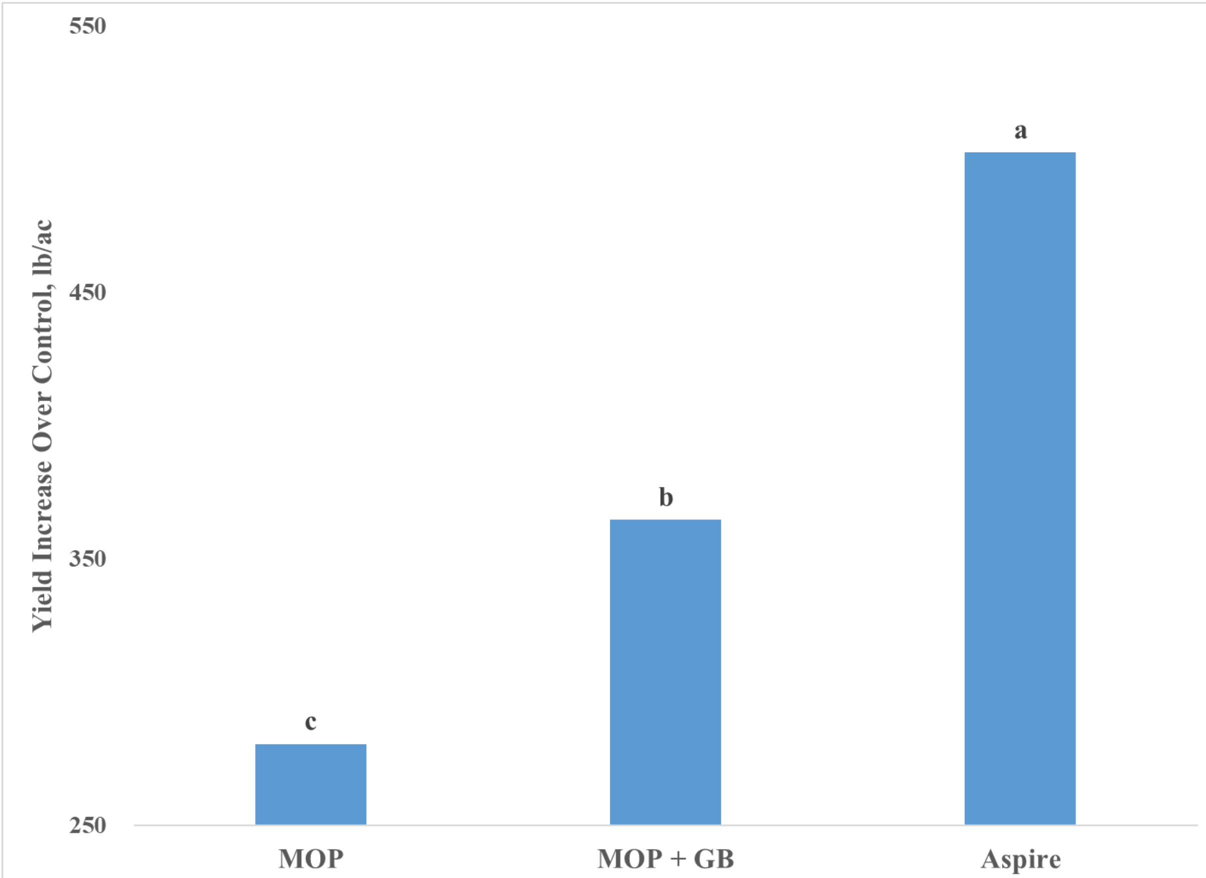


Fig. 2. Orthogonal differences for alfalfa forage yield between combined Aspire vs. muriate of potash (MOP) with or without boric acid (Granubor; GB) averaged over three years of field trials (2016-18). Reported on an "as fed" basis with 15% moisture. Bars sharing the same letters above are not significantly different. P = 0.10

SUMMARY

Fertilization with B (applied as Aspire) did increase the concentration of B within potato petioles, which resulted in increases in average size for the US No. 1 and overall tubers. These differences did not result in significant increases in yield. The increase in average tuber size resulted in increases in percentage of hollow heart and brown center with B fertilization. In contrast, there were no impacts of B on alfalfa forage B concentration or any quality parameter, but there were increases in yield with B fertilization. Aspire proved to be a more efficient source of B than the traditional form used in this study for alfalfa. Further Aspire fertilization studies are needed, especially with crops that have a narrow root system circumference and/or inefficient rooting systems.

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Struvite Phosphorus Fertilizer on Potato

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ABSTRACT

Potato (*Solanum tuberosum* L.) is a staple in the global economy and on the dinner table. It has an unusually high demand for phosphorus (P) due to its shallow, inefficient root system. Most P fertilizers are water soluble, but then precipitate quickly—potentially resulting in poor plant uptake. Crystal Green (a struvite based fertilizer) is acid soluble, but not water soluble. In theory, it remains undissolved until plant roots exude acids—potentially avoiding the precipitation reaction. The objective of these studies were to evaluate this struvite based P fertilizer on potato tuber yield and quality. Thirteen field studies were conducted from 2013-2018 with various blends of struvite and traditional fertilizer (monoammonium phosphate or MAP) compared to MAP and an untreated control. An orthogonal analysis averaging across struvite treatments and over years reveals a significant increase as a result of P fertilization for US No. 1, marketable, and total yields. When averaged across all of the struvite treatments, there was an additional increase in US No. 1, marketable, and total yields when compared to MAP. And, struvite resulted in an increase in petiole P concentration over the control. This data suggests that struvite is an efficient P fertilizer, providing greater yields than the traditional MAP.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a staple in the global economy and on the dinner table. Among crops, potato is the 14th highest in acres harvested at 24 million acres and 4th in value at \$123 trillion US dollars (FAO 2019).

One important aspect of potato production is soil fertility and plant nutrition—with phosphorus (P) being an important nutrient. Potato has unusually high demand for P due, in part, to its shallow, inefficient root system. This is especially true for the Russet Burbank variety, which is the most commonly grown variety in the United States.

Phosphorous is a required nutrient for plants to perform vital functions (Hopkins, 2015). It is part of important plant structure compounds, and it is a catalyzer of multiple biochemical reactions in plants. One of the most significant roles P plays in plant function is in helping with the capture and conversion of the sun's energy into plant compounds. Phosphorous is part of the adenosine tri-phosphate (ATP) molecule, which is plants' energy transfer system. Phosphorous is essential for early root development, crop maturation, stem and stalk strength, crop quality, and resistance to plant diseases.

Soils chemistry of P is challenging because only a small part of the total P in soil is plant available (Hopkins, 2015). Phosphorus cannot be replenished in soil except from an external source if it is lost by run off, erosion or other means (Sanyal and De Datta, 1991). As such, there has been much work to improve P use efficiency (Hopkins, 2015; Hopkins et al., 2008, 2014, 2018).

Struvite is one potential source to improve P use efficiency. It is a crystal which is made with equal molar concentrations of magnesium, ammonium, and phosphate. Struvite is made of an excess buildup of nutrients in waste water streams as it accumulates as a cement-like substance in water treatment pipes, pumps, and valves.

Ostara Nutrient Recovery Technologies Inc. (Vancouver, British Columbia, Canada) has developed a slow release fertilizer material from struvite. Their technology recovers up to 90% of P and 20% of ammonia (NH_3) from a treated wastewater stream, effectively transforming the waste stream into an environmentally-friendly fertilizer. It is somewhat soluble under neutral conditions, but highly soluble in acidic conditions (Rahman et al., 2014). As such, struvite presents a significant advantage for crops in acidic soils, which normally have relatively low soluble P concentrations.

Unlike most other P fertilizers, struvite is not water soluble in neutral and alkaline soils. Water soluble fertilizers quickly dissolve into soil solution, but then a majority of the P precipitates. This labile P has to dissolve again before plants can take it up, which is a very inefficient cycle. In theory, struvite remains undissolved until plant roots come into contact with it. The acids exuded from the roots dissolve it and, because of the close proximity of roots, a relatively higher amount of P is theoretically taken up by plants.

The objective of this study is to test the effectiveness of Crystal Green struvite for potato tuber yield and quality when grown in calcareous alkaline soils.

MATERIALS AND METHODS

Russet Burbank potato was planted at 13 field sites (planting dates ranged from April 26 to May 15) during 2013-2018 near Nampa, Rupert, Blackfoot, Grace, and Rexburg, ID and Provo, UT. The soils were calcareous sandy to silt loams with 0-2% slope and moderate to high soil fertility levels with excellent infiltration and drainage, and no impactful pesticide residues. Bicarbonate soil test P concentrations for each site are shown in Table 1.

Table 1. Bicarbonate extractable soil test phosphorus at 13 field sites

year	site 1	site 2	site 3	site 4
2013	17	22		
2014	22	19	23	
2015	27	24		
2016	17	23	18	33
2017	10			
2018	21			

Plots were arranged in a Randomized Complete Block Design with six replicated blocks with six rows by 40 foot lengths. Distance between rows was between 34-36 inches. Treatments in each year varied, but always included a control without any P fertilizer, monoammonium phosphate (MAP), and various combinations of MAP with struvite (Tables 2-5). Generally, the fertilizer was uniformly applied across the plots with a rotary spreader and then tilled into the soil by disking to a depth of four to six inches within 1-2 days. In two studies (2017-2018), the fertilizer was applied as a concentrated band applied at planting by placing the fertilizer three inches to the side and three inches down from the seed piece. Nitrogen was balanced across all treatments using urea (46-0-0).

The crop was raised per best management practices – including nutrient, soil, water, pest and crop management. The crop was scouted weekly for disease and insect pressure—revealing minimal impact and, thus, no application of insecticides or fungicides (other than what was on the seed). Weather was mostly typical, with a moderate amount of precipitation and near average temperatures. The crop was never moisture stressed severely due to being irrigated frequently because of the low water holding capacity of the soils and the minimal precipitation.

The crops were harvested between September 15 and October 25 by digging the center 20 feet of the middle two rows in each plot via mechanical digging. Tubers were weighed and graded as US No. 1, US No. 2, or cull (malformed or undersized), as well as being assessed for internal defects and specific gravity.

Statistical analysis was performed by Analysis of Variance (ANOVA) with differences between means determined by Tukey-Kramer method using SAS software (SAS 9.3, Cary, NC). A *P* value of 0.10 was used to evaluate the statistical analysis.

RESULTS AND DISCUSSION

On average, there was a significant yield increase to P fertilization for US No. 1, marketable, and total yields (Table 6). No other yield categories were significant (Table 7). Specific gravities were also increased significantly with P fertilization (Table 8). Average tuber size and petiole P was unaffected when comparing the traditional MAP fertilizer to the control (Table 8).

Orthogonal comparisons were made by averaging across all of the struvite treatments over all years. There was a significant increase in US No. 1, marketable, and total yields for struvite over MAP and the control (Table 6). And, struvite resulted in an increase in petiole P concentration over the control, even though MAP did not (Table 8).

Further orthogonal comparisons were made by parsing the data into treatments with 100% struvite and those with either low (<50% struvite) or high (>50% struvite) ratios of struvite to MAP. The yield increases for US No. 1 was 20, 31, and 40 cwt/ac for the low ratio, high ratio, and 100% struvite, respectively—with only the latter two being statistically significant over MAP (Table 9). Individual size categories were not significant (Table 10). Total yield increases were 26, 31, and 11 cwt/ac for the low, high, and 100% struvite, respectively—with only the high ratio being statistically significant (Table 9). Only the 100% struvite gave an increase for specific gravity and petiole P concentration (Table 11).

This data suggests that struvite is an efficient P fertilizer, providing greater yields than the traditional MAP. Of course, cost of the product has to be weighed into the decision of whether or not it is useful. Often the cost of the struvite materials is high.

Table 2. Phosphorus fertilizer (P_2O_5) treatments at two field sites in 2013. Fertilizer was applied as various combinations of monoammonium phosphate (MAP) and Crystal Green struvite (CGO = Crystal Green Original.

ID #	Treatment Group	Rate	MAP	CGO
		lb P_2O_5/ac	-------- % of blend --------	
----------------------------------- site 1 -----------------------------------				
1	control	0		
2	MAP	100	100	
3	MAP	75	100	
4	CG (100%)	100		100
5	CG:MAP (>50%)	100	50	50
6	CG:MAP (>50%)	75		100
7	CG:MAP (>50%)	75	25	75
8	CG:MAP (>50%)	75	50	50
9	CG:MAP (<50%)	75	75	25
----------------------------------- site 2 -----------------------------------				
1	control	0		
2	MAP	160	100	
3	MAP	120	100	
4	CG:MAP (<50%)	160		100
5	CG:MAP (>50%)	160	50	50
6	CG:MAP (<50%)	120		100
7	CG:MAP (>50%)	120	25	75
8	CG:MAP (>50%)	120	50	50
9	CG:MAP (<50%)	120	75	25

Table 3. Phosphorus fertilizer (P_2O_5) treatments at three field sites in 2014. Fertilizer was applied as various combinations of monoammonium phosphate (MAP) and Crystal Green struvite (CGO = Crystal Green Original.

ID #	Treatment Group	Rate	MAP	CGO
		lb P_2O_5/ac	-------- % of blend --------	
		sites 1 & 2		
1	control	0		
2	MAP	100	100	
10	CG:MAP(<50%)	100	75	25
11	CG:MAP(<50%)	100	90	10
12	CG:MAP(<50%)	100	85	15
13	CG:MAP(<50%)	100	91	9
14	CG:MAP(>50%)	75	50	50
15	CG:MAP(<50%)	75	75	25
		site 3		
1	control	0		
2	MAP	100	100	
10	CG:MAP(<50%)	100	75	25
14	CG:MAP(>50%)	75	50	50
15	CG:MAP(<50%)	75	75	25
16	CG:MAP(<50%)	100	91	9
17	CG:MAP(<50%)	100	85	15
18	CG:MAP(<50%)	100	77	23
19	CG:MAP(<50%)	75	77	23
20	CG:MAP(<50%)	75	65	35
21	CG:MAP(<50%)	100	65	35
22	CG:MAP(>50%)	100	50	50

Table 4. Phosphorus fertilizer (P_2O_5) treatments at six field sites in 2015-16. Fertilizer was applied as various combinations of monoammonium phosphate (MAP) and Crystal Green struvite (CGO = Crystal Green Original.

ID #	Treatment Group	Rate	MAP	CGO
		lb P_2O_5/ac	-------- % of blend --------	
		------------------------------ 2015 sites 1 & 2 ------------------------------		
1	control	0		
2	MAP	100	100	
10	CG:MAP(<50%)	100	75	25
14	CG:MAP(>50%)	75	50	50
15	CG:MAP(<50%)	75	75	25
22	CG:MAP(>50%)	100	50	50
		--------------------------------- 2016 site 1 ---------------------------------		
1	control	0		
2	MAP	100	100	
10	CG:MAP(<50%)	100	75	25
21	CG:MAP(<50%)	100	65	35
22	CG:MAP(>50%)	100	50	50
23	CG:MAP(<50%)	100	85	15
		--------------------------------- 2016 site 2 ---------------------------------		
1	control	100		
2	MAP	100	100	
10	CG:MAP(>50%)	100	25	75
		------------------------------ 2016 sites 3 & 4 ------------------------------		
1	control	60		
2	MAP	60	100	
10	CG:MAP(>50%)	60	25	75

Table 5. Phosphorus fertilizer (P_2O_5) treatments at two field sites in 2017-18. Fertilizer was applied as various combinations of monoammonium phosphate (MAP) and various Crystal Green (CG) struvite based products (CGO = CG Original; CGNXT = CG Next Generation; 15CG 85MAP = homogenous blend of 15% CG with 85% MAP; 25CG 85MAP = homogenous blend of 15% CG with 75% MAP.

ID #	Treatment Group	Rate	MAP	CGO	CGNXT	15CG 85MAP	25CG 75MAP
		lb P_2O_5/ac	---------------------- % of blend ----------------------				
2017 trial							
1	control	0					
2	MAP	150	100				
10	CG:MAP(<50%)	150	75	25			
21	CG:MAP(<50%)	150	65	35			
24	CG:MAP(<50%)	150	75		25		
25	CG:MAP(<50%)	150	65		35		
2018 trial							
1	control	0					
2	MAP	50	100				
10	CG:MAP(<50%)	50	75	25			
21	CG:MAP(<50%)	50	65	35			
24	CG:MAP(<50%)	50	75		25		
25	CG:MAP(<50%)	50	65		35		
26	CG:MAP(<50%)	50				100	
27	CG:MAP(<50%)	50					100

Table 6. Average potato yield increases relative to an untreated control for 13 studies (2013-2018). Plots were fertilized with either monoammonium phosphate (MAP) alone or in various blends of a struvite fertilizer (Crystal Green; CG). Values in bold-face type were significantly greater than the control. Comparisons between fertilized treatments is indicated by letter to the side of significant values, with those sharing the same letter being not significantly different from one another. (P = 0.10)

	US No. 1	US No. 2	Marketable	cull < 4 oz	cull malform	total yield
	------------------------------- cwt/ac -------------------------------					
MAP	**29 b**	0 a	**29 b**	0 a	(3) a	**26 b**
CG:MAP	**53 a**	0 a	**53 a**	(2) a	1 a	**51 a**

Table 7. Average potato yields for various size categories relative to an untreated control for 13 studies (2013-2018). Plots were fertilized with either monoammonium phosphate (MAP) alone or in various blends of a struvite fertilizer (Crystal Green; CG). Differences between treatments were not statistically significant. (P = 0.10)

	4-6 oz	6-10 oz	10-14 oz	>14 oz
	---------------- cwt/ac ----------------			
MAP	7	10	4	7
CG:MAP	11	17	12	11

Table 8. Average potato tuber specific gravity and size and petiole P concentration relative to an untreated control for 13 studies (2013-2018). Plots were fertilized with either monoammonium phosphate (MAP) alone or in various blends of a struvite fertilizer (Crystal Green; CG). Values in bold-face type were significantly greater than the control. Comparisons between fertilized treatments is indicated by letter to the side of significant values, with those sharing the same letter being not significantly different from one another. (*P* = 0.10)

	specific gravity	tuber size, oz/tuber	petiole P, %
MAP	**0.002 a**	0.05	0.01 b
CG:MAP	**0.002 a**	(0.16)	**0.03 a**

Table 9. Average potato yield increases relative to an untreated control for 13 studies (2013-2018). Plots were fertilized with either monoammonium phosphate (MAP) alone or in various blends of a struvite fertilizer (Crystal Green; CG), which are parsed into three categories of those with low ratios of CG to MAP (<50%), high ratios (>50%), and those with 100% CG. Values in bold-face type were significantly greater than the control. Comparisons between fertilized treatments is indicated by letter to the side of significant values, with those sharing the same letter being not significantly different from one another. (*P* = 0.10)

	US No. 1	US No. 2	Marketable	cull < 4 oz	cull malform	total yield
	------------------------------- cwt/ac -------------------------------					
MAP	**29 b**	0 a	**29 c**	0 a	(3) a	**26 c**
CG:MAP (<50% CG)	**49 b**	0 a	**49 b**	0 a	3 a	**51 ab**
CG:MAP ($\geq$50% CG)	**60 ab**	2 a	**61 ab**	(4) a	(1) a	**56 a**
CG (100%)	**69 a**	(3) a	**65 a**	(16) a	(13) a	**36 bc**

Table 10. Average potato yields for various size categories relative to an untreated control for 13 studies (2013-2018). Plots were fertilized with either monoammonium phosphate (MAP) alone or in various blends of a struvite fertilizer (Crystal Green; CG), which are parsed into three categories of those with low ratios of CG to MAP (<50%), high ratios (>50%), and those with 100% CG. Differences between treatments were not statistically significant. (*P* = 0.10)

	4-6 oz	6-10 oz	10-14 oz	>14 oz
	---------------- cwt/ac ----------------			
MAP	7	10	4	7
CG:MAP (<50% CG)	10	18	11	8
CG:MAP (≥50% CG)	17	17	13	14
CG (100%)	9	13	22	24

Table 11. Average potato tuber specific gravity and size and petiole P concentration relative to an untreated control for 13 studies (2013-2018). Plots were fertilized with either monoammonium phosphate (MAP) alone or in various blends of a struvite fertilizer (Crystal Green; CG), which are parsed into three categories of those with low ratios of CG to MAP (<50%), high ratios (>50%), and those with 100% CG. Values in bold-face type were significantly greater than the control. Comparisons between fertilized treatments is indicated by letter to the side of significant values, with those sharing the same letter being not significantly different from one another. (*P* = 0.10)

	specific gravity	tuber size, oz/tuber	petiole P, %
MAP	**0.002 a**	0.0	0.01 c
CG:MAP (<50% CG)	**0.002 a**	(0.2)	**0.03 b**
CG:MAP (≥50% CG)	**0.003 a**	(0.2)	**0.03 b**
CG (100%)	**0.003 a**	0.0	**0.06 a**

SUMMARY

The struvite based fertilizer, Crystal Green, resulted in significant increases in P uptake and, as a result, increases in US No. 1, marketable, and total yields when compared to monoammonium phosphate (MAP). These increases were relatively greater for blends that contained higher ratios of struvite to MAP. Struvite also resulted in increases in specific gravity relative to MAP alone.

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Pecan Rootstock Genotype Effects on Micronutrient Uptake in Alkaline, Calcareous Soils

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ABSTRACT

Alkaline pH and lime content of soils in arid or semi-arid production regions often result in severe micronutrient deficiencies in pecan (*Carya illinoinensis*). Producers routinely manage micronutrients, especially zinc, through repeated foliar fertilizer sprays. Nevertheless, limited phloem mobility of micronutrients creates some challenges with this practice in pecan, including difficulty achieving adequate canopy spray coverage (e.g., due to large tree size or prolonged unsuitable weather conditions). Thus, among pecan growers in the southwestern US there is growing interest in using different options for supplying micronutrient fertilizers via soil application. Based on information from other crops, the efficiency of uptake of soil-applied micronutrients by pecan roots in alkaline, calcareous soils is expected to vary with rootstock genotype. We studied the interactive effects of pecan seedling maternal genotype and soil lime content on nutrient uptake in alkaline soils. Seedlings with western-region maternal origin were expected to more efficiently acquire micronutrients from calcareous, alkaline soils than those with other origin. Eight maternal genotypes whose origins spanned the native range of pecan were used in this study: eastern ('Curtis', 'Elliott', and 'Moore'), western ('Riverside', 'VC1.68', 'Shoshoni', and 'Burkett'), and one southern ('87MX1.5.7'). Seedlings were grown in pots under three soil lime treatments, representing the range of soil lime content in New Mexico fields. Agricultural lime was added to soil in pots at 3 rates: 30% lime, 15% lime, and no added lime (Control). While the pots were supplied annually with nitrogen, phosphorus, and potassium fertilizers, no micronutrient fertilizers were applied to the trees (to foliar or soil) during the study. Leaf tissue nutrient concentrations were measured each growing season. Neither soil lime treatments nor maternal genotype significantly affected leaf mineral micronutrient levels, except for manganese and zinc. Compared with seedlings in lime-treated soils, Control seedlings had 18%, 66%, and 46% higher leaf manganese concentration in 2015, 2016, and 2017, respectively, but there were no differences among maternal genotypes. Only 'Shoshoni' seedlings demonstrated elevated leaf zinc concentration in all three seasons compared with other maternal genotypes: 'Shoshoni' leaf zinc was significantly higher than all maternal genotypes except 'Elliott', 'Curtis', and 'Moore' in 2015 and higher than all of the other genotypes in both 2016 and 2017. These data show that pecan seedling genotype influences zinc uptake, but, western maternal ancestry did not usually confer the expected advantage for micronutrient uptake in alkaline, calcareous soils. Research is ongoing to determine if the same patterns appear when these seedling genotypes are grafted to a commercial scion and when planted into a field setting.

New Hydroponic System for Testing Mineral Nutrient Deficiencies and its Application to Quinoa

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ABSTRACT

Correlating plant tissue nutrient concentrations with visual symptoms is valuable in combating mineral nutrient deficiencies and toxicities. Major crops tend to have large amounts of information regarding nutrient concentrations and visual symptoms of deficiencies, but this information is often lacking for minor crops, including quinoa (*Chenopodium quinoa* L.) Because nutrient concentrations can be easily controlled, hydroponics effectively demonstrate isolated specific nutrient related symptoms. However, many hydroponic systems present challenges in creating isolated nutrient deficiencies because nutrients are often added as salts with cationic and anionic pairs. For example, if potassium sulfate is used as the potassium (K) source, altering the K level will also impact the sulfur (S) concentrations. This creates the possibility of a dual deficiency and other potential interactions. As a result, a system was developed to create mineral nutrient deficiencies using the following single mineral nutrient sources: ammonium nitrate; phosphoric, sulfuric, hydrochloric, and boric acids; potassium, calcium, magnesium, zinc, and copper carbonates; manganese acetate; sodium molybdate; iron chelate 6% (EDDHA), along with HEDTA as a chelate. This solution, tested in an environmentally controlled growth chamber, was effective in growing plants to maturity and creating multiple nutrient deficiencies in quinoa. Stem size, plant height, and shoot and root biomass was significantly impacted for several nutrients, especially for those with low concentrations of nitrogen (N), phosphorus (P), and K. Unfortunately, the supposed adequate levels of some nutrients (based on previous work with other species) were likely toxic, especially boron (B) and manganese (Mn)—resulting in confounding results. Additional fine tuning of rates will be required to create all desired visual nutrient deficiency symptoms, but this system provides a basis for recording analytical and visual information on nutrient deficiencies in quinoa and other plants. This information, once complete, will be beneficial for farmers and their advisors, as well as scientists studying these species.

INTRODUCTION

Earth's population is 7.5 billion and growing. For many, hunger is an oppressive problem. As population grows, the demand on the resources of the earth to feed this human family also grows. To address this, there are significant efforts throughout the world to counter the burden of hunger.

Just as humans need nutrition, plant nutrition is vital for growth. Crop production requires careful nutrient management, so it is vital to identify deficiencies when they occur. For the dominant crops in agriculturally wealthy regions, such as potato (*Solanum tuberosum* L.), there is an abundance of reference material to visually and chemically recognize nutrient deficiencies

(Bennett, 1993; IPNI, 2017; Mills and Jones, 1996). This helps growers realize maximum economic yield. This reference material is often lacking for minor crops, especially those grown in areas with minimal resources. Quinoa (*Chenopodium quinoa* L.) is one with minimal information available for visual deficiency symptoms and tissue nutrient concentrations.

Quinoa could potentially help combat hunger throughout the world. Over the most recently reported decade, quinoa is harvested on 341,823 acres with a value of ~ $163 million US dollars (Food and Agricultural Organization of the United Nations, 2019). These numbers are increasing with time. In 1980, only 8 countries had farmers growing quinoa (Bazile et al., 2016). As of 2014, farmers in 75 countries were growing quinoa and 20 more were in 2015. With this growth, Bolivia and Peru remain the primary quinoa producers, providing more than 80% of the quinoa in the world.

In the United States, quinoa has grown in popularity as well. Imports have risen from 7 million lb in 2007 to 70 million in 2013 (Davenport, 2016). This is in part because of numerous health benefits associated with the grain. Quinoa is high in fiber and protein and contains all of the essential amino acids. These traits make it an important resource to help combat world hunger and malnutrition.

Hydroponics is the simplest method to provide information for a wide variety of the mineral nutrients, and correlates well with field responses. In contrast, forcing deficiency symptoms for many of the nutrients using soils is difficult to do because soils have adequate amounts of at least some nutrients. It is especially difficult to force micronutrient and secondary macronutrient deficiencies. Hydroponics provides an alternative to soils because nutrients are added directly to a solution in a controlled environment.

Commonly used hydroponic solutions are effective for creating individual nutrient deficiencies (Brown et al., 1990; Hopkins et al., 1992a, b, c, 1998; Bensen et al., 2009; Barben et al., 2011; Nichols et al., 2012; Trejo-Téllez and Gómez-Merino, 2012; Geary et al., 2015; Summerhays et al., 2017), but there are difficulties when attempting to create multiple nutrient deficiencies without having interacting factors. These traditional hydroponic solutions involve combinations of cationic and anionic nutrient salts. When attempting to adjust one nutrient, another nutrient is also impacted—creating interacting issues. For example, when using calcium sulfate ($CaSO_4$) for the calcium (Ca) source, altering the Ca concentration has the simultaneous effect of the sulfur (S) concentration being altered proportionally. Often, this is overcome by insuring that the associated ion is found in a large abundance so that it is not deficient, but this can have interactive effects on other nutrients. Another option is adding a secondary source of the associated ion, but this also can result in unintended consequences.

To resolve this difficulty and to create a simple recipe to facilitate ease of creating single nutrient deficiencies, a new hydroponic solution was developed (Cole et al., 2018). The accompanying ion for each nutrient is one of the following scenarios: 1) the same nutrient [with ammonium nitrate (NH_4NO_3) for nitrogen (N)], 2) a proton [for phosphorus (P), S, boron (B), and chloride (Cl)], 3) a carbonate anion [for potassium (K), Ca, magnesium (Mg), zinc (Zn), manganese (Mn), and copper (Cu)], 4) a chelate [for iron (Fe)], or 5) a sodium (Na) cation [for molybdenum (Mo)]. Preliminary studies showed this solution to be effective for growing plants and creating N deficiency with Kentucky bluegrass (*Poa pratensis* L.) and soybean [*Glycine max* (L.) Merr].

The focus of the current study was creating deficiencies of the aforementioned nutrients using this new solution to determine visual symptoms with associated nutrient concentrations in the tissues of quinoa.

MATERIALS AND METHODS

Quinoa was grown in an environmentally controlled growth chamber located in the Life Sciences Building at Brigham Young University in Provo, UT, USA at 4,551 feet elevation. The growth chamber lighting was supplied by a combination of metal halide and high pressure sodium lamps. Plants were grown in a 12/12h light/dark photoperiod. The temperatures were 77°F ± 2°F for 14 hours (during the light period with an additional two hours of high temperatures after the light photoperiod) and 10 hours at 59°F ± 2°F during the dark.

Each experimental unit consisted of quinoa growing in a 3 ½ gallon bucket with 11.4 inch inside diameter and 10 ¾ inch height filled with a hydroponic solution. Buckets were placed into opaque wooden boxes and covered with opaque plastic lids 0.5 inch thick. Each lid had eight (2 inch) holes with fittings secured on the underside of the lid with the threaded rings. The fittings had in inside diameter of 1.88 inch, a height above the plastic lid of 0.95 inch and extended below the lid 0.7 inch when the ring was attached (Fig. 1).

Fig. 1. Hydroponic fittings to hold plants

Two layers of white nylon matte mesh netting material with holes ~ 0.16 inch x 0.08 inch were stretched tightly and placed over the threaded side of the fitting and secured in place with a threaded ring (Fig. 1). Washed gravel ($8x10^{-5}$ to $1.9x10^{-4}$ inch) was placed on the taunt netting inside the fittings to a depth of 1 ½ inch (Fig. 2)

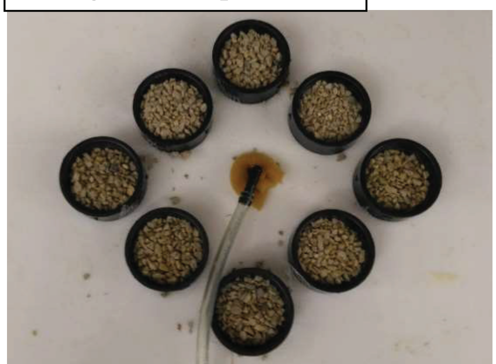

Fig. 2. Layout of fittings and tubing in the lid

Approximately 5-10 quinoa seeds (line QQ 74) were germinated by placing them ~½ inch below the top of the fitting and covering with ~1/4 inch of gravel. The seeds were watered daily from the top of the fitting using deionized water until their roots were mature enough to reach down into the nutrient solution in the bucket below.

Oxygen was supplied to the solution through PVC tubing passed through a small hole in the center of the lid. Where the tubing passed through the lid, foam was wrapped to prevent light from passing through to the solution. Bubbler air stones (1x0.5 inch; Uxcell, Hong Kong, China) were attached to the end of the tubing to diffuse the size of the air bubbles. Air flow rate was enough to have visible bubbles but avoid excessive bubbling over of the solution out of the bucket.

Fourteen treatments were established in a randomized complete block design (RCBD) with three replicated blocks. Block I was planted on 20 November 2019, two weeks prior to blocks II and III (planted 5 December 2019). A positive control contained what was estimated to be optimal concentrations of all nutrients (Table 1). Each of the other treatments was targeted to have a single mineral nutrient deficiency: N, P, K, S, Ca, Mg, Zn, Mn, Fe, Cu, B, Mo, and Cl. The deficiencies were induced by adding only 10% of the concentrations in Table 1. On the 17th day, each of the N deficient treatments received an additional ten percent of the concentrations listed in Table 1.

The nutrient solution was composed of the following: sulfuric, phosphoric, hydrochloric, and boric acids; potassium, calcium, magnesium, zinc, and copper carbonates; manganese acetate; sodium molybdate; iron 6% chelate (EDDHA); HEDTA as a chelate; and sodium hydroxide to adjust pH.

The nutrient solution was mixed in 14 liters (3.7 gallons) of deionized water with the following concentrations:

Table 1. Hydroponic nutrient concentrations (µM)													
N	P	K	S	Ca	Mg	Zn	Fe	Mn	Cu	B	Cl	Mo	HEDTA
1932	237	1122	702	1586	26.8	2.19	0.016	2.27	0.197	4.95	729	0.089	8.93

Additionally, 0.012 oz of algaecide (AlgeGone, TopFin, Phoenix, AZ, USA; active ingredient: Poly[oxyethylene(dimethyliminio)ethylene(dimethyliminio)ethylene dichloride] 4.5%) was added to each bucket.

On the 13th day of Block I's growth, fittings were transferred between treatments in an attempt to match the number of fittings containing plants between treatments. Because the gravel had a tendency to wick up the nutrient solution, each fitting was rinsed with deionized water before being placed in a new treatment.

Plants were thinned down to one plant per fitting on day 22 and 36 for Block I and Blocks II and III, respectively. The number of plants in each bucket were reduced to three fittings of one plant each on day 25 and 22 for Block I and Blocks II and III, respectively. The thinned plant material was collected, dried, ground to pass a 60 mesh screen, and analyzed for nutrient content by the Brigham Young University—Environmental Analytical Laboratory (BYU—EAL). Minerals were determined through nitric acid-hydrogen peroxide microwave digestion (EPA 3052, Ethos EZ, Milestone, Shelton, CT, USA) followed by ICP-OES analysis (iCAP 7400, Thermo Electron, Madison, WI, USA), and total nitrogen was determined by combustion (Vario EL Cube, Elementar, Langenselbold, Germany)

On about 27 December (day 37 for Block I and day 23 for Blocks II and III), the growth chamber failed. The lights and heating failed, and temperatures dropped to as low as 46-48°F. The door to the growth chamber was propped open to provide some indoor air with temperatures at ~72ºF. After 3-4 days, the problem was resolved and the growth chamber returned to normal settings.

On day 52 and 45 for Block I and Blocks II and III, respectively, each bucket received an addition of 50% of the nutrients with which it began. In block I, the K deficient and Mg deficient buckets were emptied, rinsed, and replaced with the initial nutrient solution because of mistakes during the addition.

On day 56 after planting, one plant from each replicate was harvested. Each plant height and base stem width were measured. Plant shoots were harvested by cutting at the base above the gravel. Plant roots were harvested by cutting at the bottom of the fitting and rinsed in deionized water. The biomass samples were dried to consistent mass.

Statistical analysis was performed by Analysis of Variance (ANOVA) with differences between means determined by Tukey-Kramer method using SAS software (SAS 9.3, Cary, NC). A *P* value of 0.05 was used to evaluate the statistical analysis.

RESULTS AND DISCUSSION

The treatments intended to induce N, P, and K deficiencies resulted in significant differences in plant height—with stunted growth (Fig. 3). They averaged 68, 60 and 64% shorter for N, P, and K, respectively, than the positive control. All others were statistically similar to the positive control ("none").

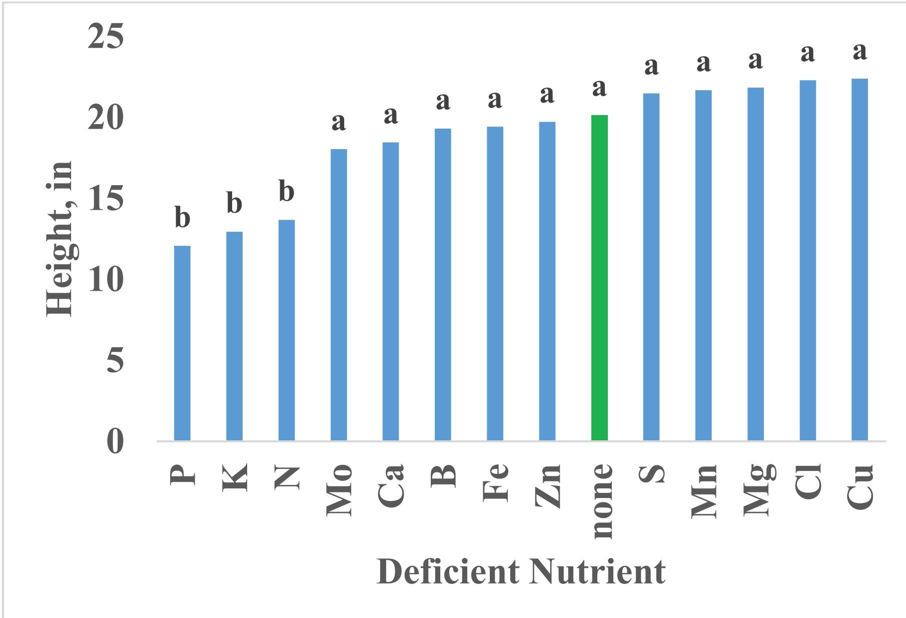

Fig. 3. Average quinoa plant height at 56 days after planting in a nutrient deficiency study. Each bar represents a different targeted nutrient deficiency compared to the positive control ("none" of the nutrients were deficient). Data sharing the same letter above the bar are not statistically different from one another. ($P = 0.05$)

Similar results were found with the width at the base of each stem (Fig. 4). Again, the N, P, and K deficient treatments showed statistically significant reductions in stem widths, while the Mn deficient treatment was significantly higher than the control. They averaged 64, 59, 47, and 121% for N, P, K, and Mn, respectively, as compared to the positive control. All others were statistically similar to the positive control ("none").

Similarly, shoot biomass was significantly lower for N, P, and K than the control (Fig. 5). The Mg, S, Mn, and B deficient treatments all had statistically significant increases in shoot growth compared to the positive control, with Mn being higher than all others. They averaged 53, 36, 26, 162, 166, 208, and 155% for N, P, K, Mg, S, Mn, and B, respectively, as compared to the positive control. All others were statistically similar to the positive control ("none").

Root biomass was also significantly lower for N, P, and K, as well as for Fe, Zn, and Cu than the control (Fig. 6). The K deficient root biomass was lower than all of the others. The Mg, Mn, B, and Cl treatments had significantly higher root biomass than the positive control. They averaged 62, 66, 16, 50, 73, 215, 286, 179, and 151% for N, P, K, Fe, Zn, Mg, Mn, B, and Cl, respectively, as compared to the positive control. All others were statistically similar to the positive control ("none").

In addition to biomass and stem width data, there were apparent differences for shoot nutrient concentrations for the 56 day harvest (Tables 2-3). Not surprisingly, all the deficiency treatments had the lowest nutrient concentrations except for iron (the sulfur treatment curiously had a lower Fe concentration), suggesting that this method of testing was somewhat successful in generating nutrient deficiencies, though further testing will be required.

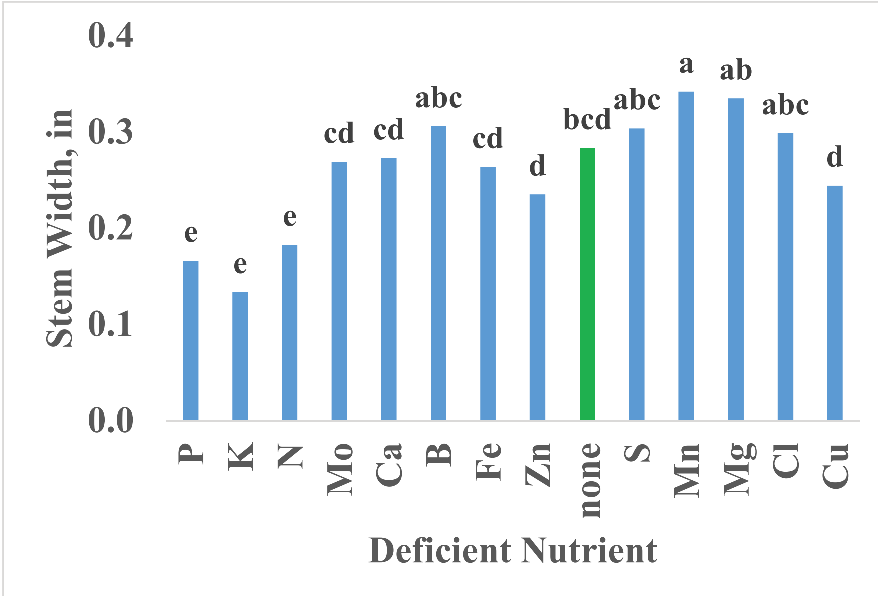

Fig. 4. Average quinoa stem width at 56 days after planting in a nutrient deficiency study. Each bar represents a different targeted nutrient deficiency compared to the positive control ("none" of the nutrients were deficient). Data sharing the same letter above the bar are not statistically different from one another. (P = 0.05)

Although there is not an extensive set of nutrient concentration data available for quinoa, with none that we are aware of at this growth stage, there are some disturbingly high levels for some nutrients (Tables 2-3). The shoots had an unusually high concentration of B and Mn (106 and 150 ppm, respectively). The theoretically Mn deficient treatment actually had wider stem widths than the control (Fig. 4). And, the B, Mn, Mg, and S deficient treatments showed statistically higher shoot biomass (Fig. 5). And, the B, Mn, Mg, and Cl had greater root biomass than the control (Fig. 6). It is possible that the hydroponic solution concentrations used in this study were too high and led to toxicity, especially for B and Mn. This will require further testing and research.

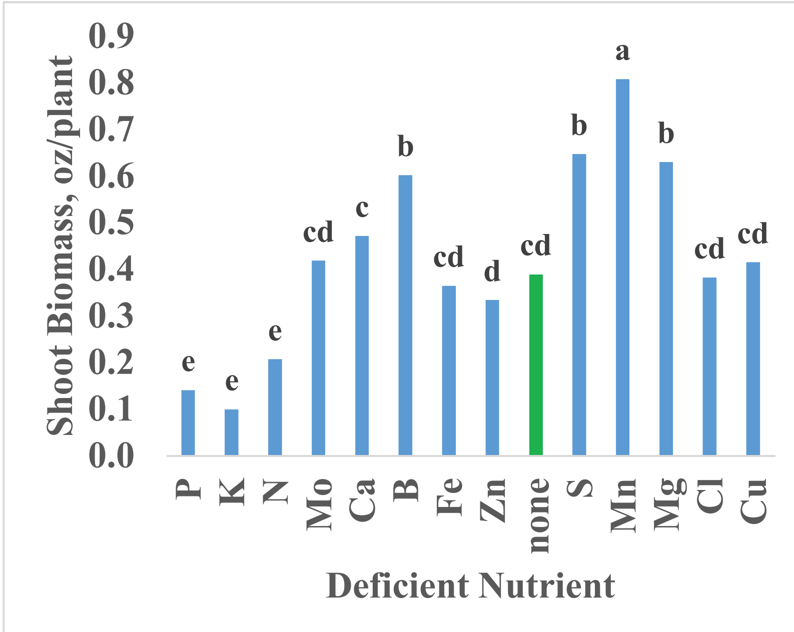

Fig. 5. Average shoot biomass at 56 days after planting in a nutrient deficiency study. Each bar represents a different targeted nutrient deficiency compared to the positive control ("none" of the nutrients were deficient). Data sharing the same letter above the bar are not statistically different from one another. (*P* = 0.05)

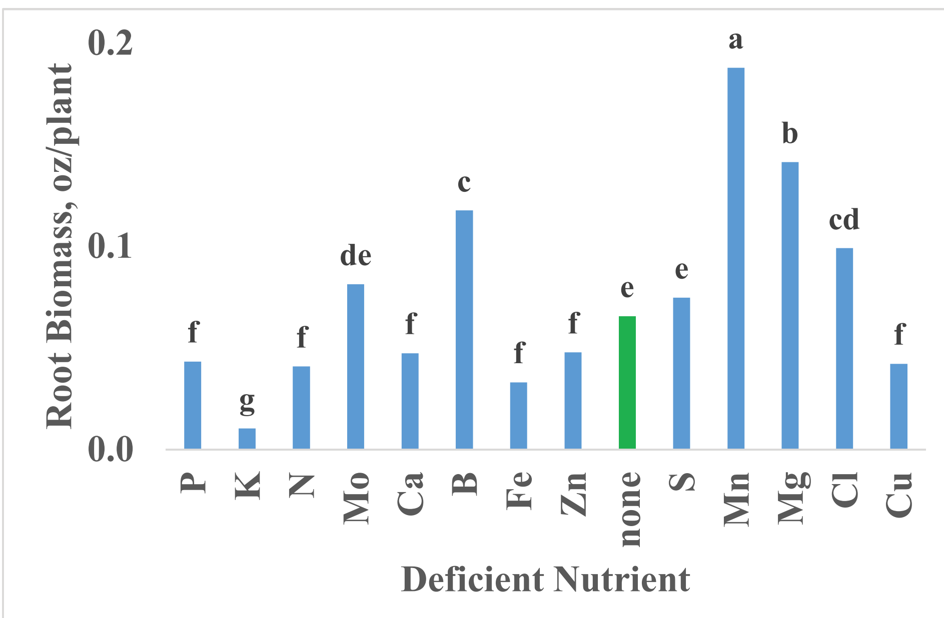

Fig. 6. Average root biomass at 56 days after planting in a nutrient deficiency study. Each bar represents a different targeted nutrient deficiency compared to the positive control ("none" of the nutrients were deficient). Data sharing the same letter above the bar are not statistically different from one another. (*P* = 0.05)

Table 2. Shoot macronutrient concentrations

Treatment (Deficient Nutrient)	N	P	K	S	Ca	Mg
None (control)	4.3	0.4	3.0	0.4	1.3	0.5
N	2.8	0.9	5.1	0.2	1.5	1.1
P	6.1	0.2	6.2	0.5	2.1	1.4
K	7.4	1.1	2.3	0.6	2.6	1.4
B	5.4	0.7	4.8	0.4	2.9	1.0
S	3.6	0.5	4.0	0.1	1.9	0.5
Ca	5.0	0.5	3.5	0.3	0.5	0.6
Mg	6.3	1.2	7.5	0.5	2.4	0.3
Cu	5.8	0.7	7.8	0.5	1.6	1.2
Zn	6.6	1.6	5.9	0.5	1.9	1.2
Mn	4.0	0.5	3.0	0.5	2.5	0.6
Fe	5.1	0.4	4.9	0.3	2.0	0.8
Average	5.2	0.7	4.8	0.4	1.9	0.9

Table 3. Shoot micronutrient and sodium (Na) concentrations

Treatment (Deficient Nutrient)	Zn	Mn	Fe	Cu	B	Na
None (control)	41	102	120	5	80	58
N	36	103	88	6	84	50
P	72	158	93	12	114	100
K	61	338	129	12	126	312
B	60	160	76	7	36	67
S	33	48	45	7	115	66
Ca	28	115	71	3	130	44
Mg	50	267	299	7	207	68
Cu	50	169	91	2	115	169
Zn	11	226	99	8	105	143
Mn	47	20	106	5	117	31
Fe	27	105	63	5	77	251
Average	43	151	107	7	107	113

In particular, the B levels in the shoot tissues were very high and above those that would be typically observed in plant tissue with levels ~10-fold higher than expected (Mills and Jones, 1996. Some of the N, P, K, S, Ca, Mg, and Mn concentrations for the treatments where they were not supposed to be deficient were also high. Additionally, future tests will also need to include a buffer to the solution to maintain pH. The initial pH values were all alkaline (7.6-8.3 for all but Ca, which was 7.2). The pH was allowed to drift naturally, with most dropping slightly to near neutral (6.8-7.6), with Ca being the drastic exception with it dropping to being acidic (4.1). The small differences in pH were acceptable for most of the treatments, but likely had a major impact on both the solution chemistry and the root physiology for the Ca deficient treatment.

Visual symptoms were also evident, although the results are somewhat convoluted given the possible toxicities referred to above. But, certainly the N, P, and K were deficient, as evidenced by the consistently poor growth in all measured parameters (Figs. 3-6). Typical chlorosis was observed in the leaves (Fig. 7).

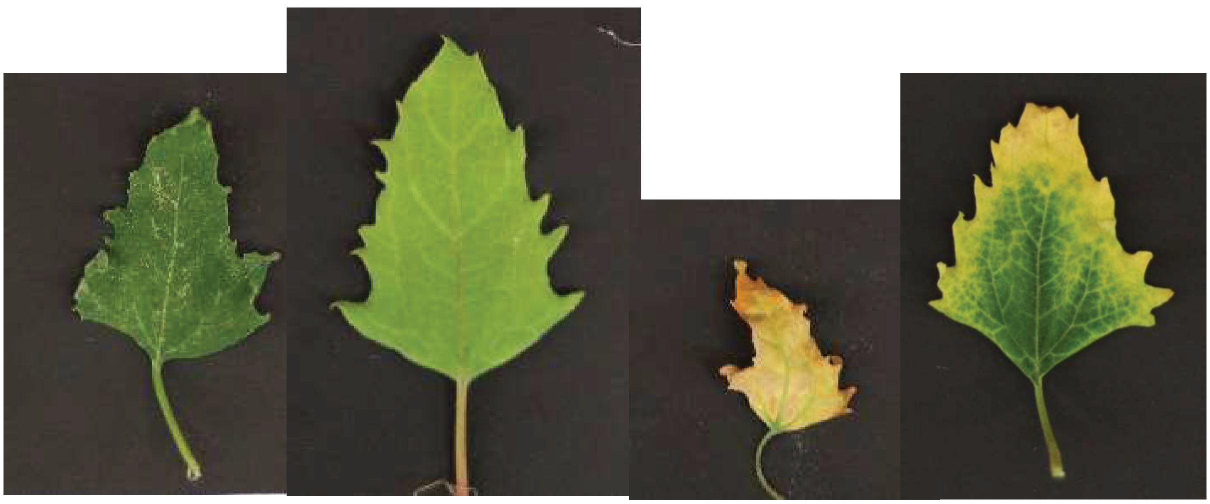

Fig. 7. From left to right: healthy leaf from the positive control, N deficient leaf, K deficient leaf, typical chlorosis observed (likely K deficiency) in many of the treatments

A visual comparison of the entire shoots shows the positive control to be mostly healthy and tall, although it appeared to have some K deficiency with lower leaves showing chlorosis on the leaf margins (fig 8). The plant tissue is also relatively low in K concentration. However, we suspect some significant nutrient interactions that are not clearly identified at this time.

Fig. 8. From left to right: No intended nutrient deficiency (positive control treatment), N deficient treatment, P deficient treatment, K deficient treatment

SUMMARY

While there is still more research that needs to be performed, this new hydroponic nutrient solution was mostly successful at growing plants to maturity and creating several nutrient deficiencies in quinoa. Nutrient concentrations, especially B and Mn, will be lowered in further testing to prevent possible toxicities as this solution is refined. Some visual symptoms have been created in quinoa using this hydroponic solution and can be a tool in creating important reference material for farmers to aid them in producing higher yields with high quality quinoa grain.

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P17

Evaluation of Nitrogen Fertilization and Drip Irrigation Levels on Yields of San Joaquin Valley, California, Forage Corn and Sorghum Cultivars

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ABSTRACT

In California (CA), approximately 500,000 acres of corn are grown annually, with most grown for dairy forage. Under reduced irrigation water (IW) supply conditions, forage sorghum acreage can increase to 90,000 acres annually. Corn nitrogen (N) demand is well documented in studies conducted outside of CA, but little research on forage corn and sorghum N use efficiency (NUE) under varying levels of IW has been conducted. With such a large statewide acreage, it is important to improve our understanding of corn and sorghum NUE, especially as state water quality regulations targeting nitrate pollution of groundwater are increasingly restrictive of inefficient applications of N. Thus, we aimed to improve knowledge of how a range of forage corn and sorghum cultivars perform under combinations of low to high supplies of N and IW. Our research objectives were: (1) determine forage corn and sorghum cultivar yield responses to irrigation water amounts ranging approximately 60 to 100% of estimated corn evapotranspiration; and (2) evaluate yield responses within each irrigation level to N fertilizer applications ranging from zero to full estimated N requirements across years and cultivars. From 2016 to 2018, we conducted a subsurface drip (SDI) irrigated field study at the University of CA Westside Research and Extension Center in Five Points, CA, in a clay loam soil to evaluate forage corn and sorghum yield response to varying levels of IW and N fertigation. Plot sizes were four rows (thirty inch spacing) wide by forty feet. The experimental design was a split-split-plot full factorial randomized complete block with three replications. Four sorghum cultivars representing mid to late relative maturity (RM) and grain and forage types as well as two corn cultivars representing early to late RM – were planted. Three IW levels – deficit for sorghum, deficit for corn, and sufficient for corn – were applied by applying a fraction of full evapotranspiration demand of forage corn in each irrigation. Three N levels – zero N applied, sufficient for sorghum, and sufficient for corn – were injected into the SDI system in split applications throughout the growing seasons to match crop uptake. At harvest, two rows were chopped and weighed with a small-plot harvester, and sub-samples were collected for measuring dry matter (DM) percent to normalize yields on a 35% DM basis. Crop year, IW level, N level, and cultivar all had significant main effects on yield ($p < 0.01$). While overall interactions between IW and N levels across all cultivars were not significant, cultivar did significantly interact with IW and N levels ($p < 0.01$). It is likely that year significantly impacted yield results due to higher residual soil N at the beginning of 2016. Across irrigation levels and years, corn peak yields generally occurred with highest N applied in the moderate and high irrigation treatments, while in sorghum, most yields peaked at the intermediate N application level. . These results will assist growers to make informed decisions about which forage corn and sorghum cultivars to plant when either IW and/or N will be limiting or sufficient.

Dry Bean Production in California

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ABSTRACT

There are four species and eight market classes of dry beans grown in California. These include lima beans (baby and large, *Phaseolus lunatus*), common beans (kidney, pink, white, cranberry, black turtle, P. *vulgaris*), blackeye (cowpea, *Vigna unguiculata*), and garbanzo beans (chickpea, *Cicer arietinum*). Dry beans are an important specialty market for California. In 2017, growers harvested 50,000 acres of dry beans valued at $60 million. Lima beans accounted for about 50% of this total acreage, with California producing nearly 99 percent of the U.S. domestic supply of dry lima beans. Garbanzos accounted for 20% of this acreage, with the beans going for canning or dry packaged markets. Blackeyes accounted for about 22% of acreage, with the rest of the acreage for common beans, with kidney beans primarily going for the dry packaged and canning markets. While dry beans fix some of their nitrogen needs, research in California documented that a modest amount of nitrogen is still needed for sustaining high crop yields, along with phosphorus and zinc. University of California Agriculture and Natural Resources (UC ANR) production manuals for growing dry beans grown in California provide recommendations for nutrient management in dry bean production. These include Garbanzo beans (chickpeas), UC ANR publication no. 8634 by Long et al. 2019; lima beans, UC ANR publication no. 8505 by Long et al. 2014; and common beans, UC ANR publication 8402 by Long et al. 2010. Recommendations for fertility in the dry bean production manuals are provided for furrow-irrigated fields as well as for sub-surface drip systems, where nutrients are applied through fertigation, with rates depending on background residual nitrogen in the soil as well as irrigation water. The information provided in these manuals will help growers comply with required nutrient management plans when growing dry beans in California, as well as to sustain profitable yields with minimal inputs. Dry beans are a healthy food choice and are important in rotational field crop production to help with insect, disease, and weed control.

P19

Developing Practical Phosphorus and Potassium Tissue Test Recommendations and Utilizing Struvite in Modern Alfalfa Systems

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ABSTRACT:

Tissue testing whole alfalfa plants at harvest provides opportunities to direct nutrient decision making more accurately. Critical levels developed allow in-season recommendations and applications and would save producers time and effort since growers are already taking samples for hay quality. Three experiments were designed including: P Study with differing rates of P_2O_5 using monoammonium phosphate (MAP); including: 0, 30, 60, 120, 240 lbs./acre on an 8.1 ppm P soil (Olson P method); K Study: differing rates of K_2O using potassium sulfate: 0, 40, 80, 160, 240, 320 lbs. K_2O/acre; Struvite Study (magnesium ammonium phosphate, $MgNH_4PO_4 \cdot 6\ H_2O$)- application at 144 lbs. of P_2O_5 /acre in differing ratios of MAP / Struvite in alfalfa including: 100:0, 75:25, 50:50, 37.5:62.5, 25:75, 12.5: 87.5, 0:100 and an unfertilized check. Results from the P Study showed that 140 and 165 lb/acre P_2O_5 maximized gross revenue after fertilizer costs for $150 and $200/ton alfalfa, respectively. Optimum phosphorus alfalfa tissue concentration was 0.24-0.25 for first cut, 0.28 - 0.29 for second cut, and 0.26-0.27 for third cut for alfalfa hay price of $150 and $200 per ton respectively. Applications of P_2O_5 decreased hay quality via increased aNDF, lignin, and decreased non fiber carbohydrates, there by emphasizing the need for

precision nutrient management to maximize profit. The K Study started with a 101, 74, and 80 ppm potassium in the soil at 0-12, 12-24 and 24-36 inch depths (ammonium acetate method) which interestingly did not provide a yield response. Replacing or supplementing MAP with struvite had no effect on first cut or first year yield or phosphorus content. The Struvite study showed that even under very low phosphorus situations, MAP could be replaced with struvite on a P_2O_5 basis with no impact on yield or phosphorus content in the hay.

INTRODUCTION:

Most inorganic phosphorus (P) fertilizers are derived from phosphate rock, where 98% of the reserves are in other countries; with the USA only holding 2% (Stewart 2002, USGS 2013). Dairy farms accumulate P through manure and each farm has a unique need for P outlets and removal to reach a whole farm P nutrient balance (WA Dept. of Ecology). In contrast, alfalfa (*Medicago* sativa) producers need to reverse the trend of declining soil test P content to maintain high crop yield and quality. To compound the problem, just a few years ago the price of commercial P fertilizers soared to record high prices, and will likely to do so again as reserves diminish and struggle to accommodate increasing demand. A viable solution is the adoption of technology to capture P from liquid manure in the form of 'struvite', a slow release form of P based fertilizer. Current PNW struvite NPK fertilizer has an analysis of (6 – 29 – 0) including 16% magnesium. Struvite is easy to handle and transport due to its low moisture content, and has a sand-like appearance. More research is needed in the use of struvite in alfalfa and would supplement the efforts of a recent federal USDA -NRCS-CIG grant titled "Mobile System for Nutrient (Phosphorus) Recovery and Cost Efficient Nutrient Transport".

With high P and K fertilizer costs it is important to apply required nutrients calibrated to one foot soil tests. Alfalfa plants can remove potassium and other nutrients from much deeper depths creating disproportional inaccuracy crop response and soil test results. Tissue testing provides the opportunity to direct nutrient decision making based on accurate critical levels for in-season recommendations that could include possible applications between cuttings or through fertigation. California scientists have developed the alfalfa tissue testing protocols; however producers are not adopting them because the test uses the middle third of alfalfa at one-tenth bloom for P & K (Meyer et al., 2008). One-tenth bloom is well past dairy quality hay stages for most PNW producers, making this California recommendation impractical. Alfalfa tissue testing has been proposed in New Mexico, which recommended a wide range from 2.0 to 3.5% K in the upper ⅓ of the plant at early bloom (Flynn et al., 1999). The current PNW alfalfa fertilizer guide states a critical level of 2.0 to 2.5% for the whole plant at first bloom but needs further refinement (Koenig et al., 1999). Research conducted in Israel suggests maximum alfalfa yield K levels should remain above 2.5% at harvest (Kafkafi et al., 1977). This research and others reveal P & K concentrations decline with crop maturity indicating the importance of the timing of tissue testing.

Fertilizer is the largest single expense in an irrigated alfalfa budget for the western U.S. Even at modest rates, fertilizer can easily reach over $216 per acre with P & K being the largest component (Norberg and Neibergs, 2014). More K is removed from the soil by alfalfa than any other nutrient (Koenig and Barnhill, 2006). Alfalfa can remove 8 lb.P_2O_5 and 54 lb. K_2O per ton of alfalfa produced (Koenig, et al., 2009), which for yields of 10 tons per acre attainable by excellent producers in the PNW, result in 80 lb.P_2O_5 and 540 pounds K_2O removable per acre per year. We are proposing to use the harvest time of mid to late bud stage (typical harvest timing for first cutting) and use the whole plant which could be taken at the same time and using the same method currently being used for quality analysis. We have selected first cutting, the one most desired by the dairy industry and because it's the most likely cutting to be nutrient limiting due to cold soils, but we are proposing to test all alfalfa cuttings. Struvite provides a slow release option we believe would work best in combinations with faster release forms such as mono-ammonium phosphate (MAP).

Research was conducted near Prosser, Washington on a low phosphorus testing soil 8.1 ppm (Olson method) and 90 ppm potassium soil (ammonium acetate method) to: 1) Develop and calibrate phosphorus (P_2O_5; P Study) & potassium (K_2O; K Study) nutrient recommendations for bud stage alfalfa using tissue testing for maximum profit, yield and direct comparison to current soil testing recommendations; 2) Compare efficacy of combinations of MAP and struvite (Struvite Study; magnesium ammonium phosphate, $MgNH_4PO_4 \cdot 6\ H_2O$) for fertilization of alfalfa; 3) Evaluate quality of hay samples at different P and K rates and tissue concentrations.

MATERIALS AND METHODS:

We established three experiments with two with a low P soil test field (Phosphorus Rate & Struvite"and one on a low K soil test field (Potassium Rate). Studies were in a randomized complete block design with four replications at establishment of a spring stand of alfalfa and harvested 3 times in 2018. Fertilizer was applied at the beginning of the study once and incorporated with tillage. The experiments' treatments and descriptions are listed below.

"Phosphorus rate" – Studying the influence of rates of P_2O_5 of MAP; including: 0, 30, 60, 120, 240 lb/acre to develop\refine tissue testing recommendations for P.

"Potassium Rate" - Response of alfalfa to six differing rates of Potassium Sulfate: 0, 40, 80, 160, 240, 320 lb K_2O/acre to develop\refine tissue testing recommendations for K.

"Struvite" - Alfalfa response to six mixtures of MAP:Struvite in alfalfa: 0:0 100:0, 75:25, 50:50, 37.5:62.5, 25:75, 12.5: 87.5 0:100; to determine if any quick release P is needed to supplement the slower release of P in struvite for spring planted alfalfa.

Sturvite and MAP was applied according to treatments desired with a Gandy drop spreader after calibration.

Tissue samples were analyzed for P & K by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP). Yield results were compared to P & K concentrations to determine critical values required for maximum yield and economic returns. Calibration of P & K shortages compared to optimum rate at harvest along with P & K concentrations of tissue samples pulled to determine appropriate fertilizer recommendations for each cutting or averaged over cuttings if similar results are found.

To determine the maturity at harvest we used the maturity ratings of Muller and Teuber (2007) where: "growth stage 2" is late vegetative stage when stem length is greater than 12 inches; no visible buds, flower or seed pods; "growth stage 3" is early bud when 1-2 nodes have visible buds and have no flowers or seed pods and "growth stage 4" is late bud when ≥ 3 nodes have visible buds, with no flowers or seed pods. "Growth stage 5" early Flower is when one node with open flower; no seed pods. "growth stage 6" late flower when ≥ 2 nodes with open flowers; no seed pods. Growth stage of ten stems was determined and average growth stage of the plot calculated.

Plots for the experiment were harvested with a flail harvester (Carter Manufacturing) for 33 inches wide and 25 foot long. Subsamples were taken weighed, dried and weighted again for harvest moisture and dry matter yield determination.

These experiments determined how P & K status affects feed quality and value as stated in objective 3. To accomplish this at each harvest, whole plant samples were collected from each treatment plot at bud stage. All harvested samples were dried at in forced air ovens at $60^{o}C$ until no weight loss occurred. Samples were ground through a Wiley Mill (Thomas Scientific, Swedesboro, NJ) to 2 mm in length, then ground with Udy Cyclone Sample Mill (Udy Corporation, Fort Collins, CO) to 1 mm before scanning and prediction for DM, CP, ADF, NDF, ash, starch, fat and TDN by FOSS 6500 Near Infrared Reflectance Spectroscopy (NIRS) using 20 percent of samples for wet lab validation by the methods of Shenk et.al., 1989 (NIRS Consortium).

Ground samples were utilized for both nutrient and forage quality analysis. Total digestible nutrients (TDN) and relative forage quality (RFQ) were estimated from the values obtained from the wet chemistry analysis.

Plots for the experiment were harvested with a flail harvester (Carter Manufacturing) for 33 inches wide and 25 foot long. Subsamples were taken and dried for harvest moisture and dry matter yield determined.

Statistical analysis was run in SAS using Proc GLM. A covariate (growth stage) was used in the struvite experiment to eliminate any affect on the quality parameters.

RESULTS AND DISCUSSION:

Phosphorus Rate Experiment:

A visual difference was apparent between the plots with no application of phosphorus and soil containing 8.2 ppm P and the plots fertilized with 240 lb/acre of P_2O_5 of monoammonium phosphate (MAP ; Figure 1.). Yield increased from 1.67 to 2.0 tons of dry matter/acre first cutting (Contrast linear $P<0.0010$) and from 5.7 to 6.4 tons/acre for the first year by applying 120 lb/acre P_2O_5, a difference of 0.33 and 0.69 tons acre, for first cut and first year, respectively. Almost half of the yield increase due to phosphorus occurred during the first cutting when the soil is cooler making phosphorus less available. Economic analysis of gross revenue after fertilizer cost (GRAFC) showed that the optimum rate of P_2O_5 was 140 and 165 lb P_2O_5 / acre, assuming $560 / ton of MAP ($0.538 /lb of P_2O_5), and an alfalfa hay priced at 150 and 200 $/ton of alfalfa hay, respectively (Figure 3). These rates correspond to phosphorus alfalfa hay levels of 0.24-0.25%for first cut, 0.28 - 0.29% for second cut, and 0.26-0.27 for third cut for alfalfa hay price of $150 and $200 per ton, respectively. Alfalfa tissue phosphorus concentration decreases with maturity and critical values for whole plants or hayed samples at the early-bud stage should be 30 and 12 percent higher than values for 10 percent bloom alfalfa for bud and late bud stages, respectively (Orloff et. al, 2012). Thus the numbers we found 0.24-0.29% minus 30% would result in 0.17 to 0.2% which most current publications consider deficient (Koenig, 2009).

Quality of alfalfa was significantly affected by rate of P_2O_5 in many parameters including: aNDF, lignin, and non-fiber carbohydrates (NFC), which influenced relative feed value and relative feed quality and nutrient value per ton (St- Pierre and Weiss method) (Table 1. and Figure 4.). Increased yield with phosphorus application more than offset the lost revenue per ton and the highest per acre value for 2018 was with the 120 lb P_2O_5 /acre rate. Changes in aNDF appear to be very closely related to lignin changes as the percentages closely follow each other with increasing phosphorus rate (Figure 5.). Phosphorus is important for bud formation and may have increased stem to leaf ratio in the hay and yield. Maturity of the alfalfa was not significant in the analysis by increasing phosphorus rate but exhibited a similar pattern to lignin content (Figure 6.) and we know that as the plant matures more lignin is formed so some quality loss could be due to advanced maturity in higher phosphorus rate plots. These results show that for long term sustainability and profitability fertilizing precision is required to maximize alfalfa quality.

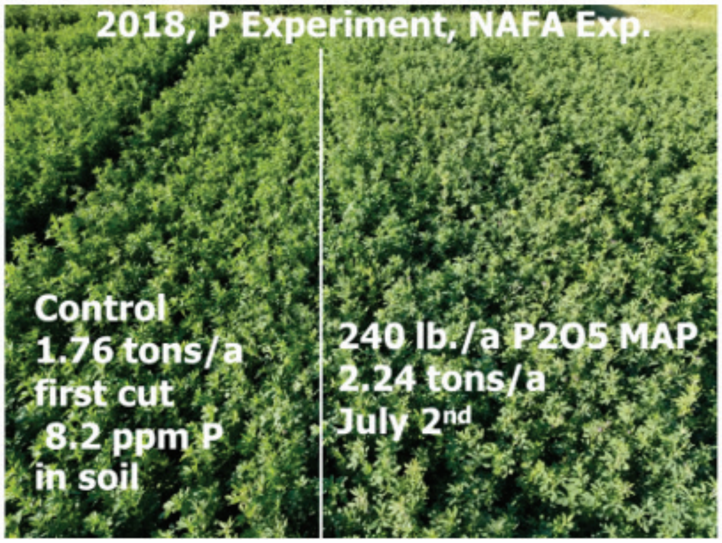

Figure 1. Field views in the Phosphorus Rate Study between the control and 240 lb / acre treatment on July 2, 2018 at Prosser, WA in a soil with a beginning P concentration of 8.2 ppm.

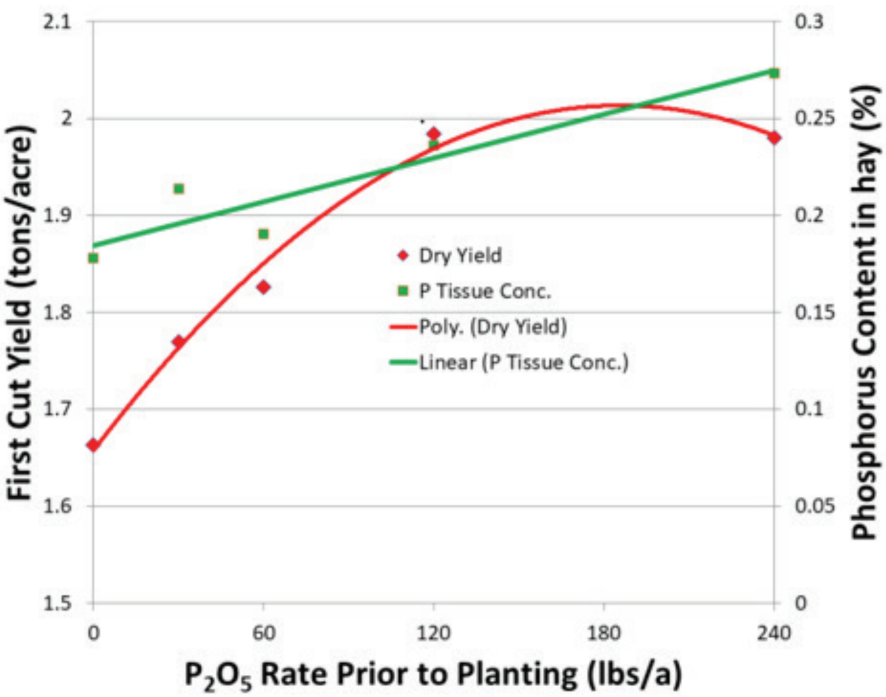

Figure 2. Phosphorus rate influence on first cutting yield and phosphorus content in the alfalfa hay at harvest.

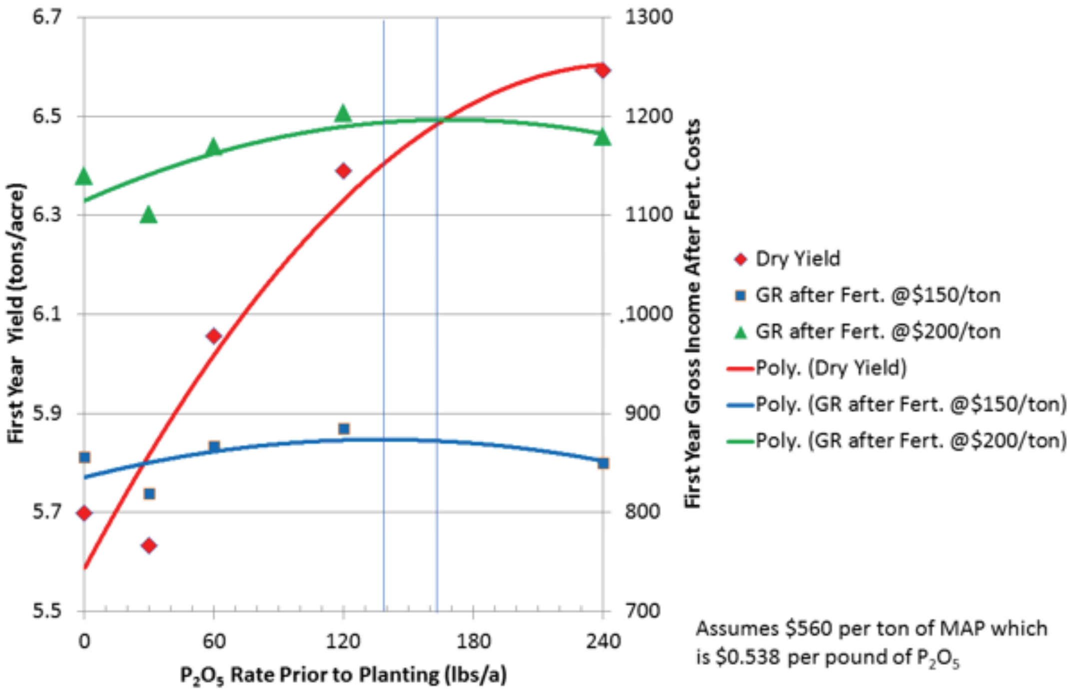

Figure 3. Economic analysis of gross revenue after fertilizer cost showed that the optimum rate of P_2O_5 was 140 and 165 lb P_2O_5 / acre which maximized gross revenue (GR) minus fertilizer cost assuming $560 / ton of MAP ($0.538 /lb of P_2O_5) and an alfalfa hay price of 150 and 200 $/ton of alfalfa hay, respectively.

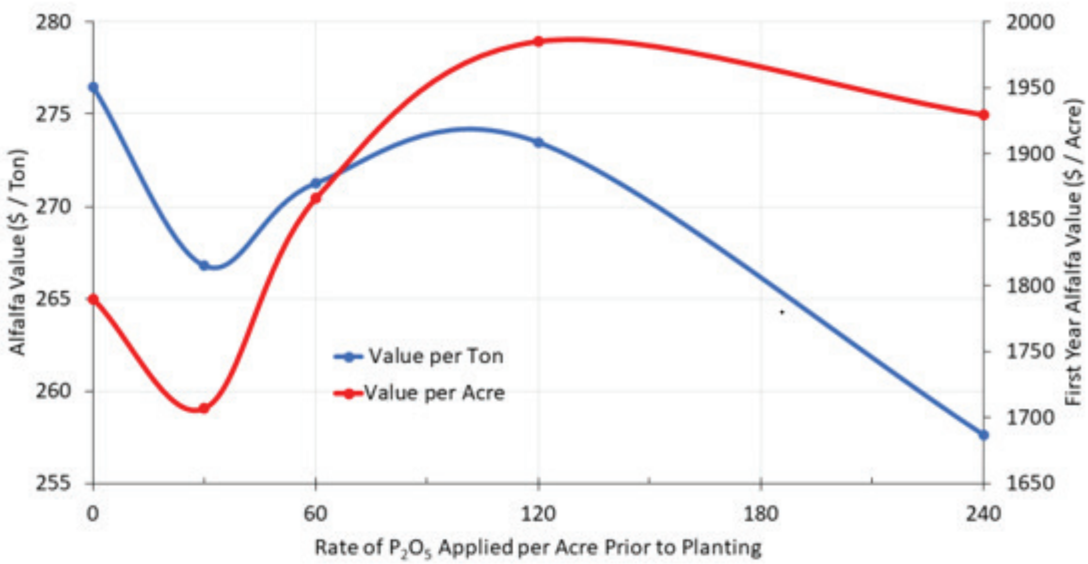

Figure 4. Influence of phosphorus rate on the nutrient value of alfalfa value per ton (St- Pierre and Weiss method) and per acre for the 2018 season.

Table 1. Quality parameters including neutral detergent fiber (aNDF), lignin, non-fiber charbohydrates (NFC), relative feed value (RFV), relative feed quality (RFQ), nutrient value per ton and per acre as influenced by rate of P_2O_5 per acre. Nutrient value was calculated using method described by St- Pierre and Weiss, 2011.

	aNDF	**Lignin**	**NFC**	**RFV**	**RFQ**	**Nutrient Value**	**Nutrient Value First Yr.**
P_2O_5 Rate/Acre	**%**	**%**	**%**	**unit**	**%**	**$ / Ton**	**$ /Acre**
0	34.92	5.72	34.70	171.54	182.53	276.47	1788.89
30	36.29	5.92	33.74	162.97	172.39	266.79	1709.19
60	35.57	5.80	34.77	167.74	176.27	271.26	1865.95
120	35.52	5.82	34.30	168.58	179.35	273.48	1985.46
240	37.73	6.25	33.14	155.59	164.38	257.61	1928.84
LSD	1.75	0.30	1.20	10.54	12.15	13.14	234.615
CV	5.89	6.2	4.3	7.7	8.4	5.9	15.34585
ANOVA Rate (P< Value)	0.0251	0.0103	0.0453	0.0354	0.0425	0.0534	NS
Contrast Rate Linear (P<Value)	0.006	0.002	0.0217	0.011	0.016	0.016	0.0667

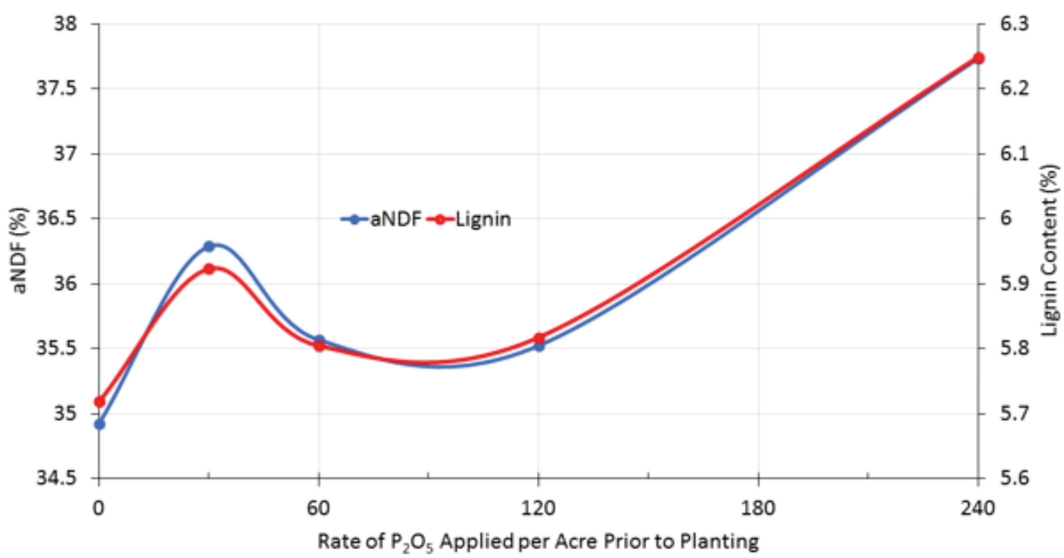

Figure 5. Influence of phosphorus rate on average aNDF and lignin content in the alfalfa hay at harvest. As phosphorus rate increased lignin increased very closely to aNDF.

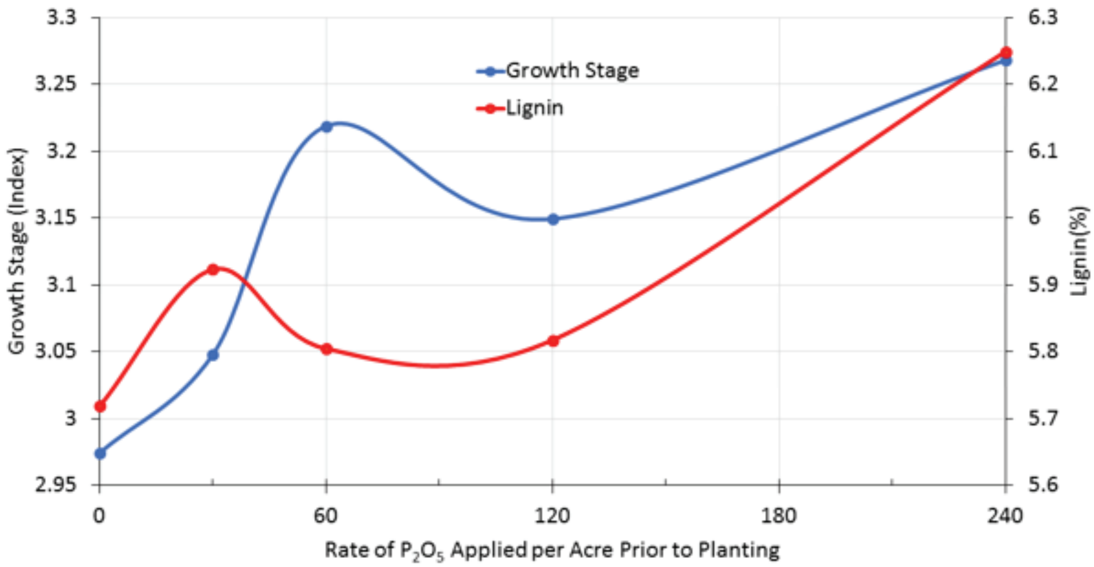

Figure 6. Influence of phosphorus rate on average growth stage index and lignin content in the alfalfa hay at harvest. Similar response only peaks at later than lignin.

Potassium Rate Experiment:

The experiment started with soil depths of 0-12, 12-24 and 24-36 inch containing 101, 73 and 79 ppm potassium in the soil (ammonium acetate method), respectively. Alfalfa yields were not responsive to fertilizer K applications (Figure 7). Potassium content without fertilizer applied averaged over cuttings 1.5 percent potassium and linearly increased as potassium rate was increased (Figure 7), commonly known as luxury consumption. The 1.5% tissue concentration of whole tops and no yield reduction conflict with current PNW recommendations of a critical concentration for sufficiency of 2.0 – 2.5 % at first bloom (PNW0611 Guide). Our cuttings were at growth stage 3.4, 3.2 and 2.5 for cuts one, two and three, respectively which is early bud for first two cuttings and late vegetative stage for the third cut. Orloff et.al, 2012 in California found that potassium tissue values for early-bud stage alfalfa and late-bud stage alfalfa should be about 20 and 12 percent higher than for 10 percent bloom alfalfa, respectively. Our research using their method would have a 1.2% potassium which does correspond with sufficiency with University of California recommendations (Meyer et. al, 2007). Further research is needed to determine the critical level of potassium at bud stage as yield was not limiting. Excess potassium applications are unprofitable both from fertilizer cost and decreased quality of hay. The 240 lb K_2O treatment pulled 308 lb K from the soil and was 155% of potassium removed from the unfertilized control. Current PNW soil testing recommendation would have been 100 lb K_2O /acre and according to our regression line would have resulted in a tissue concentration of 1.8% potassium. The K_2O treatment 240 lb/acre had a negative influence on hay quality and decreased RFV and RFQ and increased lignin (data not shown).

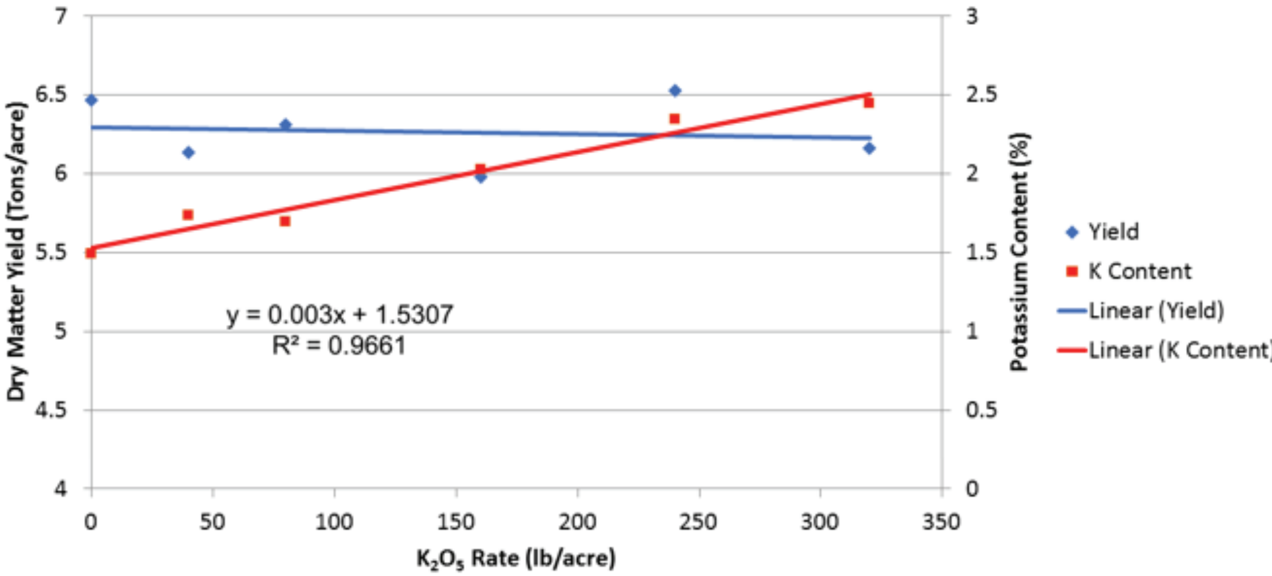

Figure 7. Potassium rate influence on potassium content of alfalfa forage at harvest in 2018. Potassium content is a typical of luxury consumption of this nutrient.

Struvite Experiment:

Yield and phosphorus content of alfalfa was not affected by replacing MAP with struvite during first cutting or first year on this very low P testing soil having 10.8, 5.7, 3.7 ppm P in the top 0-12, 12-24, and 24-36 inch depths (Figure 8 and 9). The only quality parameter that was significant was fat content in the forage (Table2). Further research needs to determine if this occurs consistently.

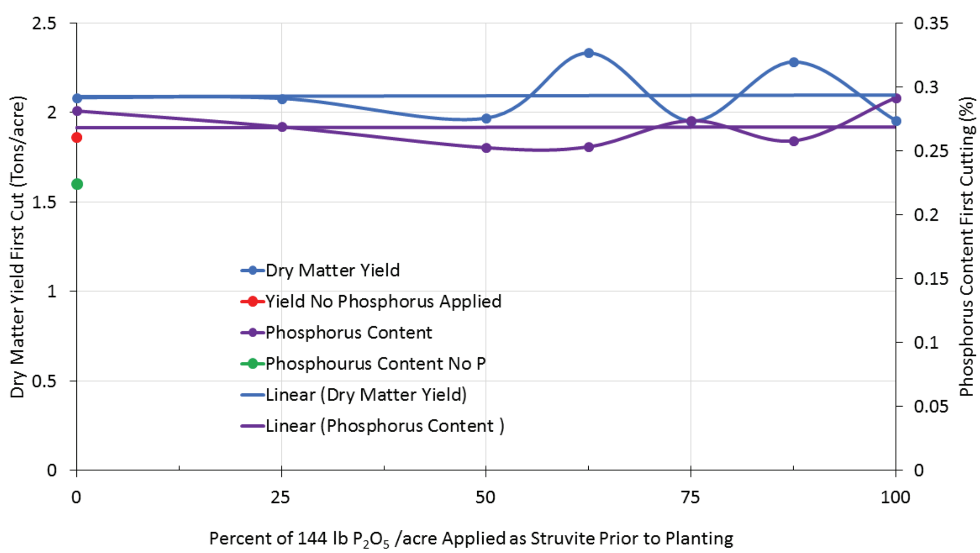

Figure 8. First cutting yield and phosphorus content as influenced by struvite replacing monoammonium phosphate (MAP) at a single rate of 144 lb P_2O_5 per acre (recommended rate for this low phosphorus soil.

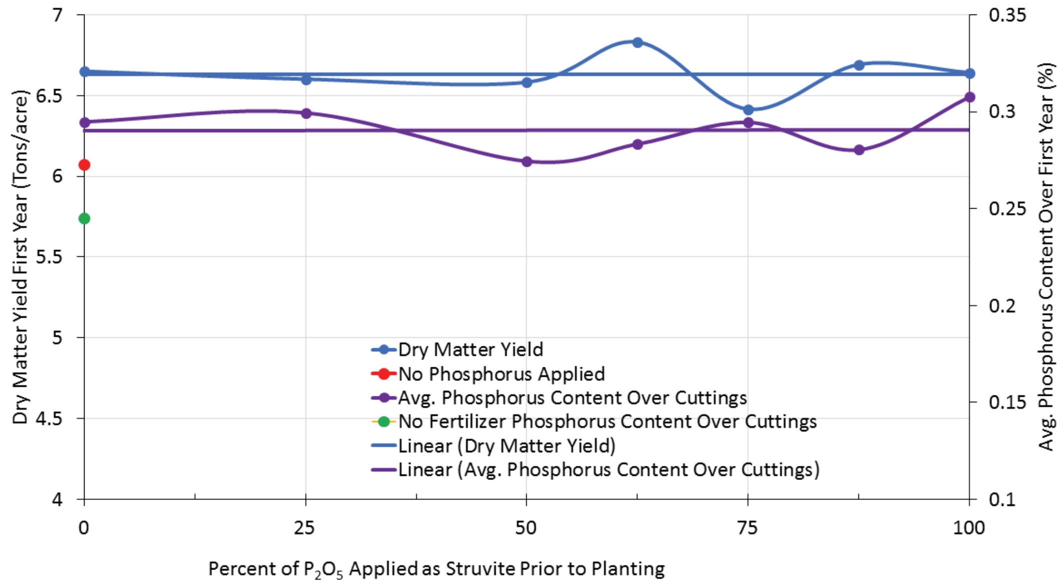

Figure 9. First year total yield and average phosphorus content as influenced by struvite replacing monoammonium phosphate (MAP) at a single rate of 144 lb P_2O_5 per acre (recommended rate for this low phosphorus soil).

Table 2. Fat in the harvested forage was influenced as MAP was replaced with struvite.

Phosphorus Source	**Fat**
Struvite Percent	**%**
0	2.23
25	2.19
50	2.28
62.5	2.17
75	2.22
87.5	2.17
100	2.12
CV	4.2
ANOVA Rate (P<Value)	0.0051
Contrast Rate Linear (P<Value)	0.0122
Contrast Rate Quadratic (P<Value)	0.0397

Summary from The First Year:

- Optimum P alfalfa tissue phosphorus content based on first year of the experiment should be between 0.24-0.28 and 0.25-0.29 when the alfalfa hay price of $150 and $200 per ton, respectively.
- First year data show that struvite can be used alone or in combination with monoammonium phosphate (MAP) when put on prior to planting and incorporated without a yield loss even on a soil averaging 8.1 ppm (Olson Method).
- Excessive phosphorus of potassium has a negative influence on hay quality and can affect aNDF, lignin, RFV, RFQ, and nutrient value of hay ($/ton).

Acknowledgements:

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Interpreting Compost Analyses

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ABSTRACT

This outreach publication is designed for wholesale buyers of compost for resale, nursery managers, public/private landscape managers, farm advisors, and farmers. The publication provides guidance on how to select a laboratory, based on intended compost end use (field application vs. potting soil). Interpretations are provided for laboratory tests available from commercial laboratories, including chemical tests (pH, soluble salt, macro- and micro-nutrients), physical tests (bulk density, particle size) and biological tests (organic carbon, compost maturity and stability). The reproducibility of compost testing methods is discussed, using data from an international compost proficiency testing program.

Download the publication at eesc.extension.oregonstate.edu.