WERA-103

Nutrient Management and Water Quality

WESTERN NUTRIENT MANAGEMENT CONFERENCE

PROCEEDINGS

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Table of Contents

Oral Proceedings

Poster Proceedings

WESTERN NUTRIENT MANAGEMENT CONFERENCE

ORAL PROCEEDINGS

THE AMMONIA RAINBOW

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ABSTRACT

Ammonia is a critical agricultural input either for direct soil application or as a precursor for other nitrogen and phosphorus fertilizers. Most of the world's ammonia supply is produced using the standard Haber-Bosch ammonia synthesis process and uses natural gas as a source of hydrogen and the energy for the reaction. Haber-Bosch ammonia synthesis has come under criticism for the significant carbon footprint from the use of natural gas as a feedstock. The development of hydrogen as a zero-carbon fuel and ammonia as a hydrogen carrier in these fuel systems has increased interest in alternative ammonia synthesis processes targeting reduced carbon footprint and the use of renewable energy sources.

An ammonia "color palette" has been developed around these ammonia synthesis methods to distinguish the processes and carbon intensity. The most commonly mentioned "colors" are "grey" ammonia made by the traditional Haber-Bosch process, "blue" ammonia made by Haber-Bosch synthesis but employing carbon capture and storage, and "green" ammonia produced by water electrolysis using zero-carbon renewable energy.

The Ammonia Color Palette			
Type	Method	Carbon Intensity	Notes
Brown/ Black	Coal gasification to produce H_2, CO and CO_2. H_2 is separated.	Very high CO_2 emitted; CO release; high energy use	primarily China, least desirable
Grey	Steam reforming natural gas into H_2 + O_2	high CO_2 emitted, high energy use	most prevalent, 96% of global production
Blue	Steam reforming natural gas into H_2 & CO_2 followed by carbon capture and storage or reuse	Potential for lower carbon; 10-20% CO_2 not captured	CCS value is uncertain*
Green	Water electrolysis into H_2 + O_2 using renewable electricity source	Low/no CO_2 emission, higher energy use	Most desirable
Yellow	Water electrolysis into H_2 + O_2 using solar power or a mixture of renewable electricity sources	Low/no CO_2 emission, higher energy usage	Same as "green" ammonia but specifically uses solar energy
Turquoise	High temp methane (natural gas) pyrolysis into H_2 + solid carbon	Low/no CO_2 emission, higher energy usage	Experimental
Pink	Water electrolysis into H_2 + O_2 using nuclear power electricity	Low/no CO_2 emission, higher energy usage; hazard waste generation.	Nuclear not considered sustainable energy source by some.

There is great interest in low- or zero-carbon ammonia, but there are still questions about costs and technology development. Some technologies are still experimental; others are in the early stages of commercialization. Current cost estimates of green ammonia range from two to four times the cost of current Haber-Bosch production. It is expected costs should decrease as renewable energy sources become more available and their costs decrease but impacts on ammonia fertilizer prices remain uncertain. Some have proposed differential pricing schemes for fertilizer and fuel, but this seems impractical. The impacts of competing demands for ammonia as fuel and as fertilizer are not yet defined but could be at cross purposes in maintaining economical fertilizer supplies.

There are questions about the true carbon savings of carbon capture and storage (CCS; Howarth and Jacobsen, 2021). The carbon footprint of this process will be directly related to the efficacy of CCS. Using ammonia as a hydrogen fuel source seems to be building momentum but the fate of the nitrogen is not clear. Some have suggested conversion of marine transport from traditional diesel fuel and other fuel oils to ammonia could increase global ammonia demand from the current demand of about 120 to 140 Tg/year to as much as almost 600 Tg/year. The environmental benefit of such a conversion would depend to large extent on the amount of leakage of reactive nitrogen from this system and combustion processes, which at present, seems a large risk (Wolfram et al, 2022).

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NITROGEN AVAILABILITY FROM ORGANIC AMENDMENTS

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ABSTRACT

Organic fertilizers and composts are valuable sources of nutrients. However, their nutrient availability is often not known and can be variable. How much nitrogen (N) becomes plant available depends on environmental factors, including temperature and soil moisture, as well as the properties of the decomposing organic material. In a previous study with different commercially available organic fertilizers and composts we found that carbon to N (C:N) ratio of the materials is a good measure to determine the availability of N. We also found that different batches of the same material can have quite variable properties and thus N mineralization capacities.

The objective of the present study was to collect net N turnover data from peer-reviewed articles and fit a model that simulates gross N mineralization and gross N immobilization to determine pool sizes and their rate constants of different materials commonly used in organic farming. We searched the scientific literature for studies where different amendments were incorporated into moist soil and found more than 100 datasets. Comparing the results from different studies is challenging because the protocols used differ widely in terms of temperature and duration. To overcome this challenge, we used a model that allowed us to determine N mineralization rates in these studies as if they all had been carried out for 100 days at a temperature of 77 °F.

The model predicted that 61 and 72.5% of total N in feather meal and guano, respectively, would be in the mineral form after 100 days under optimal soil moisture conditions. Nitrogen availability from poultry manure and poultry manure compost was lower. On average, 16–17% of total N was present as mineral N in the materials, whereas at the end of the 100-day simulation, 39.6 and 32.7% of total N from an average poultry manure and its compost, respectively, were in the mineral form. Yard waste compost and vermicompost are stable materials, with <10% of the total N in an average material being in the mineral form at the end of the 100-day simulation. Based on the results from our studies, we developed an interactive tool that allows users to estimate mineralization rates of incorporated organic amendments based on local soil temperatures and amendment properties. The tool is available online at http://geisseler.ucdavis.edu/Amendment_Calculator.html. In an ongoing project, we are now validating these results in field trials.

INTRODUCTION

Organic fertilizers and composts are valuable sources of nutrients. However, their nutrient availability is often not known and can be variable. When soil microorganisms decompose organic materials, they use some of the nitrogen (N) in these materials to produce protein and other cell components. When the materials contain excess N, the microorganisms release plant-available ammonium into soil solution. This process is called N mineralization. In contrast, most N in organic amendments is not directly plant-available. Therefore, N mineralization increases the pool of plant available N in the soil. How much N is mineralized depends on environmental factors, such as temperature and soil moisture, as well as the properties of the decomposing organic material. Especially the carbon to N (C:N) ratio has a strong effect on N mineralization.

We investigated the effects of the C:N ratio in a study where we mixed different commercially available organic fertilizers and composts with moist soil and kept the samples at 73 °F for 12 weeks (Lazicki et al., 2020). The results indicate that the C:N ratio is a good measure to determine the availability of N (Figure 1). Materials with a C:N ratio of 5 or less released 70% or more within 12 weeks. Examples of such materials are guano, feather meal or blood meal. In contrast, materials with a C:N ratio of about 17 or higher hardly mineralized N or even immobilized N from soil solution during the 12 weeks of incubation. Nitrogen immobilization reduces the pool of plant available N. We also found that different batches of the same material can have quite variable properties and thus N mineralization capacities.

The objective of the present study was to collect net N turnover data from peer-reviewed articles and fit a model that simulates gross N mineralization and gross N immobilization to determine pool sizes and their rate constants of different organic amendments commonly used in organic farming.

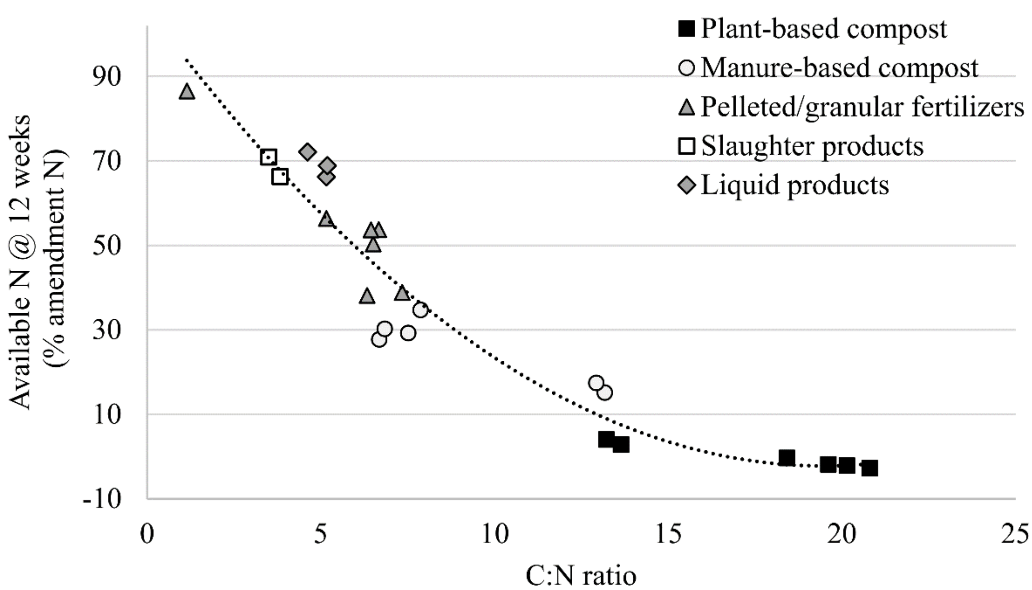

Figure 1: Relationship between amendment C:N ratio and the proportion of N in the mineral form after 12 weeks of incubation at 73 °F (Lazicki et al., 2020).

METHODS

We searched the scientific literature for studies where different materials were incorporated into moist soil and found more than 100 datasets (Table 1). We focused on laboratory studies conducted at a constant temperature and optimal soil moisture content. Comparing the results from different studies is challenging, because the protocols used differ widely in terms of temperature and duration. To overcome this challenge, we used a model that allowed us to determine N mineralization rates in these studies as if they all had been carried out for 100 days at a temperature of 77 °F.

Table 1. Characteristics of the materials included in our analysis (Geisseler et al., 2021).

Material	Datasets	C to N ratio		Initial mineral N
		Average	Range	(% of total N)
Guano	8	2.8	1.2 - 3.8	2.2 - 55.1
Feather meal	14	4.0	3.3 - 10	0 – 16
Poultry manure	29	10.3	6.3 - 19.5	3.3 - 36.8
Poultry manure compost	16	7.3	5.7 - 9.4	12.6 - 25.1
Vermicompost	21	11.1	14.9 - 35	1 - 17.8
Yard waste compost	25	16.1	9.1 - 22.3	0.1 - 8.4

RESULTS AND DISCUSSION

The results revealed that N from guano and feather meal becomes rapidly plant available (Figure 2). A slightly larger proportion of the total N in guano becomes plant available within 100 days of incorporation into warm and moist soil (70-75%) than for feather meal (50-65%). With both materials, most of the N is released within the first 20 days of the simulated incubation. Studies have shown that feather meal has a very similar N mineralization pattern to fish powder, while a slightly larger proportion of the N becomes available when blood meal is incorporated into soil.

The properties of poultry manure can be highly variable. In the 29 datasets included in our analysis, the C:N ratio ranged from 6.3 to 19.5. Some of the factors contributing to this variability among poultry manures are amount and type of bedding material, conditions during storage, processing (e.g. pelleting) and particle size. In our datasets, 16.3% of total N was on average present as mineral N in the material. At the end of the 100-day simulation period, between 24 and 47% were in the mineral form.

The poultry manure composts were a more homogeneous group than the fresh poultry manures. This may be in part due to the smaller dataset of 16, but also reflects the fact that composting generally results in the buildup of more recalcitrant material and reduced N mineralization. Between 13 and 25% of the total N in the poultry manure composts were in the mineral form at the start of the incubations. At the end of the 100-day simulation, between 30 and 35% of the total N from a material with an average C:N ratio was in the mineral form. The poultry manures included in our study were all mature, stable composts. Some materials marketed as poultry manure compost may not have reached a stable form yet. Therefore, the variability observed in practice may be bigger than our dataset suggests.

The yard waste composts included in our analysis had a relatively wide C:N ratio ranging from 9.1 to 22.3. The type of raw material used is a major factor contributing to this variability. Yard waste compost is a stable material and its N is mineralized slowly. Generally, less than 10% of the total N is mineralized during the 100-day simulation. Materials with a wider C:N ratio may even immobilize N. This means that a large proportion of yard waste compost remains in the soil contributing to an increase in soil organic matter content and soil fertility when applied regularly. The N mineralization pattern of vermicompost is similar to yard waste compost. An important difference between the two materials is that vermicompost can contain mineral N, which is directly plant available when applied.

Based on the results from our study, we developed an interactive tool that allows users to estimate mineralization rates of incorporated organic materials based on local soil temperatures and material properties. The tool is available online at http://geisseler.ucdavis.edu/Amendment_Calculator.html

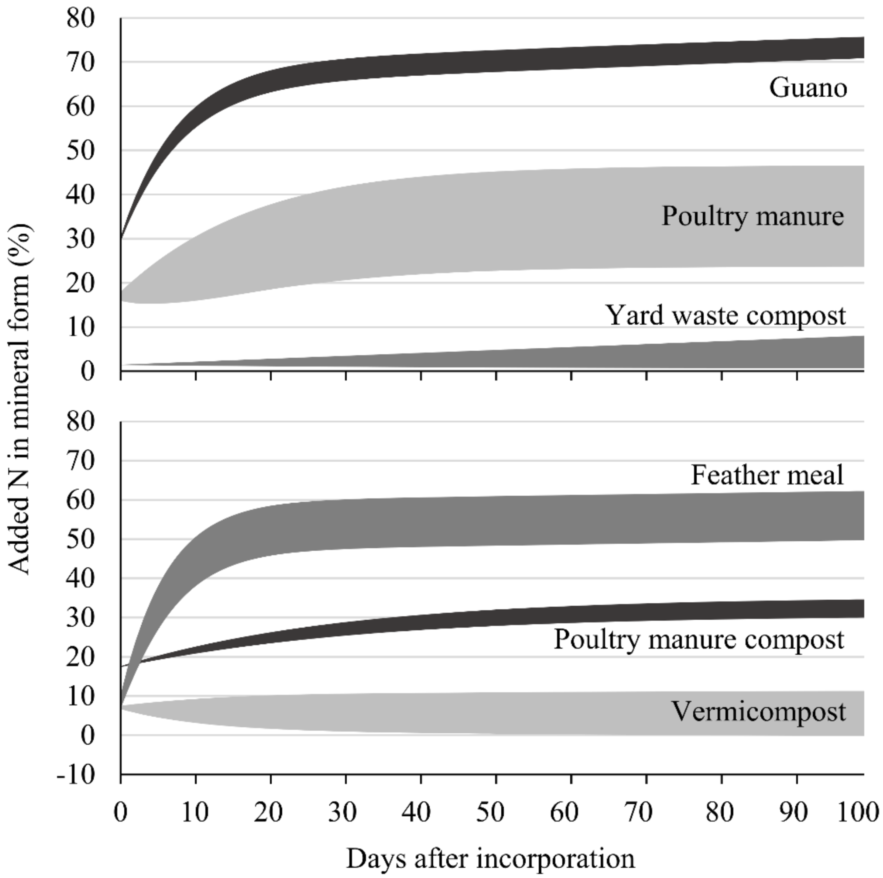

Figure 2. Simulated N turnover from organic fertilizers and composts based on minimum and maximum C:N ratios from a literature survey. The calculations assumed optimal moisture content and a constant temperature of 77 °F (Geisseler et al., 2021).

ACKNOWLEDGEMENT

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FLUSHED LIQUID DAIRY MANURE NUTRIENT DISTRIBUTION

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ABSTRACT

Some Idaho dairies use flushing systems that result in large amounts of liquid dairy manure that are applied via irrigation systems to adjacent cropland during the growing season. Solids and nutrients found in liquid dairy manure pose challenges to manure handling processes and cause environmental concerns. Separating solids and nutrients from liquid dairy manure is a critical step to improve nutrient use efficiency, reduce negative environmental impacts, and reduce manure handling costs. To better address solids/nutrients separation issue, a critical question needs to be answered: what are liquid dairy manure solid particle and nutrient distributions? Experiments were conducted to study the particle density, particle size, and nutrient (total nitrogen and total phosphorus) distributions of flushed liquid dairy manure. Flushed liquid dairy manure samples were collected from three commercial dairies in the Magic Valley region of Southern Idaho. The particle densities of manure solids were determined by the pycnometer method using a methanol medium. Solid particle distribution was determined using a set of 6 sieves (4, 2, 0.5, 0.25, 0.125, and 0.063 mm) combined with the hydrometer method ASTM D7928-17 for particle sizes less than 0.063mm. Total nitrogen (TN) and total phosphorus (TP) were analyzed using a Hach spectrophotometer (DR 5000) based on Hach methods. The Pipette Methods ASTM D6913/D6913M-17 was used in conjunction with ASTM D7928-17 to exact liquid manure samples. The test results showed that particle densities of flushed dairy manure ranged from 1.32 g/cm^3 to 2.20 g/cm^3, which are smaller than the density of soil particles (2.65 g/cm^3), solids of particles larger than 0.5mm were less than 50% of total solids (dry mass basis) for all three dairies, and liquid dairy manure phosphorus was mainly attached to particles with sizes smaller than 0.5 mm.

INTRODUCTION

Large dairies often use liquid manure handling systems because of their ease of mechanization and low labor requirements. A number of Idaho dairies use flushing systems that result in large amounts of liquid manure that are applied via irrigation systems to adjacent crop-land during the growing season. Solids and nutrients found in liquid dairy manure pose challenges to manure handling processes. Separating solids and nutrients from liquid dairy manure is a critical step to improve nutrient use efficiency and reduce manure handling costs. To better address issues related to solid/nutrients separation, a critical question needs to be answered: what are liquid dairy manure solid particle and nutrient distributions?

The objective of this research was to identify liquid dairy manure solid particle density and distribution, and nutrients associated with each particle size group.

METHODS

Liquid dairy manure samples were collected from a flushing receiving pit on each of three dairies (Dairy SF, Dairy DD, and Dairy SE) in Southern Idaho. Triplicate samples were analyzed for solid content, particle density, particle size distribution, total nitrogen (TN), and total phosphorus (TP). Solid content was analyzed based on Method 2540B (APHA, 2015). Particle density was analyzed based on the method ASTM D1217-15 (Weindorf and Wittie, 2003) using a pycnometer with a methanol medium for particle sizes of 4, 2, 0.5, 0.25, 0.125, 0.063, and <0.063 mm. Particle size distribution was determined using a set of 6 sieves (4, 2, 0.5, 0.25, 0.125, and 0.063 mm) combined with the hydrometer method ASTM D7928-17 (Days, 2002) for particle sizes less than 0.063mm. TN and TP were analyzed using a Hach spectrometer (DR 5000) based on Hach methods (Hach, 2005). The Pipette Methods ASTM D6913/D6913M-17 (Hellman and McKelvey, 1941) was used in conjunction with ASTM D7928-17 to extract liquid manure samples for analyzing the TN and TP. The apparatuses used for the test are shown in Figures 1, 2, and 3.

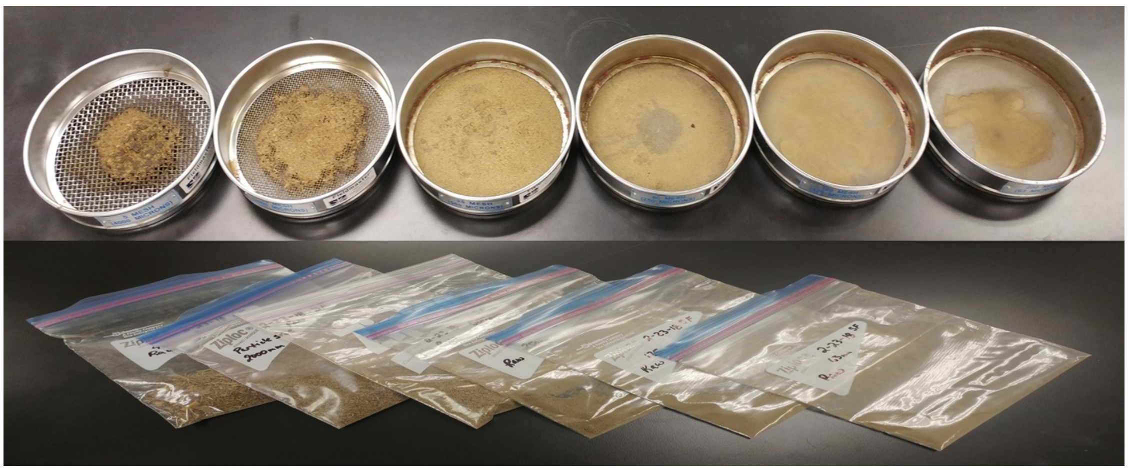

Figure 1. Sieved particles for density analysis.

Figure 2. Stacked sieve set (left) and liquid dairy manure sieve filtration apparatus (right).

Figure 3. From left: pycnometer for particle density analysis, pipette method for extracting manure samples, ASTM 152-H hydrometer, hydrometer reading of the meniscus.

RESULTS AND DISCUSSION

The particle densities (Figure 4) were found to be similar ranging from 1.32 g/cm^3 for particle sizes larger than 4 mm to 2.20 g/cm^3 for particles less than 0.063 mm.

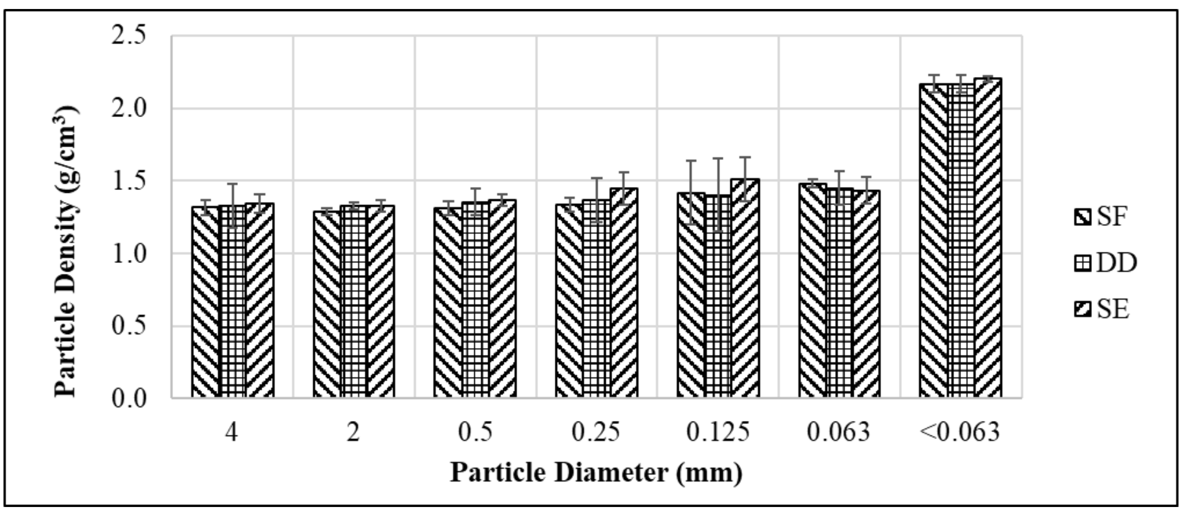

Figure 4. Flushed liquid dairy manure solid particle density of dairies SF, DD, and SE.

Flushed liquid dairy manure solid particle distributions are shown in Figure 5. It was noticed that high bedding fibers were presented in the liquid manure from Dairy DD which resulted in 32.6% of solids with particle sizes larger than 4 mm. For both Dairy SF and Dairy SE, the percentages of solids (dry weight basis) with particle sizes larger than 4mm were 8% and 17.2%, respectively.

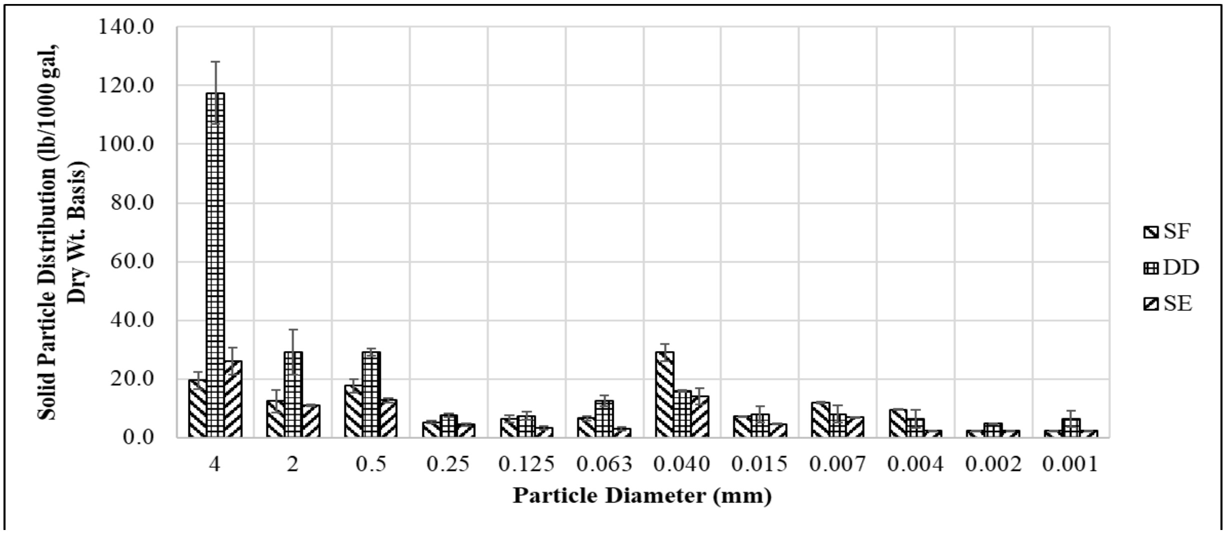

Figure 5. Flushed liquid dairy manure solid particle distribution of Dairies SF, DD, and SE.

Flushed liquid dairy manure TN and TP associated with different particle groups are shown in Figures 6 and 7. There were 4.9 lb. (or 33.6%) and 4.3 lb. (or 43.9%) of TN associated with particles larger than 0.5 mm in 1,000 gallons of flushed liquid manure for Dairy SF and Dairy SE, respectively. There was 0.8 lb. (or 6.5%) of TN attached to particles larger than 0.5 mm in 1,000 gallons of flushed liquid manure for Dairy DD. Most TP was attached to fine particles with sizes less than 0.5 mm for the three dairies. In order to separate more TP out of liquid stream, advanced separation methods beyond inclined screens are needed.

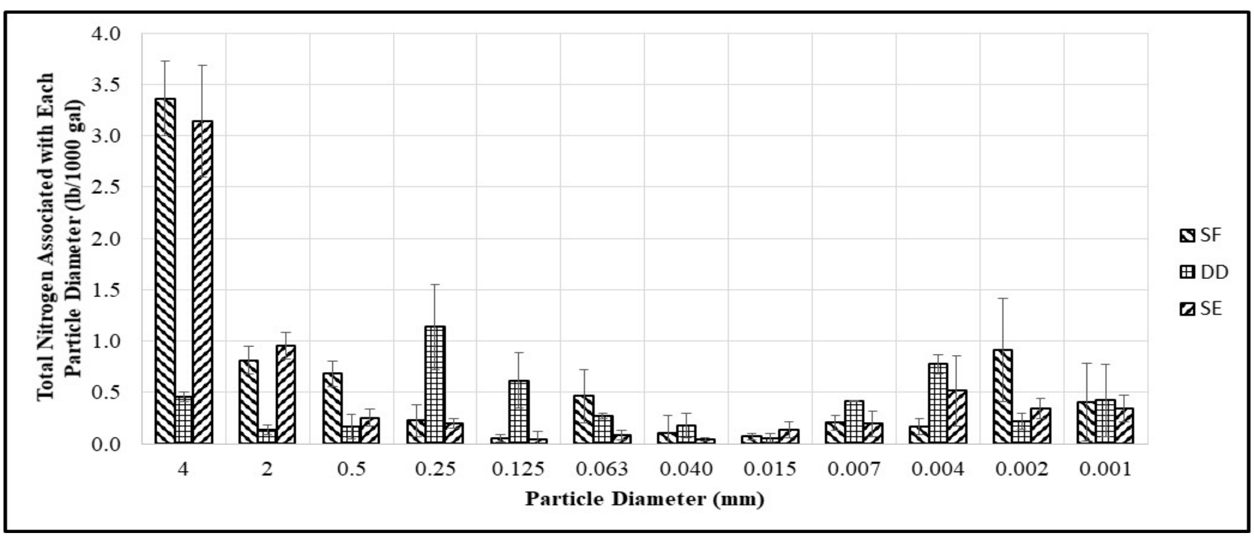

Figure 6. Total nitrogen (TN) associated with each particle diameter group in flushed liquid dairy manure.

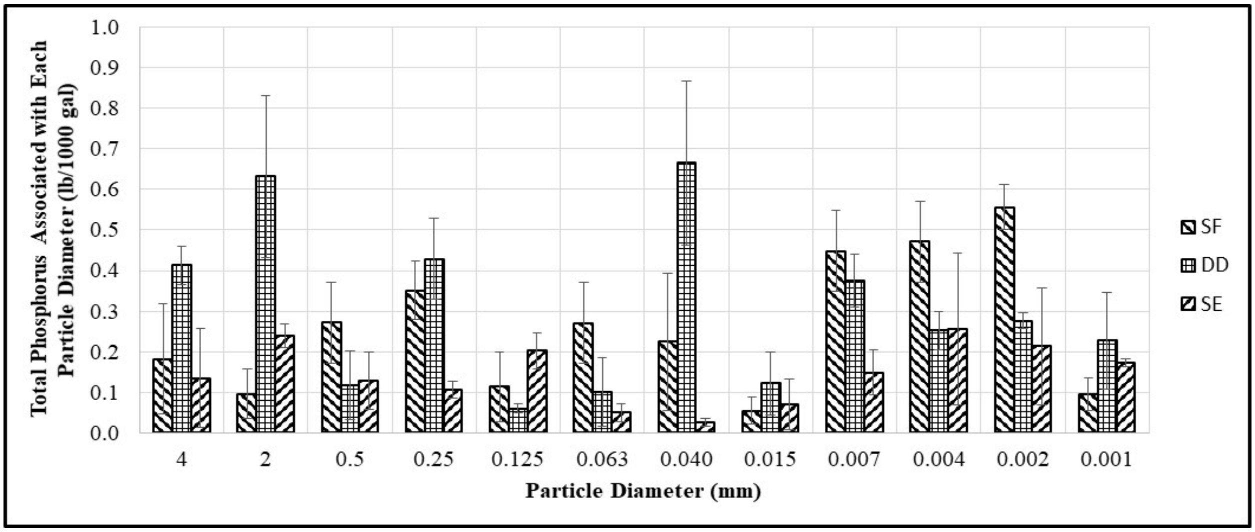

Figure 7. Total phosphorus (TP) associated with each particle diameter group in flushed liquid dairy manure.

The test results showed:

1) flushed dairy manure particle densities ranged from 1.32 g/cm^3 to 2.20 g/cm^3;
2) TN and TP distributions varied from dairy to dairy;
3) Most TP was associated with fine particles that cannot be screened out by screens;
4) Advanced separation technologies are needed to capture more TP from flushed liquid dairy manure.

EFFECTS OF LONG-TERM BIOSOLIDS APPLICATIONS IN TWO DRYLAND AGROECOSYSTEMS ON PHYSICAL, BIOLOGICAL, AND CHEMICAL SOIL HEALTH PROPERTIES

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ABSTRACT

Biosolids can be important sources of organic matter (OM) to semi-arid dryland grain systems and have the potential to mitigate some of the soil health challenges specific to these areas while providing an alternative to synthetic fertilizers. The objective of this research is to explore how long-term (20+ year) applications of biosolids at two field sites affected physical, biological, and chemical soil health properties in semi-arid dryland systems.

We collected our data from (i) a biosolids trial in a grain fallow rotation, located in Central Washington (WA), with three application rates of biosolids (2, 3, and 4.5 dry tons per acre) and (ii) a biosolids trial in a wheat-corn-fallow (WCF) and wheat-fallow (WF) rotation, located in Central-Eastern Colorado (CO), with biosolids applications occurring over ~ 20 years and based on agronomic nitrogen (N) needs of the crops.

At the WA site, we observed an increase in available water holding capacity (AWHC) and water-extractable carbon (C) and organic N concentrations with biosolids, while bulk density (BD) decreased in the two highest biosolids rates. Mineralizable C also increased at the highest biosolids rate. At the CO site, there was an increase in OM and n-acetyl-β-glucosaminidase (NAG) in biosolids-amended plots within the WCF rotation, but no changes within the WF rotation where biosolids were applied less frequently.

Our findings show that biosolids can improve aspects of soil health in dryland grain agroecosystems and that application rate matters when it comes to measurable improvements in soil health. Currently, biosolids are applied in agricultural settings based on the agronomic N needs of the crops, which is typically ~2-3 dry tons per acre; however, we saw greater changes to soil health indicators at higher application rates (3-4.5 dry tons per acre).

INTRODUCTION

Dryland agroecosystems rely on precipitation to meet the water needs of crops. While this practice is common in many different climates, it is particularly challenging within semi-arid and arid regions. Central Washington and Central-Eastern Colorado are semi-arid regions within the western United States where production challenges are often related to the low annual precipitation and the unpredictable timing and amount of precipitation, low plant-available water and slow decomposition of OM, which can limit nutrient cycling.

OM inputs are an effective way to improve soil health and function within these systems. OM can increase aggregation (Rieke et al., 2022) and water holding capacity (Bagnall et al., 2022), as well as stimulate biological activity, which can potentially improve nutrient mineralization and availability to plants. OM can be added in the form of cover crops, retained crop residue, and through external sources like amendments. In semi-arid systems, external sources of OM are necessary due to the difficulty to establish cover crops, the fallow period between crops, and the dry conditions that can limit the decomposition of crop residues. Finding cost-effective external sources of OM is a challenge within these systems.

Biosolids are cleaned and transformed products of the wastewater treatment process. They contain nutrients from food and are high in OM. Biosolids are applied as alternatives to synthetic nitrogen (N) fertilizers. Land application of biosolids is a way to close the nutrient cycle by recycling waste and redistributing nutrients and OM from densely populated areas where food is being consumed back into the less populated agricultural areas where food is being produced. This allows the nutrients being taken out of agricultural landscapes with crop harvests to be replaced.

Beyond their ability to be used as alternatives to synthetic N fertilizers, previous studies have also shown that biosolids can increase soil N and C (Cogger et al., 2013). The objective of this study is to explore how soil physical, biological, and chemical properties are influenced by long-term biosolids applications. We hypothesized that the high OM content in biosolids would result in improvements in soil health parameters that align with functions related to challenge areas for these systems. We were also interested in looking at how different application rates influenced soil health properties.

METHODS

This study was conducted on two sites, one located in Central Washington (WA) and the other in Central-Eastern Colorado (CO). Both trials have been receiving biosolids applications for 20+ years. The WA site was established in 1994 in Douglas County, WA, on a commercial farm in a grain-fallow rotation. The soil is classified as a Timentwa fine ashy sandy loam (ashy over loamy, glassy over mixed, superactive, mesic Vitrandic Haploxeroll) with 58.0% sand, 33.8% silt, and 8.2% clay. The mean annual precipitation for this site is ~10 inches per year.

The experiment is a randomized complete block design with three replications and five treatments: an unfertilized control, a synthetic N fertilizer and 2, 3, and 4.5 dry tons of biosolids per acre. The synthetic fertilizer is applied every crop year, and the biosolids were applied every four years. Biosolids are sourced from the Renton facility in King County, WA.

The CO site was established in 1999 in Arapahoe County, CO. The soil is classified as a Platner fine clay loam (fine, smectitic, mesic Aridic Paleustolls) with 25% sand, 44% silt, and 31% clay. This area of Colorado receives an average of 12 inches of precipitation per year. The experimental design is a split-plot design, with crop rotation as the main plot treatment (wheat-corn-fallow [WCF] or wheat-fallow [WF]) and fertility source as the subplot treatment (synthetic fertilizer or biosolids).

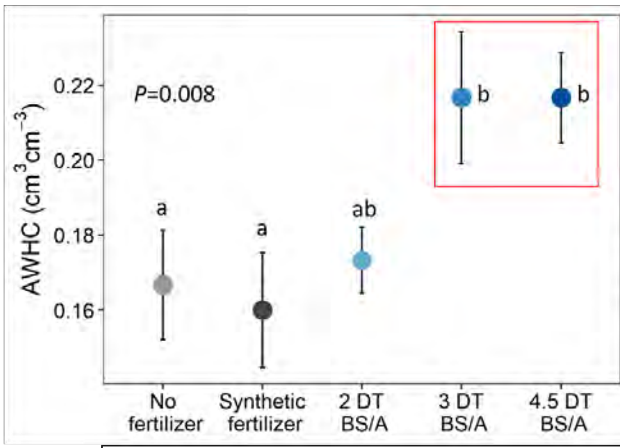
Biosolids were sourced from the South Platte Renew Facility. The rate and timing of biosolids applications were based on the agronomic N needs of the crop being grown. If the recommended application amount was less than 1.5 dry ton biosolids/acre, biosolids were not applied, due to the inability of equipment to accurately apply below this threshold.

In 2019, the Soil Health Institute (SHI) sampled both sites as a part of the North American Project to Evaluate Soil Health Measurements (NAPESHM). Physical, biological, and chemical soil health indicators were selected from the analyses run by the SHI (Norris et al., 2020) to be included in this study. We explored research questions by looking at soil health parameters related to soil functions that could mitigate some of the main challenge areas for these two agroecosystems. Within this context, we wanted to look at the functions of water regulation, soil resilience, and nutrient cycling in these systems. To do this, we looked at

AWHC, pore space, saturated hydraulic conductivity (K_{sat}), BD and aggregate stability, and C, N, and phosphorus (P) cycling enzymes, mineralizable C and N, and water-extractable C and N.

RESULTS AND DISCUSSION

We found improvements in several of the soil physical, chemical, and biological parameters at the WA site, but limited changes at the CO site. At the WA site, AWHC and BD improved with biosolids applications, while aggregate stability and K_{sat} did not change. At the WA and CO sites, we saw improvements in NAG, while phosphomonoesterase increased at the WA site. No change in β-glucosidase was observed at either site. At the WA site, we saw increases in mineralizable and water-extractable C and N.



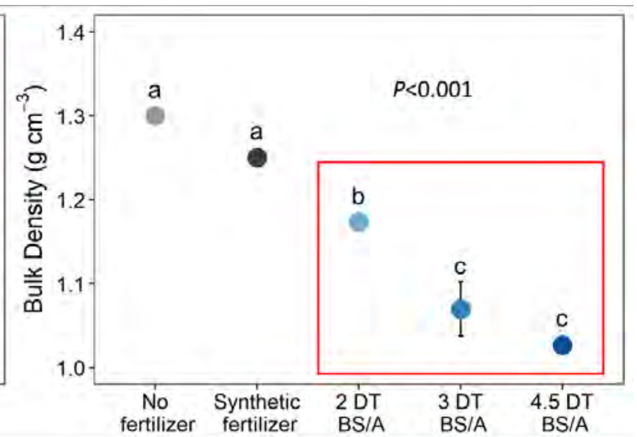
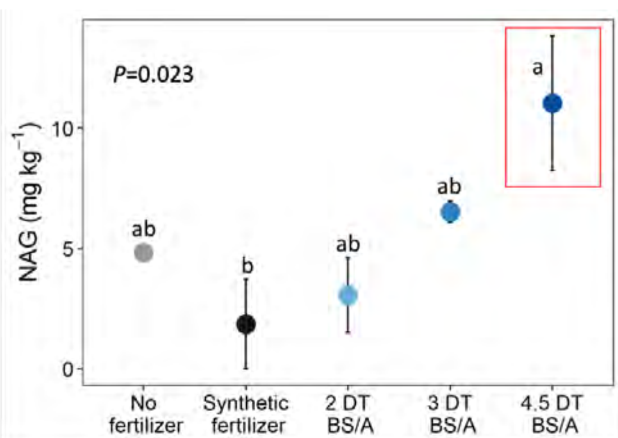


Figure 1a. At the WA site, available water holding capacity increased with the two highest biosolids applications rates.

Figure 2a. At the WA site, bulk density decreased at all biosolids application rates.



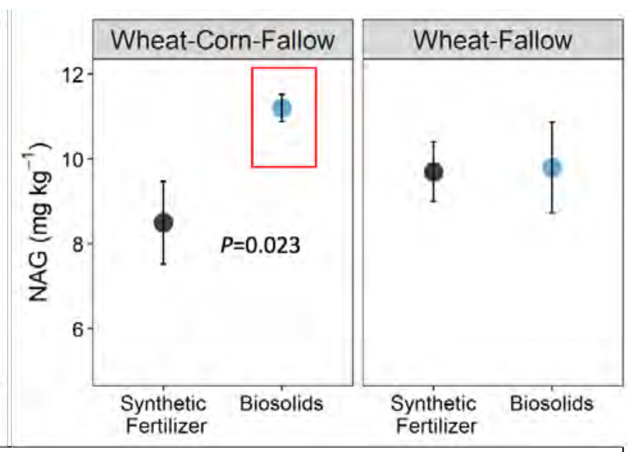


Figure 2a. NAG increased at the highest biosolids application rate at the WA site.

Figure 2b. NAG increased with biosolids in the WCF rotation at the CO site.

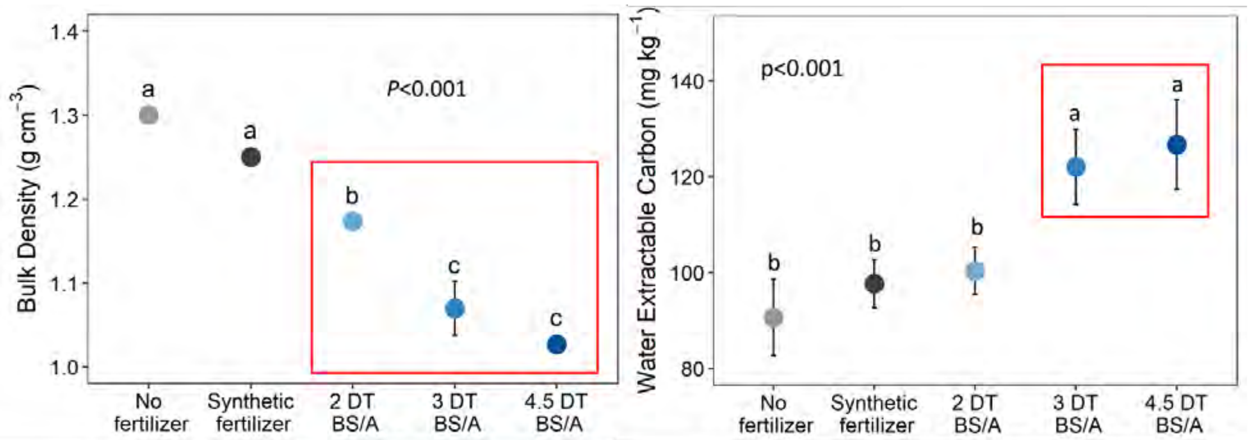


Figure 3a. CO_2-C increased at the highest biosolids application rate at the WA site.

Figure 3b. WEC increased at the two highest application rates at the WA site.

We hypothesize that the reason we did not see as many treatment effects at the CO site is due to the fact that the CO site plots received less cumulative biosolids than those at the WA site. At the CO site, biosolids are applied based on the agronomic N needs of the crops, which were usually in the 2 dry tons per acre range or below. Effects from biosolids observed at the CO site were in the cropping rotation that received greater biosolids applications (WCF). WCF rotation typically required more N than the WF due to the extra crop added to the rotation. At the WA site, we typically observed soil health indicator improvements at the 3 dry tons per acre rate, but not at the 2 dry tons per acre rate. Another factor that may be at play is that the WA site has a coarser soil texture, and sandy soils are more responsive to increases in OM inputs.

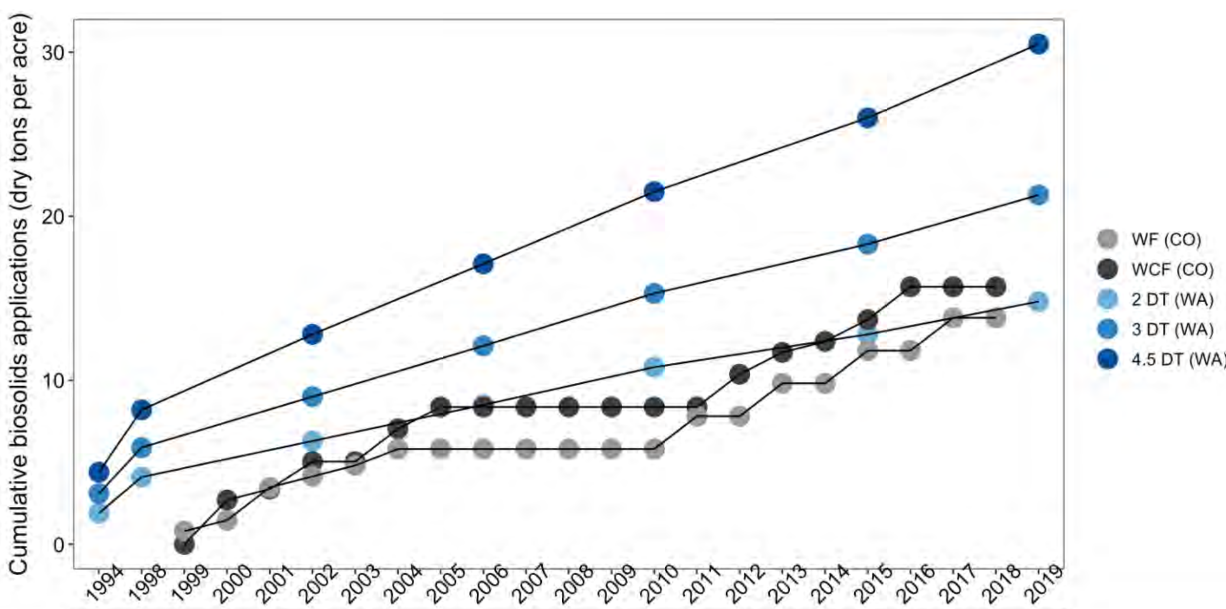


Figure 4. Cumulative biosolids applications for different treatments and cropping systems at WA and CO sites.

Overall, our results indicate that biosolids provide improvements in soil functions relevant to our challenge areas, but that application rate matters when it comes to measurable improvements in soil health. Currently, biosolids are applied in agricultural settings based on the agronomic N needs of crops, as they are at the CO site. Biosolids can increase soil P levels, which is one important reason for growers to ensure they are not overapplying biosolids. However, our research shows that in semi-arid dryland systems, particularly with coarse soils, the rate at which we can typically expect to see changes in soil health is higher than agronomic N rates being applied in some cases.

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BIOSOLIDS-BASED FERTILIZERS AS A NITROGEN SOURCE IN CALIFORNIA SMALL GRAINS SYSTEMS

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ABSTRACT

As more California municipalities begin to prioritize the diversion of waste products from landfills into agricultural systems, it is pressing for growers to understand how to utilize new inputs such as liquid-injected biosolids-based fertilizer (LBF) in their operations. Biosolids-based fertilizers can generally provide subsidized and therefore cost-effective sources of nitrogen (N) for small grains and other agronomic crops. However, while there have been long-term biosolids studies using materials derived from biosolids, near-term performance needs to be understood and documented to improve grower confidence and capacity in the utilization of these products. The objective of this research is to evaluate the performance of LBF as an N source in small grains relative to conventional forms of N fertilizer. Field trials took place over the course of three planting seasons. Laboratory incubations were also carried out to examine the behavior of the LBF relative to a pelletized biosolids-based fertilizer (PBF), and conventional urea. Results indicate that LBF produces equivalent yield and protein results in small grains when compared to conventional forms of fertilizer as an N source. Other findings indicate that there may be some ancillary benefits associated with the use of LBF as an N source by way of providing a source of phosphorous (P), carbon, micronutrients, and water.

INTRODUCTION

In response to regulatory and economic pressure, California growers are becoming more familiar with nitrogen (N) budgets. In addition to seeking out ways to improve N management strategies, growers can possibly benefit by incorporating alternative sources of N to support their crops. Liquid injected or pelletized biosolids-based fertilizers from local waste streams and processing facilities are one source that growers are beginning to explore.

These fertilizers can be subsidized and are therefore cost-effective sources of N, but their performance needs to be understood and documented to improve grower confidence and capacity in their utilization. Previous studies have documented the long-term impacts of biosolids sludge applications, but processing technology and local forms of biosolids-based fertilizers have changed in recent decades. Therefore, single-season studies should be considered in tandem with more long-term studies to understand near-term impacts on crop performance.

The objective of this research is to evaluate the performance of liquid-injected biosolids-based fertilizers (LBF) as an N source in small grains relative to conventional forms of N fertilizer. Field trials took place over the course of three planting seasons. Laboratory incubations were also carried out to examine the behavior of the LBF relative to a pelletized biosolids-based fertilizer (PBF), and conventional urea.

METHODS

Between 2018 and 2021 UC Cooperative Extension conducted on-farm trials in the southern Sacramento Valley to measure yield and protein outcomes in fall-planted wheat fertilized with biosolids-based materials across different soil types and moisture regimes. LBF ("Lystegro" by Lystek) was compared side-by-side with similar rates of conventional mineral N fertilizers. Treatments were 2 or 3 rates of LBF and an application of conventional fertilizer (anhydrous ammonia, UAN32, or urea) at a rate that matched one of the biosolids rates in terms of total N applied per acre (Table 1). LBF was injected and integrated to a depth of 6 inches on 22.5 inch spacing, although some of the material stayed on the surface depending on soil conditions. LBF total N percentages were between 3.5 and 4.6%. LBF material was roughly 90% water. All treatments were applied pre-plant to determine the relative performance of each material under similar conditions.

Yield and protein data were collected from grain harvest using grower-collaborator combines and weigh wagons. Soil and plant tissue data were collected to document the material's impact on soil and plant nutrients in-situ.

Among other tests, lab incubations were carried out to document changes in key soil attributes (N mineralization rate, Olson P, EC, and pH) between LBF, PBF, and urea. A Yolo loam (Fine-silty, mixed, superactive, thermic Fluventic Haploxerepts) was homogenized and mixed thoroughly with each of the materials separately. Soils were kept at field capacity at 75° F over the course of 12 weeks. Measurements were taken at 1, 3, 6, and 12 weeks.

Table 1: Information on three growing sites/ years where trials took place.

	2018	2019	2021
Rates applied lbs N/ acre			
LBF Low	57	66	73
LBF Medium	90	82	146
LBF High	NA	98	219
Conventional Fertilizer	90 'med'	120 'high'	130 'med'
Fertilizer Type	Anhydrous	UAN 32	Anhydrous
Relative Rainfall Pattern	Average-Droughty	Above Average	Extreme Drought
Location	Upland: Bird's Landing	Valley: Dixon Area	Valley: Rio Vista

RESULTS

Two of the three years experienced lower-than-average rainfall with extended drought periods at the tillering stage of the wheat growth cycle. In 2019, rains were above average, with sustained rainfall throughout the growing season.

Yield and Protein

Yield was equivalent between LBF and conventional N fertilizers in all years when the same or similar rates of total N were applied (Figure 1). In 2018 and 2019 there was a positive yield response to N, and some of the treatments resulted in higher yields than the control. In 2021 there was no yield response to any of the N treatments.

Protein was equivalent across all treatments in 2018 (Figure 1). In 2019 protein was relatively low across all treatments, but rates were equivalent among high-rate treatments and the low LBF treatment. In 2021 protein was higher in the LBF treatment than in the conventional N fertilizer treatment at the same N rate.

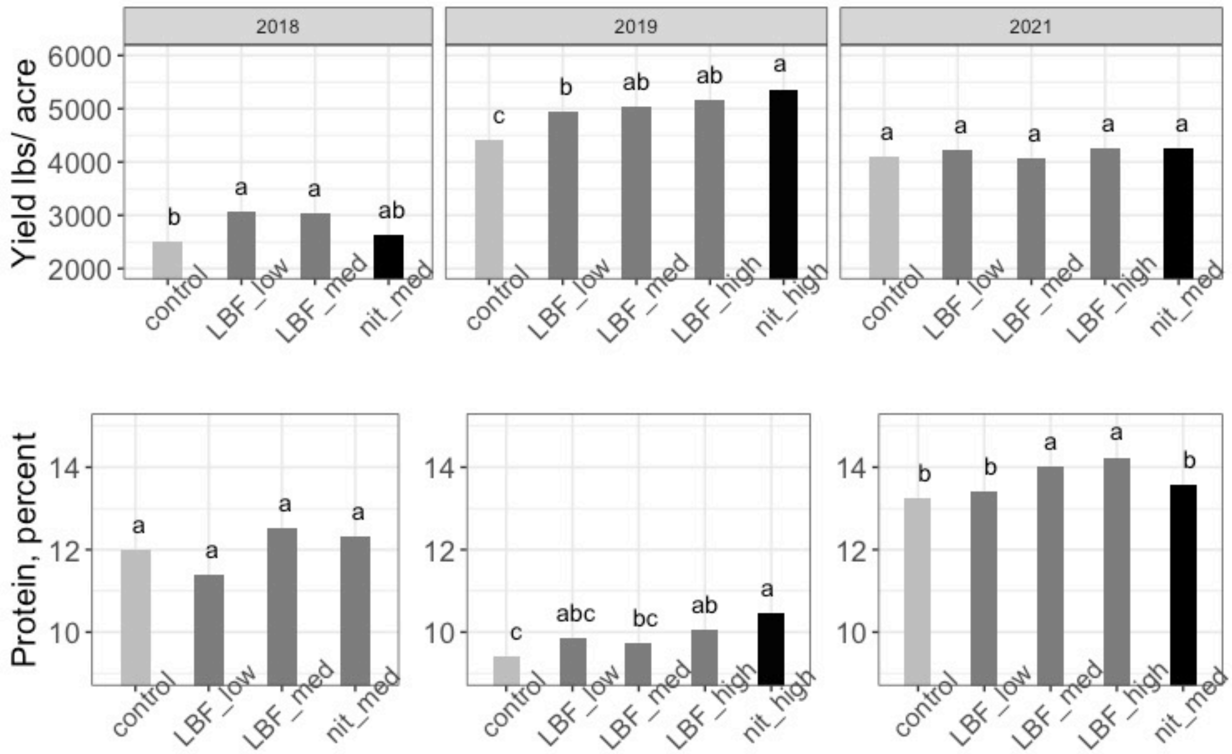

Figure 1: Yield and protein data from field trials over three site years in the Southern Sacramento Valley. Conventional N fertilizer "nit" rates are expressed as either "nit_high" or "nit_med". LBF rates are expressed similarly. See Table 1 for exact amounts of N added for each treatment. Significant difference between treatments is indicated within a given year by different letters.

Incubations

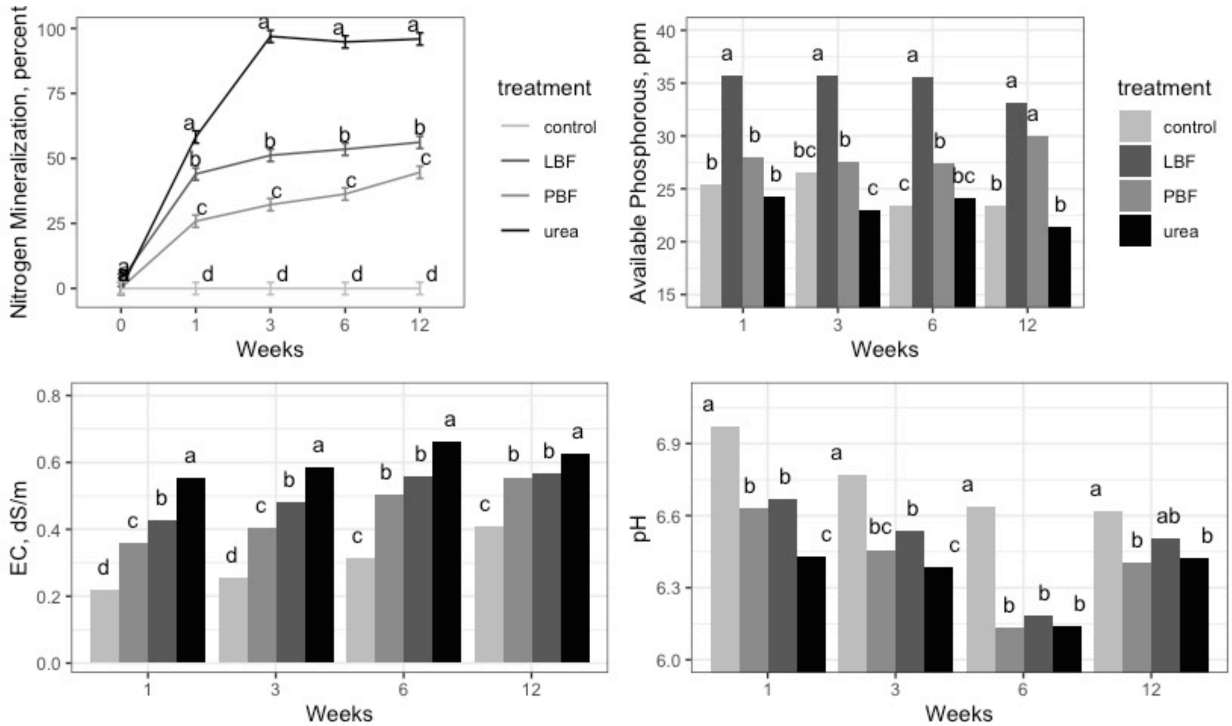

Figure 2: N mineralization, available phosphorous, salinity (as electrical conductivity, EC), and pH results from 12-week lab incubations comparing LBF, PBF, and pelletized urea mixed into a Yolo loam. Significant difference between treatments is indicated within a given week by different letters.

In the laboratory incubations, nearly all of the urea had mineralized after 3 weeks. LBF and PBF mineralized quickly in the beginning, but the rate of mineralization tapered off after several weeks. PBF maintained a higher rate of mineralization into week 12, where it approached mineralization levels comparable to that of the LBF (Figure 2).

Available phosphorus, measured as Olsen-P, was higher in the LBF than in any other treatments for the first 6 weeks. At 12 weeks, LBF and PBF became insignificantly different. P remained insignificantly different between control and urea treatments throughout the duration of the measurements (Figure2).

EC was highest in urea treatments, and remained significantly so throughout the course of the measurements; however, LBF and PBF EC increased slowly over the course of the measurements (Figure 2).

All treatments reduced pH relative to the control by about 0.3 within the first week. pH continued to decrease throughout the first six weeks before rebounding slightly in the 12th week (Figure 2).

DISCUSSION

Yield and Protein

In field trials, yield LBF treatments were equivalent to conventional forms of N when applied at similar rates of total N per acre. In some cases, yields from lower rates of LBF were also equivalent to higher rates of conventional N. In 2018 and 2021 this was possibly due to the droughty conditions that led to water limitations in the crop, reducing yield, and thus reducing the overall N uptake potential.

In 2019 however, high rainfall removed much of the N from the profile across all treatments at tillering, but lower rates of LBF still managed to produce similar yields compared to conventional treatments where 46% more N was applied (Table 1). The slower release of the mineralizable N in the LBF may have provided late-season N to make up for the difference in pre-plant application rates of total N. This is supported by the fact that protein, which typically increases with late-season applications of N, remained insignificantly different between 82 lbs/acre of N as LBF and 120 lbs/acre of N as UAN 32. In 2021 protein was also higher in the LBF treatment than that of the conventional N treatment with the same rate of N. This may also suggest late-season N mineralization or some other interaction that increased protein in the grain.

A note on application and N management

It is understood that a 100% preplant application is not the most efficient N management strategy for small grains. Rather, best practices would suggest that growers should be using N reference zones, canopy reflectance data, in-season soil nitrate measurements, and split-applications. The reality on the ground however is that many growers in the Southern Sacramento Valley are applying the majority, if not all of their N fertilizer preplant. Testing these materials provides a worst-case scenario analysis for growers who may not be able to apply in-season N.

Furthermore, given that incubations show that, relative to urea, only about 50% of total N is released by the LBF and PBF by week 12, it may be the case that the carbon applied with the LBF and PBF is increasing microbial activity over time. Increased microbial activity may be triggering a release of mineral N from labile pools of organic N already in the soil. Alternatively, there may be other mechanisms that are increasing the uptake efficacy of N by plants in LBF relative to forms of mineral N.

Growers should feel confident in using LBF and possibly PBF sources for N applications. However, best practices such as N reference zones, canopy reflectance, soil nitrate testing, and integrated in-season N management techniques should be utilized in-season. Because LBF and PBF cannot effectively be applied in-season, growers should strongly consider the combined use of pre-plant LBF with in-season applications of conventional N as needed.

Water

The fact that the 2018 site was relatively dry may have meant that the extra water applied with the LBF treatments, roughly 0.1” to 0.25” in the injection rows may have helped every other row of wheat seed access a substantial amount of water early in the season that encouraged stand establishment and root development to a greater depth in the soil. Depending on the distance from the source it may or may not be energy efficient to de-water the material. In the case where dewatering does not pencil out economically, the addition of moisture through an LBF may provide growers with a buffer against severe drought during the seedling stage, particularly during seedling establishment in dryland crops (as in the 2018 site).

Additional nutrients, pH, OM, EC

P-limited soils are rare in California, but P additions from organic waste streams could provide a side benefit to growers. The incubations document higher P availability from LBF and PBF relative to urea, and soil and plant tissue data from the field trials suggest that those differences in availability occasionally manifest as higher P concentrations in soil and plant biomass. The P applied with LBF and PBF may also support root development of seedlings, improving stand establishment. It is also the case that LBF and PBF will likely provide some amount of micronutrients to plants, but the specific range of those nutrients will likely vary depending on changes in source material and is beyond the scope of this study. Field trials indicate that there was no change in organic matter percentages (OM), but carbon changes in OM in other biosolids trials have typically only been visible over longer periods of time. Even if detectable levels of stable organic carbon are not being formed, it is likely that a portion of the carbon from LBF is being utilized by the microbial community in the field within a growing season.

EC was slightly lower in the LBF and PBF treatments as compared to urea, indicating that salt load should not be more of an issue than it is with the use of urea as an N source. In addition, pH eventually dropped and was similar among all treatments despite higher early values in the LBF and PBF treatments compared to urea. Both EC and pH behavior with these materials should serve as a reminder of the importance of good soil management and monitoring techniques.

CONCLUSION

Small grain growers working in the Sacramento Valley or in similar climates should feel confident that LBFs will likely perform as well as conventional sources of N when applied at similar rates of total N. LBFs may also provide additional benefits to growers in the form of increased P, micronutrients, or additional soil moisture. Growers should also consider the combined use of biosolids and in-season conventional N additions.

IMPACT OF VARIABLE-RATE NITROGEN ON POTATO YIELD, NITROGEN USE EFFICIENCY, AND PROFIT

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ABSTRACT

Applying variable N within a field could improve yields, nitrogen use efficiency (NUE), and economics. The object of this study was to evaluate impacts of high and low rate zones within a variable rate pre- and in-season N (VRPIN) system compared to traditional N management used by the grower in a potato-wheat-wheat cropping system. Nitrogen zones were created within five potato fields in 2021 and 2022 near Grace, Idaho, USA. Nitrogen rates for each zone were determined based upon yield goal levels and other variables. Uniform strips were placed through all zones as a positive control based on N management used by the grower. All N for the growing season was applied shortly after planting with a polymer coated urea (PCU). Yield samples were collected at 4-6 locations within each zone and the uniform strips to assess tuber grade, size, external and internal defects, and specific gravity. Variable rate N significantly improved total, marketable and U.S. No. 1 yield in high-yield potential zones compared to their respective control strips across all fields combined. Although yields increased, NUE decreased with increased VRN rates and increased with decreased VRN rates. The grower increased profits by an average of \$364 ac^{-1} with VRN across all potato fields.

INTRODUCTION

Nitrogen application is a vital step in crop production and continues to be an environmental concern due to its high volatilization and solubility properties (Hopkins et al., 2020). As yields can vary extensively throughout a single field, improving N management has the potential to not only improve yields and crop quality, but also improve input costs, and decrease environmental concerns (Hopkins et al., 2020). Variable rate nitrogen (VRN) is a process that could achieve these goals within agriculture. Utilizing grower field knowledge, historical yield, and other field data can determine yield potential zones for variable rate pre- and in-season N (VRPIN). Studies have used crop sensing, modeling, historical yield maps, topography and soil properties to create management zones, some collectively and some individually (Bourdin et al. 2017; Pedersen et al. 2021; Schwalbert et al. 2019). While some studies have shown success in VRN zones, others have not (Long et al. 2015; Schwalbert et al. 2019).

Utilizing VRN within potato has the potential to improve production, tuber size specific gravity and other quality components in the respective crop (Hopkins et al., 2020). While studies have been performed to test the effectiveness of in-season VRN (Bohman et al., 2019; Bohman et al., 2020), more field-scale studies are required to address the pre-emergence VRN portion of VRPIN within potato. This study was developed to create and test simple and feasible VRPIN zones that growers can utilize to optimize N management and improve nitrogen use efficiency (NUE) and economics.

A simple approach to variable-rate nitrogen management that utilizes field history and grower knowledge is needed to advance precision nitrogen management. Practicing such simple variable rate pre- and in-season N (VRPIN) approaches have the potential to reduce fertilizer needs, save money, reduce environmental impacts, and increase production. Precision nitrogen management has been studied extensively in other regions of the country, but few replicated field-level trials exist in Idaho or Utah. Local studies are needed to validate whether a simple VRPIN approach is feasible and economical for potato producers in this region.

METHODS

In 2021 and 2022, ten potato fields ranging in size of 124, 87, 45, 87, 57, 62, 22, 99, 121 and 64 ac for fields 1-10, respectively, with wheat-wheat-potato rotations, located near Grace, Idaho, USA (elevation 5535 ft above sea level) were established as field sites. This area has a semi-arid climate typified by relatively hot days and cool nights during the growing season. The average annual precipitation is 15 in with the majority occurring during winter as snow.

Two to four zones were visually identified within each field (Fig. 1) based on utilizing layers of information, including: grower field knowledge, topography, bare soil imagery, yield map histories of potato and rotational crops, historical in-season visible and normalized difference vegetation indices (NDVI) imagery. These layers were used to find overlapping patterns of zones that could represent average, high, or low yields with or without limitations that are or are not possible to correct.

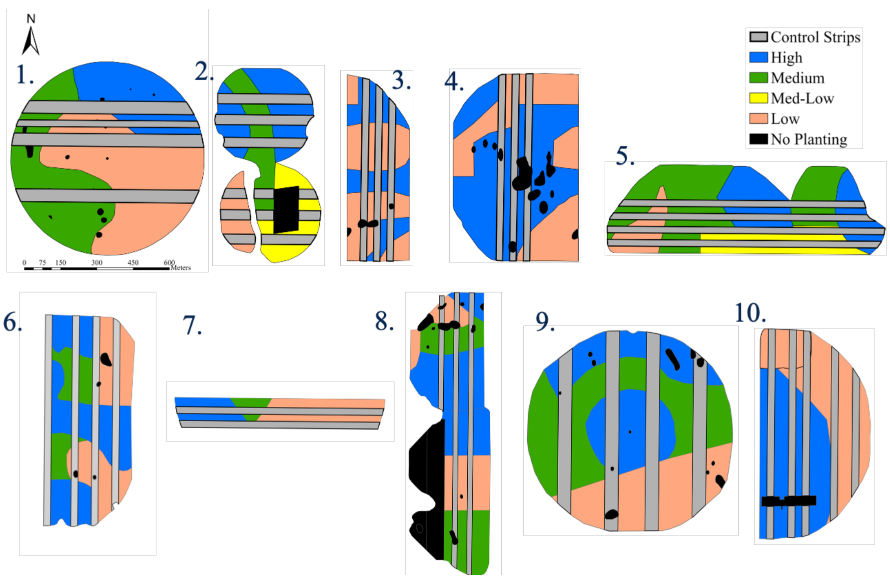

Figure 1. Nitrogen zones for ten potato fields (1-10) with 2021 experiments in fields 1-5 and 2022 experiments in fields 6-10.

Banded fertilizer was applied at 7.2 lbs N ac^{-1} uniformly to all fields prior to planting. Potatoes were planted between 11 and 15 May, 2021 and 13 and 20 May, 2022 in 2.8 ft wide rows with varieties including: Russet Burbank (fields 1, 6, 8 and 10), Frito Lay 2137 (fields 2, 4 and 9), Actrice (fields 3 and 7) and Waneta (field 5), (Fig. 1). Soil samples (12-15 cores per sample) were collected randomly throughout each zone to 1 ft deep between 18-19 May, 2021 and 6 & 8 April, 2022. These samples were air dried, ground (< 0.08 in) and analyzed for NO_3-N. The base N rates for each zone were determined as a function of variety and yield goal, with reductions for residual topsoil N, crop residue, irrigation water NO_3-N concentration, and legume and/or manure credits (if any) (Hopkins et al., 2020). The N predicted to be needed for the season was applied via broadcast with a Miller Condor fertilizer spreader (St. Nazianz, Wisconsin, USA) shortly after planting between 27 May and 03 June, 2021, and 02 June and 09

June, 2022 using a polymer coated urea (PCU; Nutrien, Saskatoon, Canada) (Table 1). Control N strips were placed through all zones as a positive control based on N management used by the grower. The N was incorporated into the soil during hilling, which occurred shortly after fertilization.

Table 1. Pre-emergence nitrogen (N) rates for each zone in ten potato fields. Zones were based on yield potential, with some fields not having all zones (not applicable = N/A).

Zone	Field									
	A	B	C	D	E	F	G	H	I	J
	- - - - - - - - - - lbs N ac^{-1} - - - - - - - - - -									
Control	160	120	130	130	140	160	130	160	130	170
High	190	150	160	160	170	190	160	190	160	200
Medium	160	120	N/A	N/A	140	160	130	160	130	N/A
Med-Low	N/A	105	N/A	N/A	120	N/A	N/A	N/A	N/A	N/A
Low	130	90	100	100	110	130	100	130	100	140

The crop canopies were monitored in-season at least twice weekly for visible and NDVI pattern changes, especially row closure differences utilizing Sentinel 2 and Landsat 8 satellite imagery (FarmShots, Durham, North Carolina, USA). Composite petiole samples (Hopkins et al., 2020) were taken in the control N strips three times within each season to evaluate overall nutrition and NO_3-N trends and then, based on the control petiole NO_3-N concentration and canopy imagery, composite petiole samples were taken in every zone and analyzed for NO_3-N by the ServiTech, Inc. laboratory (Dodge City, Kansas, USA). If NO_3-N levels were low based on Hopkins et al. (2020), additional fertilization plots were created within the applicable zone to apply VRN to small portions of each zone.

Tuber samples were collected at harvest (17-27 Sep, 2021 and 19-29 Sep, 2022), approximately 21 d after vines were chopped and then sprayed with sulfuric acid, to determine yield and quality at 4-6 locations within each zone in a paired sampling structure. Each pair consisted of a sampling from the control strip and the VRN zone. Samples were hand collected using a four-row windrower (crossover) (1 ft by 33 ft^2) in 2021 and a combination of a four-row and 6-row windrower (crossover) (1 ft by 43 ft^2) in 2022. Tubers were separated by grade (U.S. No. 1, U.S. No. 2 and malformed; USDA, 2011) and then counted and weighed for each grade. Average tuber size was calculated by dividing the weight of all tubers within a specified grade by the respective count.

All replicated data were analyzed by ANOVA (SAS Studio 3.8, SAS, Cary, North Carolina, USA) with mean separation performed by Least Significant Difference (LSD).

RESULTS AND DISCUSSION

The amount of N applied within the VRN zones were compared to the amount of N that would have been used with the control rate across the entirety of each field. The average difference in VRN rates compared to control rates resulted in an increase of 0.1 lbs N ac^{-1} with a range of -9 – 8 lbs N ac^{-1} across all fields (Fig. 2). The VRN treatments had very minor impacts on total N rates applied, as N was reappropriated from low to high productivity areas. This process resulted in the same N cost for both approaches.

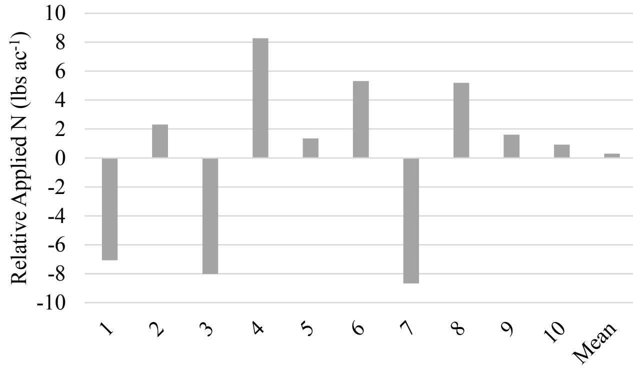

Figure 2. Difference in total amount N applied (lbs ac^{-1}) if using VRN method compared to positive control rate (grower standard practice rate) throughout entirety of fields; with data shown as VRN minus control.

In-season assessment of N status via visible scouting, NDVI imagery, and petiole tissue sampling revealed optimal N values throughout the growing season. While the option to variably apply N in-season was available, it was decided to not do so for any of the fields based on the lack of variability across zones in 2021 (all zones were classified as low; Hopkins et al., 2020). The rates applied at the pre-emergence for this study could have been high enough across all zones to negate the need for in-season VRN.

Yields measured and averaged by the potato harvester's yield monitor were 339, 393, 384, 232, 330, 312, 437, 272, 303, and 401 cwt ac^{-1} for fields 1-10, respectively and were considered good for the high elevation and seed potato region. Yield, quality, and internal measurements were collected in small plots within each VRN zone and control strip within each field. Although data on tuber size, specific gravity and internal measurements were collected and significant differences were observed, these results will not be discussed within this paper. The small plot measurements showed significant Treatment × Zone interactions for total, marketable and U.S. No. 1 yields (Table 2). Significant differences were observed between high and low VRN zones and their respective control strips in combined fields for total, marketable and U.S. No. 1 yield (Fig. 3).

Table 2. *P* values from ANOVA with statistically significant values shown in bold-face type ($P = 0.05$)

Response	Treatment	Zone	Field x Trt.	Trt. x Zone	Field x Trt. x Zone
Total Yield	**<0.0001**	**0.0022**	**0.0034**	**0.016**	0.5862
Marketable Yield	**<0.0001**	**0.0006**	**0.0009**	**0.0249**	0.5463
U.S. No. 1 Yield	**<0.0001**	**0.0002**	**0.0001**	**0.0307**	0.5849
NUE	**<0.0001**	**<0.0001**	0.089	**<0.0001**	**0.0061**

The VRN treatment yielded significantly higher than control strips in high zones across total, marketable and U.S. No. 1 yields, and although not significant, showed to yield numerically higher in low zones compared to their respective control strips (Fig. 3). This shows that the high yield potential zones did increase yields with increased rates of N, and the low yield potential zones did not result in a negative yield response with lower rates of N. A study with similar N rates showed similar results in that it did not result in significant differences in tuber yields between VRN and uniform rates when VRN rates were lower than the uniform rates (Bohman et al., 2019). Another study also found no significant differences in tuber yields between VRN and uniform rates, but the zones were not set up by the same design and was not a full-field trial (Morier et al., 2015). Bowen et al. (2022) did find positive responses in yields with the VRN rates, and also did not find any significant negative yield impacts from lowered VRN rates.

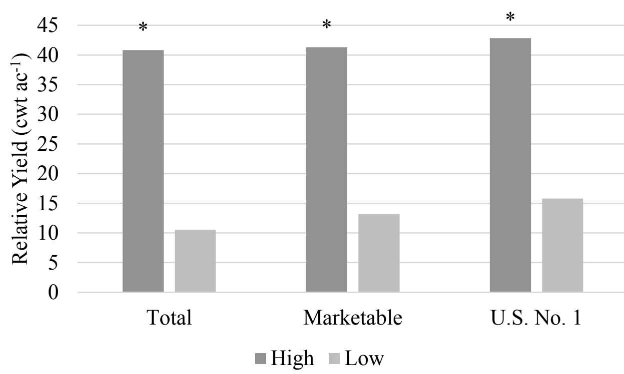

Figure 3. Relative yield (VRN – Control) by zone for total, marketable and U.S. No. 1 yields, with significant differences shown with an * (*P* < 0.05).

Relative NUE (VRN – Control) was observed based on yield (cwt ac^{-1}) ÷ N rate (lbs ac^{-1}) from small plot measurements in each field (Fig. 4). Where N rates were increased in the high zones, NUE decreased, and where N rates were lowered in the low zones, NUE increased. Overall, the differences in NUE between VRN treatments and Control strips were significant for both high and low zones with all fields combined. By observing these values, it could be determined that too much N was applied in all fields within the high zones and rates could be decreased to improve NUE. Fields 4 and 7 did not result in significant NUE differences within the low zones like the other fields did. For field 7, this could be because the variety 'Actrice' requires a lower optimal rate of N, but a higher rate of N was applied across the field for all zones, thus potentially creating a buffer effect on the NUE ratio. Field 4 yielded lower overall, and seemed to have some unknown, underlying conditions within the low zones that could be negatively impacting yields and thus lowering the relative NUE. Although NUE could have been improved, the grower increased profits by an average of \$364 ac^{-1} with VRN across fields 6-10 in 2022 alone (Ryan Christensen, personal communication). These profit gains validate the simple steps within this study.

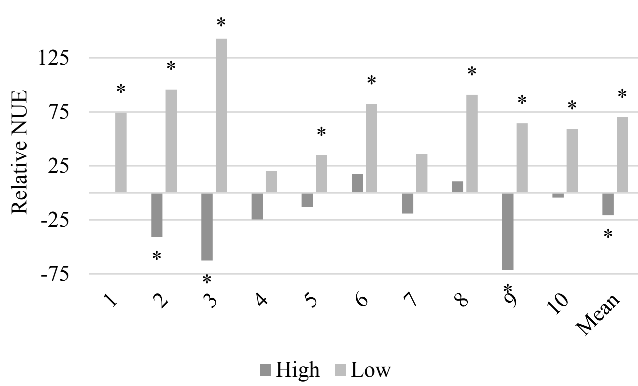

Figure 4. Relative nitrogen-use efficiency (NUE) (VRN – Control) within individual fields and zones. Significant differences shown with an * (*P* < 0.05).

CONCLUSION

In general, utilizing the VRN procedure used in this potato study benefited total, marketable and U.S. No. 1 yields significantly within the high yield potential zones, and did not negatively impact yields within the low yield potential zones. Overall, the increase in yield, crop quality and profit is possible with careful reallocation of N throughout fields, although rates could be decreased to improve NUE. These results represent ten site years of data, five from 2021 and five from 2022.

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FLORAL HEMP RESPONSES TO NITROGEN FERTILIZATION IN THE HIGH DESERT

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ABSTRACT

The performance of floral hemp under N fertilization is influenced by environmental conditions, management, and cultivar selection. Greenhouse and field studies evaluated the effect of different levels of supplemental N fertilization on hemp cultivars (Berry Blossom, Red Bordeaux, and Tahoe Cinco) in Northern Nevada. Nitrogen increased plant height, canopy cover, stem diameter, and shoot biomass, but other physiological parameters were dependent on the cultivar. We evaluated the use of a SPAD meter for ease of determining leaf N deficiency, and correlations with leaf chlorophyll content showed that the SPAD meter was a reliable tool in two of the three cultivars but not in Tahoe Cinco. Nitrogen treatment increased overall CBD yield, which was driven by increases in inflorescence biomass. Our studies suggest that hemp may have a positive response to soil N management, but adjustments based on genotype by environment interaction should be aimed at maximizing cannabinoid yield either by increasing biomass and/or CBD concentrations.

INTRODUCTION

Cannabis sativa L. cultivation rapidly increased in the US after federal and state regulations considered hemp (with a tetrahydrocannabinol or THC concentration <0.3%) an agricultural commodity. Although hemp has multiple uses, the three most promising from a market perspective are fiber, oilseed, and pharmaceuticals (Cherney and Small 2016). Different cultivars are selected based on the target use (i.e., cultivars for CBD production differed from fiber cultivars). For fiber hemp, the stem and fiber quality of the cultivars is emphasized for their use in the fabric industry, building materials, and automotive purposes, and research on fiber hemp in Nevada is being conducted as well (e.g., Solomon et al., 2022). CBD production has generated much interest from very diverse stakeholders. Cannabinoids such as CBD are becoming popular for relieving pain, and are potentially useful for epilepsy, schizophrenia, and Alzheimer's (Laverty et al. 2019). For ranchers and farmers, hemp can become an alternative crop to help them increase the profitability of their operations; yet, as a non-insured crop, producers are at higher economic risk without clear management strategies.

Scarce information exists on hemp production guidelines, and before 2015, agronomic research on industrial hemp in the United States was lacking (Williams and Mundell 2018). This information gap can lead to the adoption of inefficient production methods, which could result in environmental impacts from increased erosion to non-point source pollution, affecting crop profitability in the long term. Recommendations on nutrient management for hemp are broad, scarce, and sometimes extrapolated from other growing regions or other cannabis production systems (e.g., Backer et al. 2019; Bernstein et al. 2019); recommendations are between 50 and 240 lb of N per acre (Papastylianou et al., 2018; Williams and Mundell 2018). Studies have reported environment-by-cultivar interactions, and differences in N requirements depending on the purpose of hemp production (Wylie et al., 2020; Aubin et al., 2016; Struik et al., 2000).

Our main research objective was to evaluate the responses of floral hemp cultivars to nitrogen fertilization in the field. We consider that increasing understanding of agronomic practices is pivotal to moving forward the hemp industry in regions with a challenging climate and environmental conditions (e.g., soils and short growing season) such as the Great Basin.

MATERIALS AND METHODS

Two separate studies on floral-hemp cultivar responses to N fertilization were conducted at the Valley Road Agricultural Experiment Station, University of Nevada, Reno. The greenhouse study included two cultivars Berry Blossom and Red Bordeaux, and the field study included those two cultivars and Tahoe Cinco. All cultivars were obtained from Plant Fuel Genetics, LLC. Seedling production was similar for both studies. Seeds were started in a greenhouse in seeding trays with a 3:2 ratio of potting soil (Miracle Gro Potting Mix, OH, USA) and medium, fine-grain sand (Quickrete, GA, USA). Two weeks after planting, seedlings were fertilized twice weekly with 0.28 ounces of 12-4-8 fertilizer per gallon of water (Miracle-Gro, OH, USA) until transplanted.

Greenhouse study: Seedlings were transplanted into three-gallon pots filled with the same 3:2 ratio of potting soil and sand (see above). After plant establishment (5 days), plants received, three times a week, two N treatments through watering: low N (42 ppm; N-) and high N (182 ppm; N+). The two N treatments consisted of modified Hoagland solutions with all other macro and micronutrients kept at the concentration of the full-strength Hoagland solution. At 38 days after transplanting (DAT), half of the plants in each N treatment were switched to the other N treatment to understand plant responses to changes in N availability. A total of nine to 12 plants were in each treatment group (N+, N+ to N-, N-, and N- to N+; 43 plants in the trials). Evaluations on canopy cover, biomass, and SPAD readings were conducted (see below) until the termination of the experiment at 15 weeks from the start of treatments.

Field study: Three-week-old seedlings were transplanted in the field in a randomized complete block design with four blocks total. Each block consisted of an N+ and a control (i.e., no additional N) treatment. Six drip lines (planting rows) conformed a block divided into two strips (main plots). Planting density was four feet between rows and three feet between plants (12 ft^2 per plant). Each plot had seven plants per row (21 plants per plot). Measurements were only conducted on the middle row or drip line within an N treatment, and the outer rows were considered buffers. The two most representative plants in the middle row were marked and used for all measurements (see below). Three rounds of 30 lb $acre^{-1}$ N were applied through fertigation (29, 46, and 59 DAT, totaling 90 lb $acre^{-1}$ N), using a urea solution injected with a fertigation pump (DEMA, MO, USA). Soil samples prior to the experiment indicated that organic matter was 2.89%, and nitrate, phosphorus, and potassium were 32 ppm, 10 ppm, and 156 ppm, respectively.

Morphological measurements

Plant height was measured from soil level to the apex of the main shoot. Stem diameter was measured 2.5 cm above soil level. Soil canopy cover images were taken every two weeks with an Agricultural Digital Camera, and pictures were pre-processed in PixelWrench2 (TETRACAM Inc., CA, USA). Images were then imported into R for analysis of canopy cover (R Core Team, 2019) as described in (Bristow et al., 2021).

SPAD measurements

SPAD measurements were conducted with the handheld portable fluorimeter MultispeQ (PhotosynQ Inc., MI, USA). The most recently mature leaf, third to fifth leaf down from the top of the canopy, was marked for measurements. The leaf was changed as needed between weeks of measurements as new leaves matured. Measurements were taken three times a week between 12:00 PM and 2:00 PM. Two measurements were recorded per leaf on the center leaflet avoiding the midrib.

Flowering time and inflorescence sampling

A plant was considered as flowering if clusters of pistils were present at the shoot apical meristem and axillary meristems (Spitzer-Rimon et al., 2019). The date of flowering was recorded and weekly monitoring continued until all plants reached the flowering stage. Inflorescence samples were taken at 90% of pistil dieback. The term dieback refers to the percentage of pistils that had turned from milky-white to orangey-brown, were dry and hardened. The 90% inflorescence samples were harvested on 111 DAT for Tahoe Cinco and 113 DAT for Berry Blossom and Red Bordeaux. Inflorescence samples were taken from two marked plants in the center of the plot and composited into one sample. Inflorescence samples were stored at -80 °C until processed.

Cannabinoid analysis

From each inflorescence sample, a ~5 g of fresh material was cut into smaller pieces and 1 g of it was placed into a glass scintillation vial with 30 mL of 100% ethanol (Koptec, PA, USA). The sample was homogenized with a handheld homogenizer (Pro Scientific, CT, USA) for 90 seconds. The solution was allowed to settle for 24 hours and 20 µL of supernatant was filtered through a 0.45 µm and 25 mm Nylon filter (Thermo Fisher Scientific, MA, USA) into a 2 mL amber glass vial (Thermo Scientific, TN, USA) with 80 µL of 100% ethanol for a 1:3 dilution. Glass vials were kept below 40ºC to avoid decarboxylation before HPLC analysis. Analytical cannabinoid standards were obtained from Restek (2018 Restek Corporation, PA, USA). External standards were prepared and HPLC methodology was followed as described in (Farnisa, 2022). The absorbance of cannabinoids was measured at λ = 238 nm for CBDA and THCA and 220 nm for CBD and THC with a bandwidth of 4 nm. Cannabinoid concentrations were calculated as total CBD = CBD + (CBDA x 0.877) and total THC = Δ^9-THC + (THCA x 0.877). CBD and THC concentrations were usually too low to routinely measure with a negligible concentration and peak area of approximately 0.05% or less.

Plant biomass

Plants were cut at 2.5 cm above soil level. Inflorescence clusters were harvested from the plants and fresh weight was recorded. Leaves and stems were combined and fresh weight was recorded. A subsample of the fresh inflorescence and shoot harvest were taken and dried in an oven at 60 °C and dry weights were recorded after 48 hours. Percent of subsample dry weights were used to calculate total dry biomass weights.

Statistical analysis

All statistical analysis was performed in R 4.0.2 software (R Core Team, 2019). The effect of 'treatment', 'cultivar', and their interaction (fixed effects) on the response variables was investigated using linear mixed-effect models (lme4 package). Random effects were chosen based on the Akaike information criteria (AIC) (ANOVA function, base R) and may have included 'block' or 'plot' with 'DAT' nested for response variables with repeated measures. Data were transformed as needed, and model assumptions were checked and met (performance package). Root mean square error was used to determine the best-fit model (lmerTools package). For analyzing effects on time to flowering, a generalized linear mixed effects model (lme4 package) on binary data with 'DAT' as a repeated measure was used. The alpha for all models was 0.05. Post-hoc multiple-comparisons were conducted by the unrestricted least significant difference (LSD) test with the multcomp function (emmeans package).

RESULTS AND DISCUSSION

Nitrogen fertilization was found to be important for the vegetative development of floral hemp, especially early in the growing season (Figure 1A). Shoot biomass increased and earlier flowering was observed in plants that received more N (Figure 1B and 2; respectively). Under field conditions, the existing level of N in the soil could determine decisions on N requirements, timing, and fertilization strategies for hemp (Finnan and Burke, 2013). For instance, soils with high inorganic N and organic matter can show a lower response to N fertilization (Struik et al. 2000). Hemp trials at the University of Nevada, Reno, have shown little response to N additions above 100 lb acre^{-1} (Barrios-Masias and Solomon, *unpublished data*). Under greenhouse conditions, hemp showed to be responsive to additional N even after 38 DAT (Figure 1A; N- to N+ treatment), suggesting that a delay in N fertilization may not be detrimental to final biomass production, and could benefit nitrogen use efficiency.

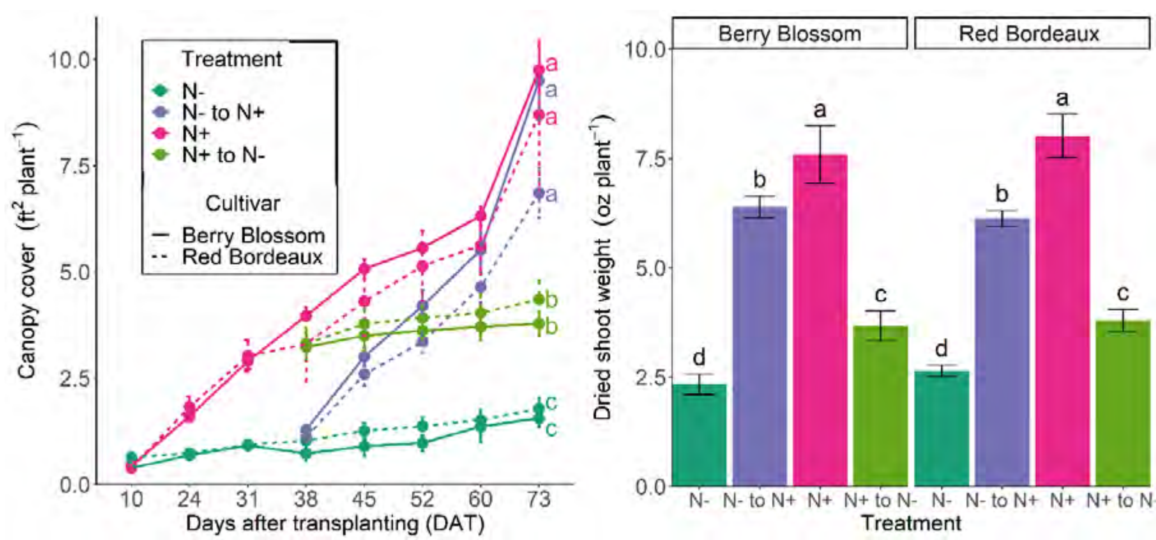

Figure 1. Greenhouse study showing aboveground biomass measured by soil canopy cover (A) and dried shoot weight (B) of hemp varieties grown with high or low N fertilization. At 38 DAT, half of the plants in each treatment were switched to the other N treatment to understand the effects of reduced or increased availability of N after plant establishment. Plants were harvested at 73 DAT before full flowering.

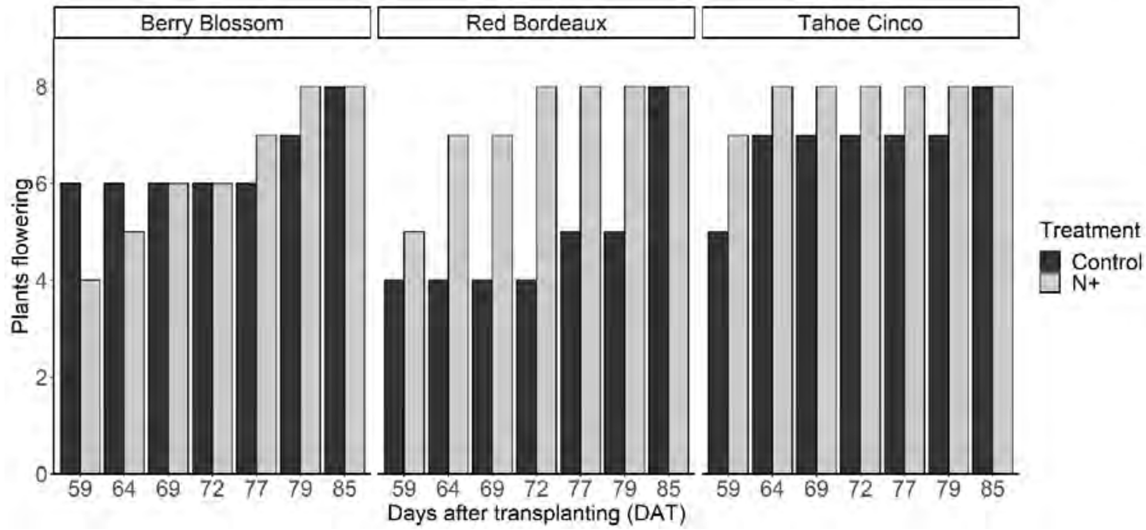

Figure 2. Field study showing the flowering time as days after transplanting (DAT) of three hemp cultivars under two N treatments.

Soil Plant Analysis Development (SPAD) measurements determine 'greenness' in a leaf and can be used as a proxy to indicate N deficiencies (Tang et al., 2017; Anderson et al., 2021). The greenhouse and field trials showed differences in SPAD readings between N treatments, except Tahoe Cinco, which showed no difference in SPAD (Figures 3A and 3B). Yet, differences in N concentration as a result of N treatment were observed in field hemp for all cultivars including Tahoe Cinco (Figure 3C). Overall, SPAD values, leaf chlorophyll, and leaf N concentration increased with higher soil-N availability, but cultivars responded differently, suggesting that the use of instruments based on 'greenness' should be calibrated to particular production conditions. For instance, the maximum SPAD readings of high N treatments in the greenhouse were lower than in the field, which could be a result of ~20% lower light intensity (i.e., photosynthetic active radiation) in the greenhouse than in the field. Our field SPAD measurements under control conditions were similar to Anderson et al. (2021) who suggested that SPAD readings below 44 indicated N deficiency. Thus, the use of a SPAD meter could be an easy tool to monitor nitrogen content in plants and help growers decide on their nutrient management plans if cultivar and environment are taken into account.

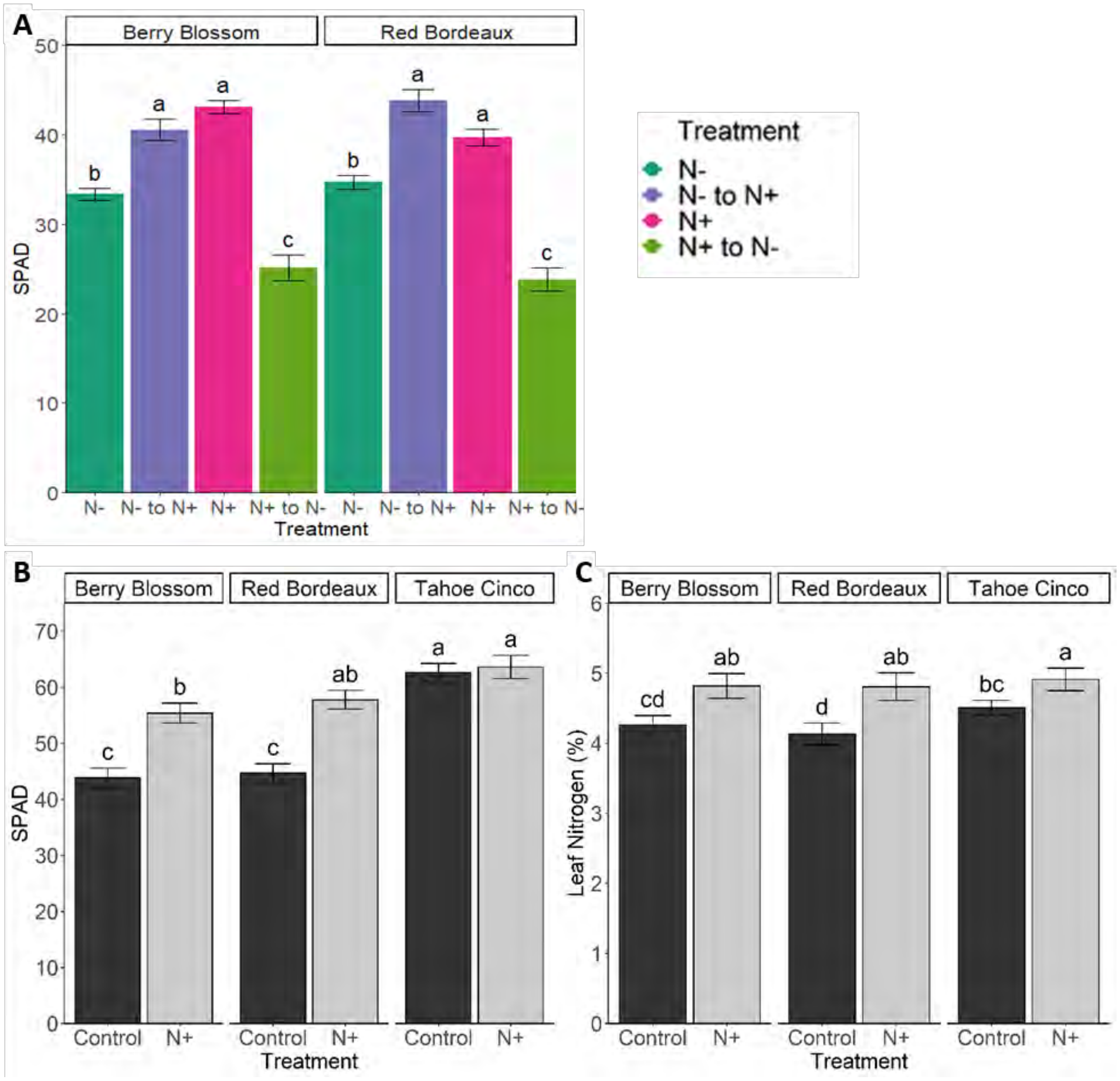

Figure 3. SPAD measurements in the greenhouse trial (A) and in the field (B), and leaf nitrogen content in the field (C) of hemp cultivars under low (N- or control) and high N (N+) availability. Measurements were taken during the peak of vegetative growth and initiation of flowering. Refer to Materials and Methods for specifics on greenhouse and field trial N treatments.

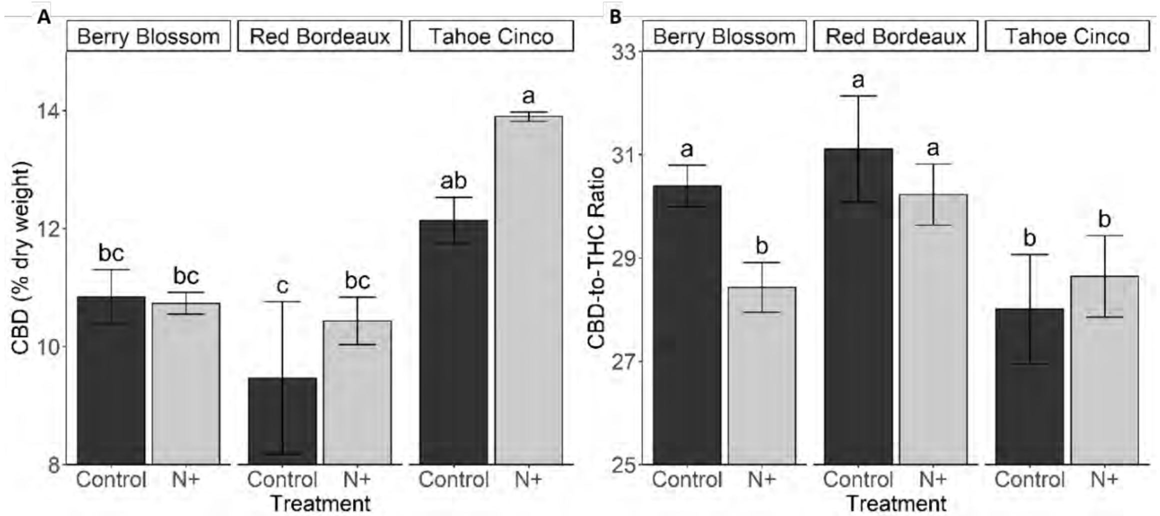

Figure 4. Field study showing CBD concentrations (A) and CBD-to-THC ratio (B) of three hemp cultivars under two N treatments. Measurements were taken when flowers showed a 90% pistil-die back.

CBD concentrations were found to be more dependent on cultivar than N fertilization (Figure 4). Yet, other studies have shown mixed effects of N on cannabinoid concentrations. Increases in N fertilization decreased CBD and THC concentrations by at least 10%, while overall higher cannabinoid concentrations have been reported in treatments receiving less N (Anderson et al., 2021; Saloner & Bernstein, 2021). On the contrary, Kakabouki et al. (2021) reported that CBD concentrations increased with N fertilization. In our study, the cultivar by N treatment interaction affected overall CBD yield as it was driven by increases in inflorescence biomass (data not shown), and suggests that cultivar is an important consideration to increase overall CBD yield per unit area while maintaining THC below 0.3%. Other studies have also shown that increasing N fertilization results in higher biomass and increases in CBD yield per plant (Atoloye et al., 2022; Caplan et al., 2017). Nonetheless, further understanding of how nitrogen affects cannabinoid accumulation patterns and inflorescence biomass can help growers select cultivars and plan nutrient management based on their particular environmental conditions.

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VARIABLE RATE N AND P MANAGEMENT FOR HIGH-VALUE VEGETABLE CROPPING SYSTEMS

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ABSTRACT

The Lower Colorado River Region (LCRR) of Arizona and California and their environs produce more than 90% of the nation's cool-season vegetables during the fall-winter-spring period. Large amounts of N and P fertilizers are currently utilized for maximum yield and quality. Phosphorus fertilizers are applied pre-plant based on a soil test of a composite field sample. Nitrogen is applied by side-dress based on a plant midrib or petiole N analysis, or soil nitrate-N test, from a composited field sample. The current practice is a single prescribed rate of P and then N over a large production block. The prospect of variable rate applications across a production block had not been evaluated. Studies conducted from 2014 to 2016 evaluated variable rate pre-plant P applications and studies conducted from 2018 to 2022 evaluated variable rate side-dress N applications compared to standard practices. Studies included lettuce (*Lactuca sativa*), broccoli (*Brassica oleracea italica*), and cauliflower (*Brassica oleracea botrytis*), the most common winter vegetable crops in the low desert. Conductance surveys were the principal basis for delineating management zones in all studies. However, we also evaluated 3-band active reflectance sensing implemented on-the-go as a potential tool in fertilizer decisions. The results show that zone management generally resulted in reductions in N and P fertilizer, compared to existing practices, with no positive or negative effects on marketable yield. Reflectance measurements showed trends associated with plant vigor but were highly dependent on the size of the crops at the time of side-dressing N fertilizer. Reflectance measurements alone were not consistent as a basis for driving variable rate fertilizer decisions, but it leaves ample room for the integration of other sources of information to increase accuracy. Zone management sometimes produced results inferior to high-resolution grid soil sampling, but the latter is not economically feasible

INTRODUCTION

The Lower Colorado River Region (LCRR) of Arizona and California and their environs produce more than 90% of the nation's cool-season vegetables during the fall-winter-spring period. Large amounts of N and P fertilizers are currently utilized for maximum yield and quality. In studies, we have shown most cool-season vegetables produced in the desert will respond to P fertilizers up to a sodium bicarbonate P soil test level of 30 to 35 mg/kg. As pre-plant soil tests approach these critical soil test P levels, the probability of crop response to P fertilizer drops dramatically. However, P fertilization based on a composite soil sample from a production unit assumes relatively uniform fertility within the unit, which is inconsistent with our findings. In high-resolution sampling of vegetable production fields in the desert, we have found large in-field variability in soil test P levels within production units (CVs from 18 to 90% usually exceeding 50%). It is reasonable to assume that a P fertilizer rate based on a composite soil sample results in parts of the field being under-fertilized and parts over-fertilized.

Nitrogen is applied by side-dress based on a plant midrib or petiole N analysis, or a pre-side-dress soil nitrate-N test, from a composite field sample. We have also found considerable variation in soil nitrate-N across a field before side-dressing. The prospect of variable rate applications across a production block had not been evaluated. The objective of these studies was to evaluate variable rate (VR) pre-plant P application and VR side-dress N applications for the economically important vegetable crops in Arizona.

METHODS

Studies conducted from 2014 to 2016 evaluated variable rate pre-plant P applications and studies conducted from 2018 to 2022 evaluated variable rate side-dress N applications compared to standard practices   Studies included lettuce (*Lactuca sativa*), broccoli (*Brassica oleracea italica*), and cauliflower (*Brassica oleracea botrytis*), the most common winter vegetable crops in the low desert. For the P studies, we compared grid and zone-based P management to the current grower's practice. However, for the N evaluations, we only compared zone management to current practices due to the economic limitations of high-resolution grid sampling schemes.

Conductance Surveys

Prior to planting, fields were surveyed using a Geonics Dual-dipole EM38 meter mounted on a mobilized assessment platform with an integrated sub-meter accuracy GNSS (Global Navigation Satellite System) receiver, with all survey and GNSS position data logged into an on-board portable computer. These pre-plant conductance surveys were performed for both P and N studies. These data were analyzed using the ESAP software package (https://www.ars.usda.gov/pacific-west-area/riverside-ca/us-salinity-laboratory/docs/esap-model/) and the spatial response surface sampling algorithm in the ESAP-RSSD program. At each sampling location, a single 1.2 m soil core was extracted using automated soil auguring equipment and split into four depth-specific 30 cm samples. The soil samples collected from each core were bagged, labeled, and subsequently used for chemical and physical analyses. Subsets of all soil samples were oven-dried to determine soil moisture content. The results of these surveys were used as a basis for defining management zones (Figure 1).

Soil testing

Pre-plant soil samples, the basis of pre-plant P fertilization, were collected by a management zone or on a grid sampling scheme to a 30 cm depth. The soil samples were bagged, labeled, and subsequently processed using a sodium bicarbonate extraction and colorimetric determination of P. Prior to N side-dress applications, multiple soil cores were collected to a 30 cm depth and composited within a zone. Soil samples were air-dried and extracted with 2N KCl. Total ammonium and nitrate N were determined colorimetrically. Ammonium was determined using the indophenol blue method, and nitrate was determined using Griess-IIosovay method after reduction with copperized cadmium. These both were measured using an ALPKEM RFA2 automated colorimeter.

VR Application

The application rig consisted of a CAT-II tractor with a 3-point hitch and conventional electric/hydraulic power ports. Trimble FMX (Sunnyvale, CA) GNSS equipment of RTK (real-time kinematics) correction level was installed in the power unit to provide the VR controller with real-time geographic position data. Both VR and GNSS displays were mounted inside the tractor cab. The application implement was built using a 20 ft wide (6-row), 3-bar frame of 4x4 inch steel bar. This frame supported the tank, hydraulic drive, pump, distribution lines, and injection shanks. Prior to field application events, this system was calibrated and tested to confirm the accuracy of controlled fertilizer delivery rates and field-ready conditions.

Spectral Sensing

A 3-point hitch tractor-mounted frame holding three ACS-430 active spectral sensors manufactured by Holland Scientific (Lincoln, NE). This array allowed surveying every-other row of the entire field. These sensors were fitted with three filters for the simultaneous acquisition of reflectance in the red (670nm), red-edge (730nm), and near-infrared (780nm) bands. Sub-inch precision GNSS equipment was used to geo-locate the sensor output while scanning the crops. At the vehicle speed and sensor refresh rate, this system recorded one data point every 11 inches in the direction of travel. This instrument setup provided high-spatial-resolution data (i.e. 10k georeferenced 3-channel spectral data points per acre).

N Tissue Testing

Tissue samples were collected within management zones two to three weeks after side-dressing and irrigation to track the impacts of variable rate application and for correlation to final yield. All tissue samples were oven-dried and ground. These samples were extracted to measure nitrate and digested using hydrogen peroxide and sulfuric acid to determine the total N. Nitrate in the tissue was determined using the method noted above for soils. Total N was determined using the indophenol blue method noted above.

Yields

We collected yields for this study a day before the commercial harvesters entered the field. Mature heads were cut, graded, and weighed in the field following a GNSS-referenced sampling protocol established to provide meaningful yield assessments in both the variable rate plots and the grower control.

Maps and Data Visualization

All geo-referenced data layers collected in this study from pre-plant to yield were mapped using contouring options and algorithms embedded in Trimble Ag Software. For variables with high spatial resolution such as soil conductance and 3-channel active spectral surveys, we employed the Average Method algorithm with a cell size of 125 ft. and maximum smoothing. For variables sampled on a point basis, we employed the Inverse Distance algorithm with a search radius ranging from 60 to 75 ft. and a cell size of 125 ft. with maximum smoothing (Figures 2, 3, and 4). Geographic mapping of soil/plant variables provides a framework for geostatistical analyses and a digital template to implement VR through the generation of output prescription (esri shape) files.

RESULTS

Over ten sites, yields were not significantly different between variable rate P management and current practices (GSP). In a few situations, variable rate-based applications resulted in a higher net P application rate than the grower standard practice (GSP) but not for most sites. The net fertilizer savings over all sites was 20% for grid and 12% for zone-based sampling schemes, compared to the GSP. However, the fertilizer cost savings often did not cover the additional costs involved in surveys, sampling, and sample analysis. Grid management was seldom economically feasible, even with the current high fertilizer process. The zone management was often not economically beneficial for the fertilizer prices that existed back in

2013 to 2017 period when we did this work. However, a more recent economic evaluation using current fertilizer prices shows more consistent positive economic outcomes to variable rate P management. This strategy may be immediately applicable where environmental issues restrict P fertilization rates.

The variable rate N studies are on-going, but results processed to date indicate consistent fertilizer savings with no reduction in yield. The vegetable industry is very competitive and uniformity, as well as yield, are sought-after objectives as multiple harvests increase costs to the shippers. Thus, growers often fertilize the entire field for the weak area of a field to achieve uniformity. This approach not only results in inefficient N use it potentially has other consequences. In fact, on one lettuce site, the excess fertilizer applied by standard practice resulted in high tissue N content and reduced yield in a management zone that called for a much lower N rate (see Figure 5 below). We are finding about a 20 to 30% saving in N fertilizer use by variable rate management compared to the current practice. At current fertilizer prices, the costs of soil survey and additional sampling are covered by these savings. The data we have collected suggest variable rate technologies provide a means of achieving optimal yield and uniformity with desirable economic and environmental outcomes.

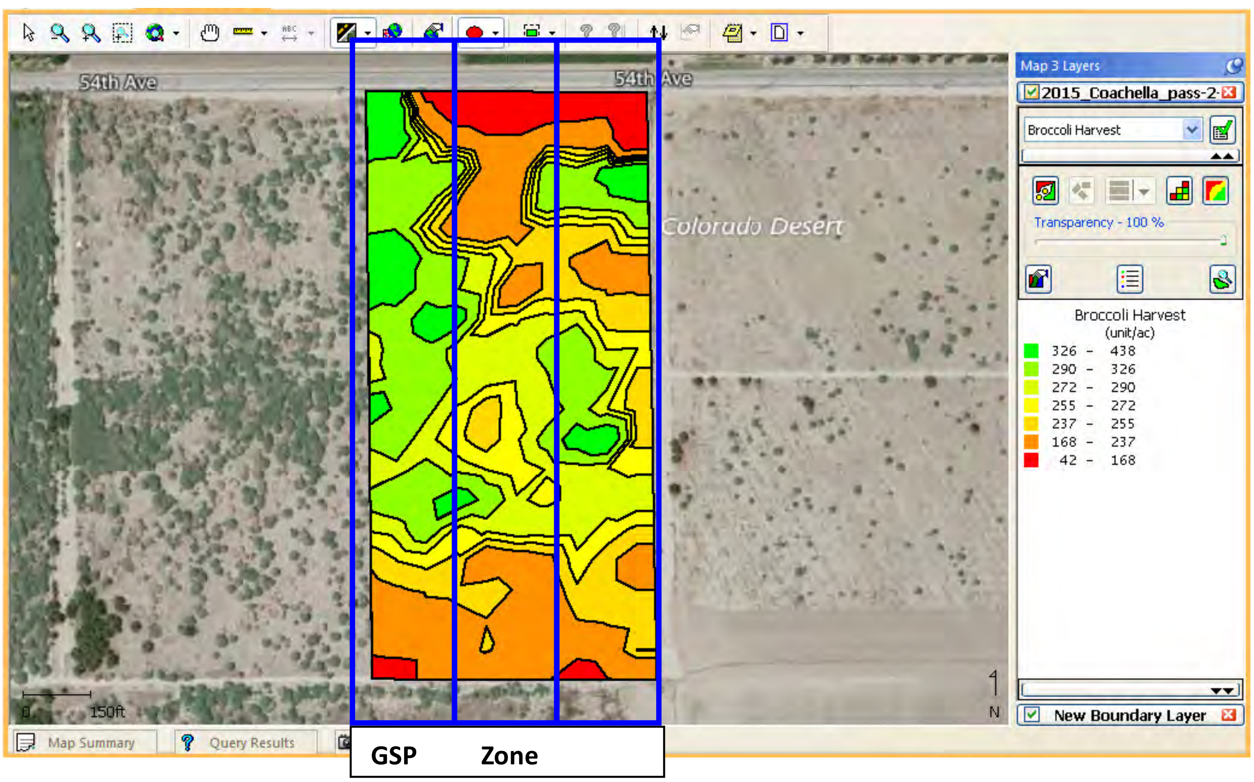

Figure 1. Broccoli field in the Coachella valley California split into Grid, Zone, and growing practice management areas.

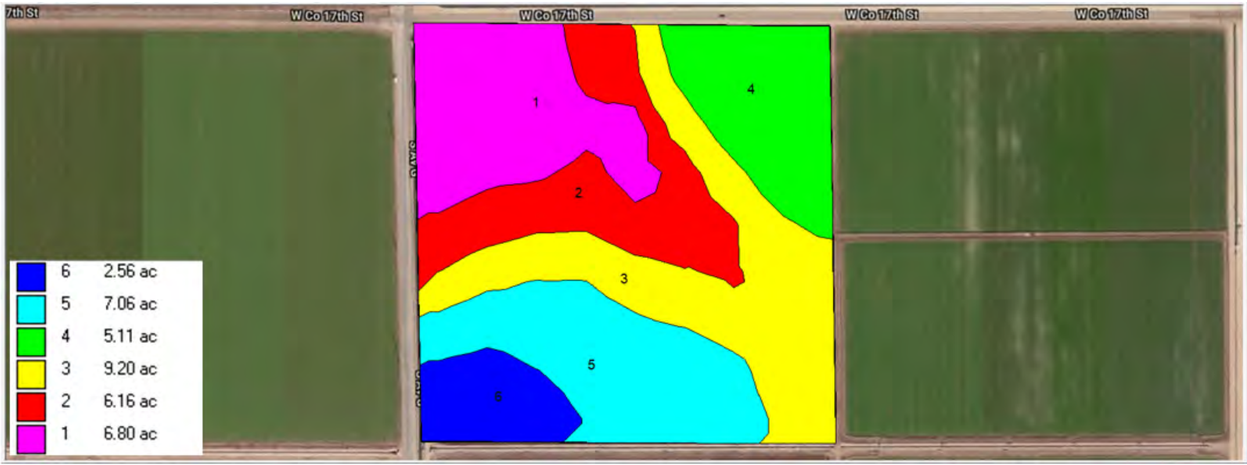

Figure 2. Management zones defined for lettuce production in an irrigation district south of Yuma, Arizona.

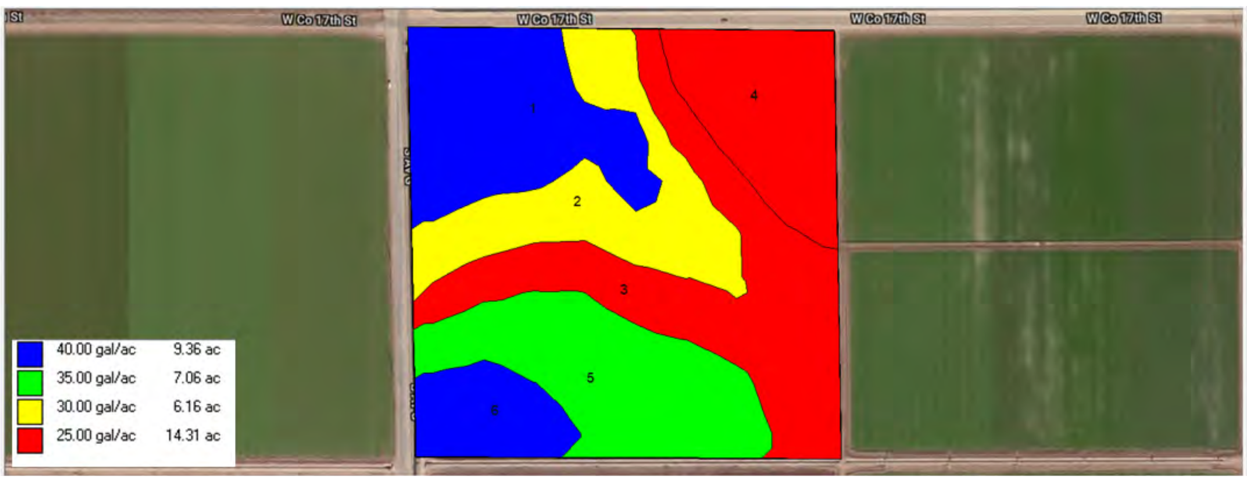

Figure 3. Nitrogen side-dress prescription map for lettuce field above. The grower used 60 gallons UAN 32 over the standard practice half of the field.

Figure 4. Nitrogen side-dress prescription map for lettuce in an irrigation district north of Yuma, Arizona.

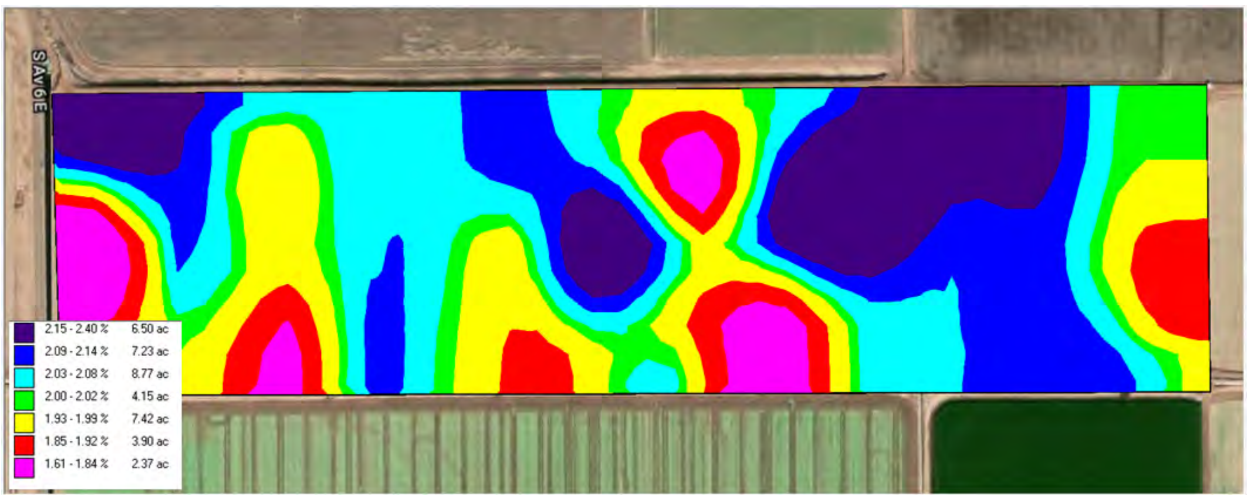

Figure 5. Measured leaf N content after side-dress for the site above.

SPOON-FED NITROGEN AND PHOSPHORUS MANAGEMENT FOR SUBSURFACE DRIP IRRIGATED COTTON (*GOSSYPIUM HIRSUTUM*)

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ABSTRACT

Subsurface drip irrigation (SDI) is becoming a popular option for maximizing the water use efficiency of cotton (*Gossypium hirsutum*), especially in semi-arid environments of the Midsouth and Western United States. Applying fertilizers through SDI provides an opportunity to prescriptively apply nutrients at peak nutrient demand which could minimize loss and increase uptake, but the application timing needs to be better understood. The objective of this study was to develop nitrogen (N) and phosphorous (P) fertigation strategies using SDI that increases nutrient use efficiency (NUE) and cotton lint yield. Two cotton varieties were grown to understand the impact of cotton development on nutrient uptake: DeltaPine (DP) B2XF 2143 (late-maturing variety) and DP B2XF 2020 (mid-maturing variety). Nitrogen was applied as urea ammonium nitrate (UAN) at three or nine respective timings for a maximum of 168 kg N ha^{-1}, and P was applied as phosphoric acid (PA) at one, three, or nine respective timings for a maximum of 50 kg P ha^{-1}. Cotton lint yield was determined, and the cotton plants were partitioned into their physiological components of stems, leaves, burrs, seed, and lint at first open boll. Each component was analyzed for nutrient composition using Inductively Coupled Plasma Optical Emission spectroscopy following nitric acid digestion. There was no difference between cotton varieties on cotton lint yield. Cotton lint yields were greatest with nine N and one P application timings. Generally, nine N applications resulted in greater lint yield compared to three timings; however, one application of P generated a greater amount of cotton lint compared to three or nine timings. Calcareous soils are common in semi-arid environments, and P adsorbs calcium and magnesium, making them unavailable for cotton uptake. A single application of P likely allows for P reversion throughout the cotton growing season, which provides for increased plant uptake. For N, greater applications of N probably minimized losses from denitrification and immobilization. Results demonstrate that prescriptive N fertilizer applications produce greater lint yield and reduce nutrient losses compared to greater quantities applied at fewer frequencies. Phosphorus is best applied as a single application for the greatest lint production.

INTRODUCTION

Subsurface drip irrigation (SDI) is becoming a popular option for maximizing the water use efficiency of cotton (*Gossypium hirsutum*), especially in semi-arid environments of the Midsouth and Western United States. In the Texas High Plains, where underground water resources from the Ogallala Aquifer are rapidly declining, there is increased adoption of water conservation technologies like center pivot and drip irrigation. In addition to increased water efficiency, drip irrigation also allows for more precise fertilization through fertigation with the application directly in the plant root zone. Applying fertilizers through SDI provides an opportunity to prescriptively apply nutrients at peak nutrient demand which could minimize loss and increase uptake. Still, the application frequency and timing are poorly understood. The objective of this study was to develop nitrogen (N) and phosphorous (P) fertigation strategies using SDI that increase nutrient use efficiency (NUE) and cotton lint yield.

MATERIALS AND METHODS

Cotton was planted at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX. The Center includes a recently installed SDI system with 67 zones that allows the flexibility and control to apply nutrients through fertigation to each zone precisely. Plots were four rows wide (40" spacing) by 68 ft long. Treatments were arranged as a split-plot design with four replications. Main plots were designated to variety and fertility treatments were assigned to split plots. The cotton varieties consisted of DeltaPine (DP) 2143 B2XF NR and 2020 B2XF planted at 53,000 seeds $acre^{-1}$. The fertility treatments consisted of 150 lb N A^{-1} as 32-0-0 at three or nine respective timings; and 45 lb P A^{-1} applied as phosphoric acid at one, three, or nine respective timings (Table 1).

Table 1. Application schedule for the 2022 growing season.

Applic: 1	Applic: 3	Applic: 9
7-Jun	7-Jun	7-Jun
		17-Jun
	24-Jun	24-Jun
		1-July
	8-July	8-July
		18-July
		29-July
		12-Aug
		26-Aug

Soil samples were collected on 17 March 2022 from each plot and analyzed by Ward Laboratories (Kearny, NE, USA) for residual nitrate (NO_3) and ammonium (NH_4), and P, potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), sodium, iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and boron (B) concentrations and soil pH and electrical conductivity. Cotton (DP 2143 and DP 2020) was planted on 27 May 2022. Fertilizer was applied via fertigation on 7, 16, 24 June, 8, 15, 18, 29 July, and 12, 26 August 2022 (Table 1).

At first open boll (3 October 2022), two 1-m rows of cotton plants were destructively sampled from each plot and separated into leaves, stems, burs/bracts, seed, and lint to determine the mineral concentration and determine nutrient uptake. Dry weights were collected, and samples were ground for analysis. Each component is in the process of being analyzed for mineral composition using Inductively Coupled Plasma Optical Emission spectroscopy following nitric acid digestion at Water's Agricultural Laboratories in Camilla, GA. We are waiting on the results. Cotton lint yield was determined from mechanical harvesting on 12 December 2022. Harvested samples were ginned on a scaled gin at Texas A&M AgriLife Research and Extension in Lubbock, TX. For High Volume Instrument analysis, ginned lint samples were sent to the Fiber and Biopolymer Research Institute (Texas Tech University, Lubbock, TX).

All statistical analyses were performed using SAS version 9.4 (SAS Institute, Inc., Raleigh, NC, USA). Data analysis was conducted using a generalized linear mixed model. (PROC GLIMMIX) with variety and fertility application treated as the fixed effect and replication as the random effect. Normality was determined using the Shapiro–Wilk test, and all data were normally distributed. Means of treatment effects were compared within variety using Fisher's least significant difference (LSD) at $p < 0.05$.

RESULTS AND DISCUSSION

There were no differences between cotton varieties on cotton lint yield, although DP 2143 generally outperformed DP 2020 (Figure 1). With DP 2020 and three N fertilizer applications, cotton lint yield was greater with zero, one, and three P applications than with nine applications. When N was applied in nine equal applications, lint yields were greater with one P application compared to the no P control and three applications. Regardless of variety, fewer P applications generally generated more cotton lint than three or nine applications.

Calcareous soils are common in semi-arid environments, and P adsorbs to and precipitates with calcium (and magnesium), making it unavailable for cotton uptake (Table 2). A single application of P likely allows for more significant P movement to plant roots via diffusion and desorption throughout the cotton growing season, which provides for increased plant uptake. Nine P applications may be causing antagonistic effects with zinc and possibly other micronutrients. Past work has demonstrated greater P uptake with nine applications even though lint yield was reduced. This leads us to hypothesize an antagonistic effect of increased P uptake reducing the uptake of other essential elements. Results demonstrate that prescriptive N fertilizer applications result in greater lint yield and minimize nutrient losses compared to greater quantities applied at greater frequencies. For N, greater applications of N likely minimized losses from denitrification and immobilization.

SUMMARY

Results suggest that fewer applications and larger doses of P fertilizer fertigated during the growing season result in greater lint yield regardless of cotton variety. The frequency and dose of N fertilizer did not appear to influence cotton lint production. Given the limited amount of information generated from a single site year, recommendations cannot be made. Additional research is being conducted and will be available in late 2023.

Table 2. Soil characteristics of the research plot at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX, to a 36-inch depth.

Depth	pH	EC	NO_3N	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
		umhos/cm	------	------	------	------	------	ppm	------	------	------	------	------
0-6"	7.74	523	14	22	322	2344	528	38	64	4.3	0.21	10.2	0.73
6-12"	8.09	421	13	6	258	2840	672	29	73	3.3	0.15	5.5	0.67
12-24"	8.19	458	9	5	249	4723	707	28	98	5.0	0.13	4.4	0.85
24-36"	8.00	781	35	11	201	4707	477	65	167	4.1	0.12	4.3	0.87
Average	8.00	546	18	11	257	3653	596	40	101	4.2	0.15	6.1	0.78

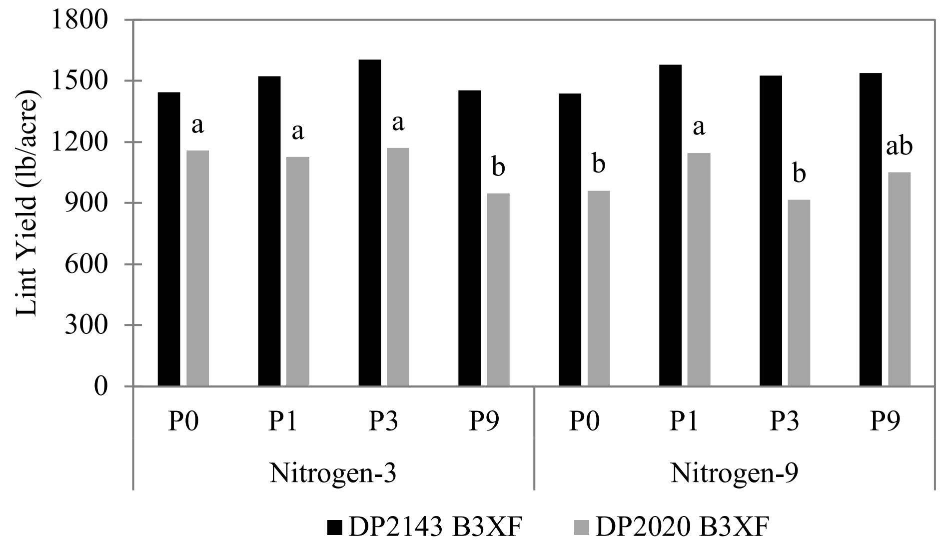

Figure 1. Cotton lint yields for two varieties, two nitrogen fertilization timings, and four phosphorus (P) fertilization timings at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX. Letters represent significant differences between phosphorus fertilization frequency within cotton variety and nitrogen application frequency. Differences were only determined for DP 2020 B3XF but not DP 2143 B3XF.

PERFORMANCE OF PUBLIC AND PRIVATE FERTILIZER RECOMMENDATIONS FOR CORN, ALFALFA, AND SMALL GRAINS

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ABSTRACT

There are many sources that growers utilize to determine fertilizer needs for crops such as private and public labs, crop advisors, and fertilizer dealers. In many cases, these sources provide recommendations for a specific crop that can vary greatly, and the resulting fertilizer and application rates recommended can lead to large differences in costs for the grower. Evaluating the effectiveness and economics of current fertilizer guidelines and recommendations will help growers to make better-informed decisions about recommendation sources and fertilizer levels. An experiment was established in 2021 with 12 sites across the state of Utah in alfalfa, small grains forage, and corn to test and compare fertilizer recommendations from five labs. The recommendations tested were from two public labs (Utah State University and the University of Idaho) and three private labs located in the Western United States. Based on a large composite soil sample sent to multiple labs, the corresponding macronutrient and micronutrient rates recommended by each lab were then applied in four replications at each site. All fertilizer products were broadcast-applied as granular products in the spring of 2021. Results from 2021 showed little to no differences in crop yield or forage quality between the five recommendations and the nonfertilized control. Trials at seven of the sites were repeated in 2022 to confirm results, with little to no differences being observed in the second year. Thus, over two seasons and 37 total harvests, there were few differences in yield and forage quality between fertilizer recommendations and the nonfertilized control. In the few cases where production was improved, the nonfertilized control was still the most profitable. The cost for each of the recommendation treatments varied greatly ($350-$1,800 per acre). These results do not indicate that fertilizers are unnecessary, but that there are large differences in recommendations and room for improvement and public-private coordination.

INTRODUCTION

Fertilizer bills can contribute to some of the highest input costs on the farm. Applying the right amount, at the right time, and in the right way can drastically influence farm profits. Too little or too much fertilizer can hurt the bottom line, prompting many growers to seek outside help for making these important decisions.

The most common sources for fertilizer recommendations are from private and public soil testing labs, crop advisors, fertilizer dealers, and university extension services. Private labs are sometimes criticized for being too liberal with their fertilizer recommendations and public labs for being too conservative. These differences make it difficult for farmers to know where to get the best recommendations from. While both public and private advisors actively try to avoid or correct nutrient deficiencies to help growers thwart yield and profit loss, these efforts can sometimes lead to excessive and unprofitable fertilizer recommendations. Unbiased comparisons of the most common fertilizer recommendations from public and private sources are needed to help growers improve their nutrient management practices. This need prompted a set of on-farm research trials in Utah to investigate how various fertilizer recommendations perform. Few previous studies have compared how various recommendations perform (Follet and Westfall, 1986; Follet et al., 1987; and Jacobsen et al., 2002). The objective of this research is to evaluate and compare the fertilizer recommendations from several public and private soil testing labs based on how they impact crop yield, quality, and economic returns.

METHODS

The field research for this experiment was conducted in 12 fields on farms across the state of Utah in corn, alfalfa, and small grains in 2021 to test and compare the fertilizer recommendations of five labs. The recommendations tested were from two public labs [Utah State University (Cardon et al., 2008) and University of Idaho] and three private labs located in the Western United States. A single, large composite soil sample from the 0-12 inch depth from each field was dried, ground, split, and sent to each of the labs for analysis. Each of the labs was also given information such as previous crop, current crop to be grown, and yield goal to calculate recommendations. The macronutrient and micronutrient rates recommended by each lab were then applied in four replications at each of the 12 fields. A control with no fertilizer applied was also included.

All fertilizer products were broadcast-applied in the early spring of 2021 as dry granular products due to difficulty in applying isolated liquid fertilizers to small plots. Fertilizer products were chosen to isolate nutrients as much as possible so that precise amounts of nutrients could be applied together. For example, triple super phosphate and ammonium nitrate were used to isolate phosphate and nitrogen rather than more commonly used fertilizer mixes.

In 2022, the trials were repeated at 7 of the 12 sites to confirm results. Due to logistics and additional time to plan and prepare for trials in 2022, a composite sample was collected for each of the six treatments rather than a single composite for the entire plot area. Soil test values from the 2022 samples were used to develop and apply the new recommendation in 2022. This was completed by treatment and the treatment locations were not changed. The dry, granular micronutrients (Zn, Mn, B, and Cu) were replaced with liquid forms of the isolated nutrients to provide more uniform application of the micronutrients over the plots.

In both years, crop yield was measured in all plots using standard hand-harvest methods or farm-scale machinery. All yield samples were dried, ground, and scanned with NIRS to determine common crop quality parameters for corn, alfalfa, and small grain forage. Fertilizer prices were obtained from local fertilizer cooperatives, and we utilized separate fertilizer prices in both years for the economic assessment, so prices were reflective of the conditions in the study years. The 2021 prices (spring of 2021 when fertilizer was purchased) were much lower than in 2022 due to the rapid increase in fertilizer prices during 2021-2022.

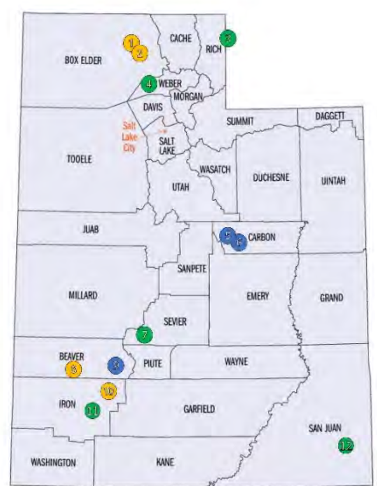

Figure 1. Map of 12 research sites. Green = alfalfa, Blue = small grain forage, Yellow = corn.

The 12 fields in this experiment represented a large range of soil organic matter levels (0.9 – 3.1%) and a range of soil textures (gravelly sandy loam to silty clay loam). They were also located in several regions of Utah and represented various elevations and growing environments (Figure 1).

Table 1. Background information for site locations.

Farm #	Crop	Soil pH	Organic Matter %	Soil Texture	Max Difference in Costs Among Labs 2021 ($/ac)	Max Difference in Costs Among Labs 2022 ($/ac)
1	Corn	8.2	2.2	Silt Loam	564	1771
2	Corn	7.5	3	Loam	704	1328
3	Alfalfa	8.2	2.6	Silt Loam	233	443
4	Alfalfa	7.7	0.9	Loamy Fine Sand	791	1222
5	Small Grains	8.1	2.5	Silty Clay Loam	224	878
6	Small Grains	8.1	2.9	Silty Clay Loam	201	740
7	Alfalfa	8	1.8	Gravely Sandy Loam	657	845
8	Corn	7.9	2.5	Silty Clay Loam	362	853
9	Small Grains	7.6	3.1	Loam	341	351
10	Corn	8.1	2.5	Loam	418	962
11	Alfalfa	8	1.9	Silty Clay Loam	540	1333
12	Alfalfa	7.8	1.9	Fine Sandy Loam	439	836

RESULTS AND DISCUSSION

How much did soil test values vary among labs?

For the single composite samples analyzed in 2021, soil nutrient levels varied among labs. A moderate level of variation is expected because the same soil cannot be analyzed twice. Most measured soil nutrients (K, Zn, Mn, B, Cu) varied about 20% among labs, others (N and P) varied around 35%, and sulfur (S) varied the most at 62% among labs.

These variations in soil nutrient concentrations caused some of the differences in the amount of fertilizer recommended, but most of these differences were due to differing calibrations and critical values utilized by each lab. The nutrients recommended and fertilizer rates varied greatly among labs. For example, the three macronutrients (N, P, K) varied across the 12 fields by an average of 118, 66, and 140% among labs, respectively. Micronutrients were recommended by private

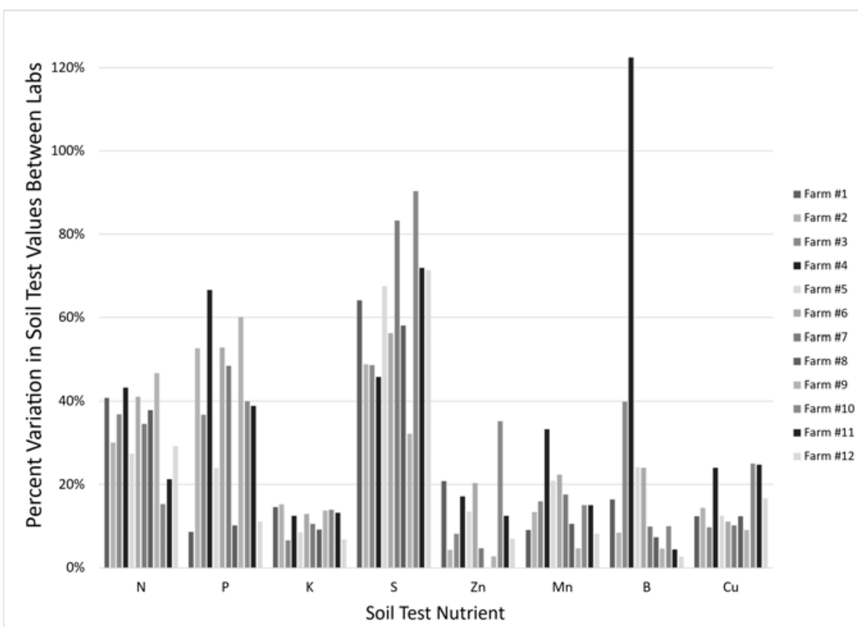

Figure 2. Variation in soil test results among for three private labs (#1, 2, and 3) and two public labs (Utah State University and University of Idaho).

labs more frequently than by public labs and varied by more than 200% among the five labs. Zinc, Manganese, Sulfur, and Boron were commonly recommended by the private labs.

How much did recommendations vary among labs?

The variation among labs between recommended nutrients and application rates resulted in large cost differences among recommendations. The two public labs cost an average of $320 to $530/acre across the 12 fields and the three private labs varied $375 to $1,120/acre. The difference in the fertilizer recommendation costs among the five labs ranged from $350 to $1,770/acre across the 12 fields. Application costs are based on fertilizer prices paid in late-spring 2022.

Soil test values from samples collected in the spring of 2022 from 10 sites from each of the six treatments were compared to those from 2021 to monitor changes in soil nutrient concentrations. For some of the main nutrients (N, P, K, and S), the nonfertilized control often experienced the smallest percent changes in soil test values (Figure 3). On average, soil test nitrogen values changed 17-151% in treatments where lab recommendations were applied, compared to 11% in the control plots. Labs recommended 40-115 lbs/acre of N on average across all sites. Phosphorus changed 29-105% for fertilized plots (70-220 lbs/acre) compared to 24% for the control. Potassium concentrations decreased 12-27% for lab treatments (17-136 lbs/acre) and the control decreased 12%. Sulfur value changes ranged from -31% to 42% for fertilized (9-47 lbs/acre) plots and decreased 5% for the control plots.

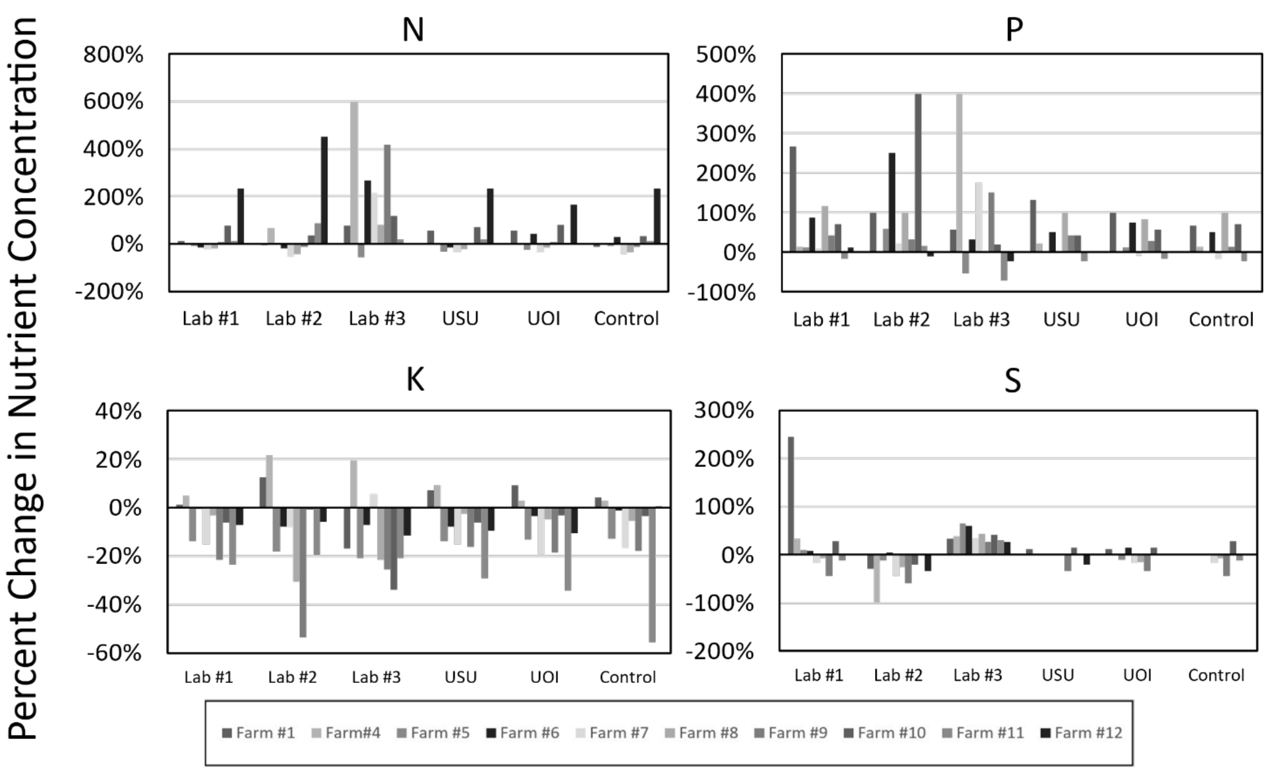

Figure 3. Percent change of soil test nutrient concentrations from 2021 to 2022 by treatment for three private labs (#1, 2, and 3) and two public labs (Utah State University and University of Idaho).

How did recommendations perform?

Results from 2021 indicated that there was little to no statistical difference in crop yield among the five fertilizer recommendations and the control, where no fertilizer was applied. Across the four corn fields, there was no statistical difference in crop yield or forage quality between treatments. Due to fertigation by cooperating growers, all plots, including the control were fertilized with nitrogen. This addition of nitrogen on the control plots may be why no improvements with the lab treatments were observed but results still indicate that no other nutrient besides nitrogen was needed to improve corn yield.

The five fertilizer recommendations also had no effect on alfalfa yield or forage quality at five fields with a total of 16 alfalfa cuttings (2-4 cuts at each field). No effects of treatments were observed at two of the three small grains fields. At one small grain site, Farm #6, one private and one public lab recommendation (Lab #1 and USU) increased small grain yield by 1 ton dry matter/acre above the nonfertilized control (Figure 4). The public lab's fertilizer recommendations improved yield enough to make it more profitable than the nonfertilized control, but the private lab's yield increase was not substantial enough to cover additional fertilizer costs.

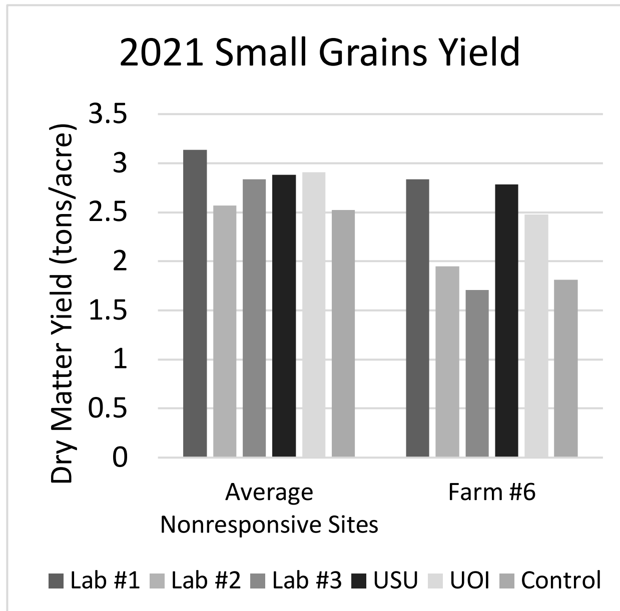

Figure 4. Differences in small grains forage yield due to fertilizer treatments in 2021.

Results from 2022 were similar to those from 2021, with little to no statistical difference in crop yield or forage quality at the seven sites where the experiment was repeated. In the two corn sites, the fertilizer treatments had no effect. No differences between treatments were observed at two of three alfalfa sites or at either of the small grains fields. In one alfalfa field, USU's recommendation yielded slightly lower than any of the other treatments. No differences in forage quality between treatments were observed at any of the sites. In most cases, yield increases resulting from the lab recommendations were not large enough to make the treatments more profitable than the nonfertilized control. In 2022, there was one field where the USU treatment was more profitable than the nonfertilized control, and several other cases where lab recommendations came very close.

CONCLUSIONS

In summary, over two seasons and 37 total harvests, few differences in yield or forage quality were observed between the five fertilizer treatments and the unfertilized control, but the cost of these treatments varied greatly. Even in cases where treatments improved production, the nonfertilized control was still almost always the most profitable. In several fields, the USU recommendation had comparable return to N as the control and in one case it had greater return to N than the control. This suggests that Utah State University guidelines are among the most profitable but that there are still cases where fertilizer recommendations need to be reduced or adjusted.

The results of this study do not indicate that fertilizer can always be withheld on these or similar fields. Many nutrients can have long-lasting impacts on crop production for several years. It does mean that there is a large opportunity to improve public and private fertilizer recommendations. It also demonstrates vast differences in fertilizer recommendations and costs among private and public labs, and points towards the need for better synchrony among recommendations.

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CROPMANAGE DECISION SUPPORT TOOL FOR IMPROVING IRRIGATION AND NUTRIENT EFFICIENCY OF COOL SEASON VEGETABLES IN CALIFORNIA: A DECADE OF FIELD DEMONSTRATIONS AND OUTREACH

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ABSTRACT

Vegetable growers on the central coast of California are under regulatory pressure to reduce nitrate loading to ground and surface water supplies. California is also implementing the Sustainable Groundwater Management Act (SGMA) which may limit agricultural pumping in regions such as the central coast where the aquifer has been over-extracted for irrigation of crops. Growers could potentially use less N fertilizer, address water quality concerns, and conserve water by improving water management and matching nitrogen applications to the N uptake pattern of their crops. Two tools available to growers, the soil nitrate quick test (SNQT) and reference evapotranspiration (ETo) data from the California Irrigation Management Information System (CIMIS), have been shown to help better manage water and fertilizer nitrogen in vegetable production systems. However, the adoption of these practices has not been widespread. One reason may be that these techniques can be time-consuming to use, and vegetable growers have many crops for which they make daily decisions on fertilization, irrigation, pest control, and tillage. To address the time constraints in managing water and fertilizer on a field-by-field basis, a web-based software application, called CropManage (CM) (cropmanage.ucanr.edu) was developed to facilitate the implementation of the SNQT and ET-based irrigation scheduling in 2011. Additionally, CM enables growers to quickly estimate the N fertilizer contribution from background levels of nitrate in their irrigation water. Since launching CM, trials were conducted in commercial vegetable fields on the central coast to evaluate the accuracy of the fertilizer and irrigation recommendations and provide outreach on irrigation and nitrogen management to growers, farm managers, and irrigators. The main crops evaluated were head and romaine lettuce, and broccoli. The results of these trials demonstrated that in many situations significant savings in water and fertilizer could be attained compared with the grower standard practice by following the CropManage recommendations without jeopardizing yield or quality.

INTRODUCTION

The central coast of California, which has a mild Mediterranean climate, is a major producer of vegetables consumed in the US. Inputs for the production of vegetables in this region are intensive. Most medium to large vegetable production operations produce two to three crops per field each season in small plantings ranging from 5 to 15 acres. Due to their high value and the importance of quality, cool-season vegetables are typically fertilized and irrigated to achieve maximum yield. Because only a portion of the N taken up by these crops is removed in the harvested product, crop residues incorporated into the soil typically breakdown rapidly and mineralize significant amounts of nitrate-N, which can easily be leached during irrigations. As a result of intensively producing vegetables over many decades, much of the groundwater underlying these valleys have nitrate concentrations greater than the US EPA drinking water standard of 10 ppm N. Additionally, over-extraction of groundwater for irrigation has led to saltwater intrusion into the aquifers near the coast.

Growers on the central coast currently face water quality regulations that will restrict the use of nitrogen fertilizer. The Agriculture Order adopted by the Central Coast Regional Water Quality Control Board (CCRWQCB) in 2021 requires that growers estimate nitrogen loading to groundwater through annual reports of applied nitrogen and nitrogen removed in the harvested product. The Ag. Order sets limits on how much loading of nitrate to the groundwater will be allowed in the future. Additionally, the Sustainable Groundwater Management Act (SGMA), passed by the state legislature after the drought in 2014, will limit pumping in basins where groundwater has been severely depleted.

Growers could potentially use less N fertilizer, address water quality concerns, and conserve water by improving water management and matching nitrogen applications to the N uptake pattern of their crops. Two tools available to growers, the soil nitrate quick test (SNQT) and reference evapotranspiration (ETo) data from the California Irrigation Management Information System (CIMIS), have been shown to help better manage water and fertilizer nitrogen in vegetable production systems. The SNQT was introduced to central coast vegetable growers in the early 2000s (Hartz et al., 2000) and ET-based scheduling of irrigations was made possible on the central coast with the establishment of a network of CIMIS weather stations in the 1990s. However, the implementation of these tools by vegetable growers has not been widespread. One reason may be that these techniques can be time-consuming to use, and vegetable growers typically have many crops for which they make daily decisions on fertilization, irrigation, pest control, and tillage. To address the time constraints in managing water and fertilizer on a field-by-field basis, a web-based decision support tool, called CropManage (CM) (cropmanage.ucanr.edu) was developed to facilitate the implementation of the SNQT and ET-based irrigation scheduling in 2011 (Cahn et al., 2015, 2022). Additionally, CM enables growers to quickly estimate the N fertilizer contribution from background levels of nitrate in their irrigation water and maintain records of water and fertilizer applications for regulatory compliance.

Since the initial release of CM, outreach efforts combined with the expansion of supported crop types and improved model accuracy have helped widen the acceptance of CM as a decision support tool. This paper presents the results of trials conducted in commercial broccoli, head and romaine lettuce fields where fertilizer N and/or water applications were guided by CM and compared with a grower standard practice.

METHODS

Software description

CropManage is a database-driven web application hosted on Amazon Web Service. It was first launched to the public in 2011 and has since undergone several major updates to stay current with changes in online software technology. Users can access CM through a web browser on their smartphone, tablet, laptop, or desktop computer. The user interface was developed in concert with collaborating growers and designed to be intuitive for users to navigate. To begin using CM, growers follow an onboarding routine to enter information about their ranches or farms, such as locations of fields, soil types, fertilizer types, and source of weather data. CM uses web tools, such as Google Maps and UC Davis SoilWeb to facilitate this process. A structured query language (SQL) database manages information associated with ranches, fields and plantings within fields, which are used to drive the irrigation and N fertilizer decision support models. The database minimizes the necessity for the reentry of information each time an irrigation or fertilizer application is made. CM is designed so that multiple users from the same farming operation can view ranch and crop information.

CM automatically retrieves reference ET data from CIMIS, and uses a crop coefficient model based on canopy development to estimate crop water requirements. Cahn et al. (2022) summarizes the irrigation equations used in CM, which are based on Gallardo et al. (1996) and FAO56 (Allen et al 1998). Fertilizer N recommendations are based on comparing soil nitrate test values with a threshold for optimal growth and by estimating future crop N needs using N uptake demand curves. Crop N uptake of many cool season vegetables has been intensely researched during the past decade through field sampling of commercially grown crops (Bottoms et al. 2012, Smith et al. 2016). The N fertilizer recommendation is also adjusted by crediting for N available in irrigation water, and N mineralization from soil organic matter and crop residues.

Outreach

CropManage has been extended to the vegetable industry through various approaches, including presentations at industry meetings, hands-on trainings, and field demonstrations. Presentations at industry meetings introduce the decision support tool to growers, consultants, and farm managers, and demonstrate the potential benefits of the application for improving water and nutrient management on a field-by-field basis using site-specific data about the crop, soil type, and weather. Hands-on training provides an opportunity for clientele to receive intensive instruction on how to use the online tool, and adapt it to their farming operation. During three to four-hour trainings, participants learn how to set up their farm on CM, create and customize plantings, and retrieve recommendations on water and fertilizer applications. Participants are encouraged to bring a tablet or laptop computer to complete a series of exercises during the training. Local trainings are conducted in groups of 20 to 30 participants, or on-site with a small group from a farming operation.

Commercial field trial demonstrations have been conducted to compare the irrigation schedule and fertilizer management of the grower with CM recommendations. At most field sites, a flow meter interfaced with a datalogger was installed on the mainline of the irrigation system to automatically retrieve and post irrigation events in CM. Soil moisture sensors, such as tensiometers or volumetric sensors, were sometimes installed in demonstration fields to verify that the crop received adequate soil moisture. The SNQT was used to monitor nitrate concentration in the root zone of the crops. Field demonstrations offered an opportunity to train staff on how to make decisions on irrigation and N fertilizer applications using CM. In many cases, growers were also interested to experiment with reducing water and/or N fertilizer applications during the trial by following CM recommendations, or an intermediate level between the CM recommendation and the grower's standard practice.

Commercial scale field trials

Twenty-six field trials were conducted in commercial broccoli, head and romaine lettuce fields across 16 farms in the Salinas Valley between 2012 and 2019. These trials served to both validate the CM algorithms and to demonstrate potential savings in nitrogen fertilizer and/or water. The trials presented in this paper were conducted in large plots (0.25 to 1-acre areas), where treatments were not replicated. Both the CM and standard treatment plots were established adjacent to each other in the same field and were usually more than 30 ft wide and the length of the field to accommodate an evaluation of yield using commercial equipment and professional harvest crews. Water and nitrogen fertilizer applications were applied to the plots separately. Applied water volumes were monitored using flowmeters. All irrigation and fertilizer applications and soil test results for the treatments were archived in CM. Irrigation methods included sprinkler, drip, and furrow, but at most sites, the crops were established with sprinklers and irrigated by drip thereafter. Soil textures varied from sandy loam to clay loam among field sites. Relative yield was calculated for the CM treatment relative to the grower standard. Yield and relative yield data for the CM and grower standard practice were statistically compared using SAS general linear means procedure, where each site was considered a replication of the CM and grower standard treatments.

RESULTS AND DISCUSSION

Approximately 60 introductory presentations on the decision support tool have been made at industry meetings to date, and 42 hands-on trainings have been conducted throughout California. Approximately 280 field demonstrations were conducted in commercial vegetable fields during this period by UC advisors, crop consultants, resource conservation district staff and vegetable industry staff. More than 3,300 users created CM accounts, and the online tool has provided more than 63,000 irrigation and 20,000 fertilizer recommendations to users during the past decade. Users entered almost 15,000 SNQT values into the decision support tool.

Field trial results comparing CM and standard practices demonstrated that the CM decision support tool can save substantial amounts of nitrogen fertilizer and water without jeopardizing yield. Total water savings averaged 27% relative to the grower standard across the 5 broccoli field trials (Table 1). Water savings averaged 34% relative to the grower standard practice during the period after crop establishment, which was when CM recommendations could be implemented. Nitrogen fertilizer savings in the 3 broccoli trials where N management was an objective were 24% relative to the standard. Broccoli yields were not statistically different between treatments with the CM plots averaging 98% of the yield of the grower standard.

The trials demonstrated an average of 31% savings in fertilizer N relative to the standard practice, where the CM treatment and grower standard averaged 104 and 151 lbs N acre^{-1}, respectively (Table 2). Fertilizer savings were mainly achieved by crediting for residual mineral N in the root zone of the soil and N available from irrigation water. For some trials (sites 8,9,12,13, and 18), the fertilizer N rate of the standard practice may have been lower than is typically used because the growers were experimenting with reducing fertilizer N applications. The average N fertilizer rate for lettuce reported to the CCRWQCB by growers on the central coast for years 2014 – 2017 was 183 lbs N acre^{-1}. Hence potential N savings following the CM recommendations could be as high as 43%.

Water management was an objective for only 6 of the 15 lettuce trials and on average applied water volumes were similar between CM and grower treatments. This result is likely because lettuce is usually over-irrigated during germination (crop establishment) and often under-irrigated later in the season. CM recommendations were only implemented after plants were established in these trials. In some of these trials (sites 11,12,14, and 16) water was reduced under the CM treatment by an average of 15% after establishment, but in the other trials (sites 13 and 15), the grower standard irrigated less than the CM treatment.

Across all sites yields of lettuce under the CM treatment were generally equal to or higher than the grower standard (averaging 107% of the yield of the grower standard), and were not significantly different between the two management regimes.

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Table 1. Applied water, N fertilizer, and yields of large-scale commercial field trials in broccoli comparing CropManage (CM) recommendations with a grower (Grower) standard practice. Trial objectives are noted as nitrogen management (N), water management (Water) or both (Water/N)

					Applied water				
Site #	Objective	Year	Crop	Treatment	Total	Post Establishment	Applied N	Commerial Yield	Relative Yield
					------- inches -------		----- lbs/acre ----		%
1	Water	2013	broccoli	CM	20.4	12.9	166	14741	105
				Grower	33.5	26.1	166	14006	100
2	Water	2013	broccoli	CM	19.6	15.2	187	20382	97
				Grower	35.4	31.0	187	20930	100
3	Water/N	2015	broccoli	CM	20.4	16.2	154	12897	93
				Grower	23.1	18.9	169	13934	100
4	Water/N	2015	broccoli	CM	16.0	11.2	118	7746	96
				Grower	15.5	10.7	206	8068	100
5	Water/N	2017	broccoli	CM	12.7	9.6	165	13067	97
				Grower	15.0	12.3	199	13472	100
Average				CM	17.8	13.0	158	13766	98
				Grower	24.5	19.8	185	14082	100

Table 2. Applied water, N fertilizer, and yields of large-scale commercial field trials in lettuce comparing CropManage (CM) recommendations with a grower (Grower) standard practice. Trial objectives are noted as nitrogen management (N), water management (Water) or both (Water/N)

					Applied water				
Site #	Objective	Year	Lettuce Type	Treatment	Total	Post Establishment	Applied N	Commerial Yield	Relative Yield
					------- inches -------		----- lbs/acre ----		%
6	N	2012	head	CM	20.1	9.8	143	65713	102
				Grower	20.1	9.8	183	64307	100
7	N	2012	head	CM	8.0	4.9	149	18760	98
				Grower	8.0	4.9	211	19114	100
8	N	2013	head	CM	13.6	4.3	62	38434	117
				Grower	13.2	3.9	124	32765	100
9	N	2014	head	CM	4.8	2.3	27	20655	107
				Grower	4.8	2.3	54	19364	100
10	N	2014	head	CM	20.1	11.6	118	11334	128
				Grower	20.1	11.6	250	8861	100
11	Water/N	2016	head	CM	7.5	5.0	140	54692	102
				Grower	8.4	6.2	154	53573	100
12	Water/N	2016	head	CM	14.8	5.3	32	41928	99
				Grower	15.8	6.3	62	42387	100
13	Water/N	2017	head	CM	9.1	5.0	7	44758	108
				Grower	7.9	3.8	63	41526	100
14	Water/N	2017	head	CM	17.0	8.1	118	27185	121
				Grower	17.7	8.9	155	22511	100
15	Water/N	2018	head	CM	23.5	9.7	92	40014	96
				Grower	21.5	7.7	155	41496	100
16	Water/N	2012	romaine	CM	9.2	3.8	177	18389	103
				Grower	11.1	4.9	177	17935	100
17	N	2013	romaine	CM	14.6	7.6	162	15644	98
				Grower	14.6	7.6	263	15946	100
18	N	2017	romaine	CM	10.1	4.1	71	27035	109
				Grower	10.1	4.1	96	24903	100
19	N	2017	romaine	CM	8.4	4.4	128	40515	110
				Grower	8.6	4.6	120	36832	100
20	N	2019	romaine	CM	7.2	3.8	129	27177	105
				Grower	6.9	3.3	191	25789	100
Average				CM	12.5	6.0	104	32816	107
				Grower	12.6	6.0	151	31154	100

MANUREDB: CREATING A NATIONWIDE MANURE TEST DATABASE

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ABSTRACT

Manure nutrients serve an important role in crop production, however, compared with commercial fertilizers, there is a lack of standardized information. When exact manure values are not known, manure book values have been referenced. Recent data from midwestern United States (US) laboratories indicate manure nutrient concentrations have changed from book values published by Midwest Plan Service (Lorimor et al., 2004) and American Society of Agricultural and Biological Engineers (ASABE, 2014). The recent data includes over 80,000 samples from three midwestern laboratories. Trends, similarities, and challenges arose when comparing these samples and these observations solidified the need to update manure nutrient book values. The University of Minnesota obtained an Agriculture and Food Research Initiative (AFRI) National Institute of Food and Agriculture (NIFA) grant to create a manure nutrient database (ManureDB) to update these values using FAIR principles (Findable, Accessible, Interoperable, and Reusable). Working with a stakeholder group, the Minnesota Supercomputing Institute, and Minnesota Department of Agriculture (MDA), the project team developed a database schema, sample template, laboratory data legal agreement, data upload process, and website to support the database. The project is in the laboratory data collaboration phase, looking to add more partners and data points from various regions, animal types, production systems, and time periods. Laboratories share past manure data and annual data going forward with no customer names or addresses shared to avoid privacy concerns. Eventually, a public-facing website will show aggregate summary data for a region, animal type, or time period. With changing animal genetics, feed sources, manure handling and storage systems, climatic conditions, and improved laboratory testing, having more current manure test values will improve nutrient management planning, manure storage design, prioritization of conservation programs, and agricultural modeling.

INTRODUCTION

When land-applied, livestock manure provides nutrients for growing crops. However, these nutrients are variable depending on animal species, age, diet, management, housing, climate, and manure storage and handling. Knowing what nutrients are contained in a certain manure can aid farmers to better match manure application to field and crop needs and reduce the risk of nutrient loss to the environment. Recent data from three midwestern United States (US) labs indicates manure nutrient data has changed from book values published by Midwest Plan Service (2004) and American Society of Agricultural and Biological Engineers (2005). Some states have also pulled together their own manure nutrient estimations. While these are helpful references, some of the values were pulled from narrow regions with few samples two decades ago. Animal nutrition, genetics, housing, and manure handling and storage continue to evolve, impacting the resulting manure analysis. This manure database project will be the largest of its kind that we are aware of in the United States. Laboratories, universities, the United States Department of Agriculture (USDA), and private agricultural businesses have all expressed interest in this data.

METHODS

To compare manure nutrient data spanning the last decade, the University of Minnesota obtained over 80,000 samples from three midwestern laboratories between 2012-2021 for preliminary data for this database project. With data sorted by animal type and manure consistency (solid or liquid), those medians and ranges were compared to the published manure book values.

The University of Minnesota received an Agriculture and Food Research Initiative (AFRI) National Institute of Food and Agriculture (NIFA) grant to create a manure nutrient database (ManureDB) using FAIR principles (Findable, Accessible, Interoperable, and Reusable). Working with a stakeholder group, the Minnesota Supercomputing Institute, and Minnesota Department of Agriculture (MDA), we developed a database schema, sample template, laboratory data legal agreement, data upload process, data standard operating procedures (SOP), and website. The project is still in the laboratory collaboration phase, where we are adding more laboratory partners and data points from various regions, animal types, production systems, and time periods. Laboratories share past manure data and annual data going forward with no customer names or addresses shared to avoid privacy concerns. With a dozen laboratories signed on so far and the first official data sets coming in, we should have over 120,000 samples in the database in the first quarter of 2023. Eventually, a public-facing website will show aggregate summary data for a region, animal type, and time frame, with some of those dashboards already available for internal viewing. This initial data strengthens our ability to evaluate representative sample sizes for data aggregation and presentation.

RESULTS AND DISCUSSION

When comparing the 2012-2021 preliminary manure data medians, trends, similarities, and challenges arose and these observations solidified the need to update manure nutrient book values. For example, in Figure 1, medians for 10,869 Midwest liquid dairy manure samples were lower for total N, P_2O_5, and K_2O and higher for NH_4-N than the published MWPS book values. While this manure database resource will give better manure nutrient estimates, this should also encourage farmers to test their manure more frequently. Fertilizer prices are higher than ever, so utilizing manure nutrients where they get the most value is of fiscal importance. With many states working on nutrient reduction strategies for water quality improvements, knowing more about manure characteristics can improve those strategic plans. Animal feeding operation regulations could be improved with updated manure book values by having better estimates of how much land would be required for new animal feeding operation construction. A new barn location could be compared to available land for manure application to prevent manure overapplication in a specific area. Knowledge of what are appropriate manure application rates for agronomic and environmental reasons can assist environmental regulators in farmer education and relevant nutrient management regulation. With more interest in carbon modeling, carbon sequestration, and carbon markets, we have received queries already for estimates of manure carbon content. Having a larger database of many manure types can create a useful resource for manure carbon reference numbers. Having more realistic numbers can improve these carbon models and programs. This database can also show us improved estimates of other less studied manure components such as chloride, which has become a water quality concern in some regions.

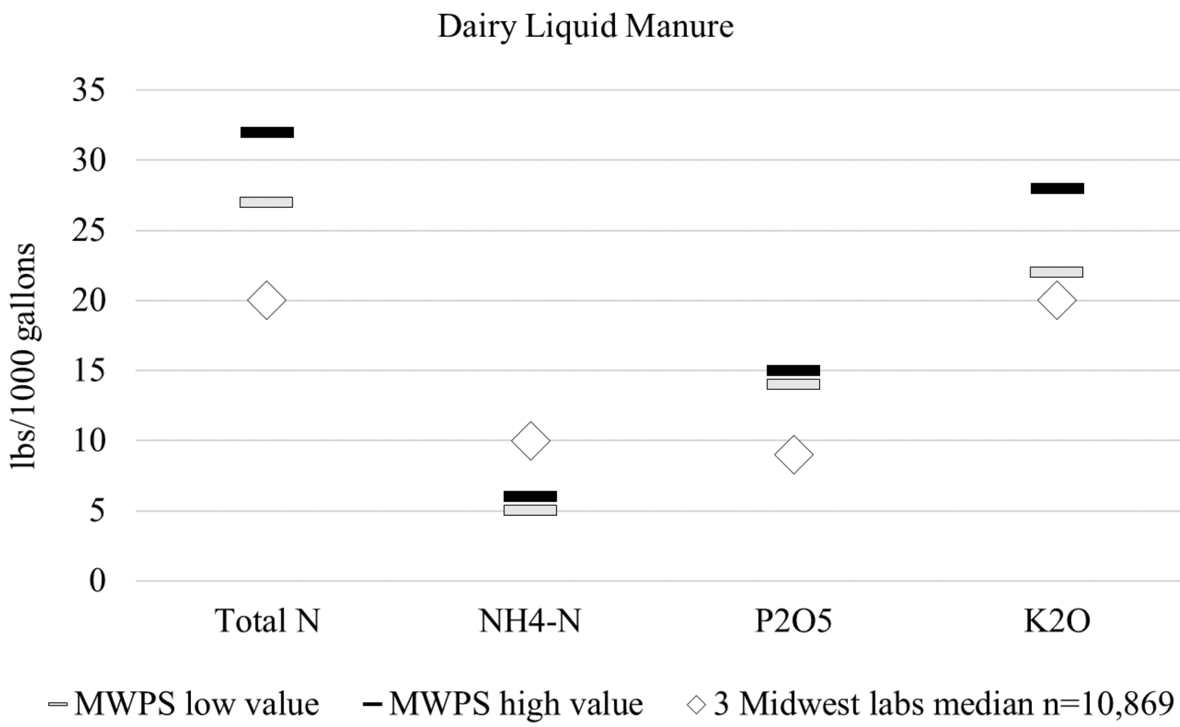

Figure 1. Comparing liquid dairy manure Midwest Plan Service book values to medians from 10,869 samples from three Midwestern laboratories between 2012-2021.

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IMPROVED SMALL GRAIN NITROGEN USE EFFICIENCY WITH CALIFORNIA SITE-SPECIFIC DECISION SUPPORT

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ABSTRACT

California (CA) small grains cover approximately 500,000 acres annually and are generally fall-sown and grown during the winter months when most precipitation occurs. Highly variable precipitation and irrigation patterns across CA plus more recent fertilizer nitrogen (N) price volatility makes determining fertilizer N application recommendations particularly challenging. With a goal to improve N use efficiency (NUE) in CA small grains, our objectives were to 1) establish field-scale improved NUE demonstration sites, 2) host field days to view and discuss results of new decision support tools, 3) measure learning outcomes among participants, 4) and measure crop productivity as a result of improved NUE methods. We established 16 field-scale demonstration sites over three growing seasons starting in 2019. We hosted six field day events, four being held virtually due to COVID-19 restrictions. Participants at these education events (n = 42) indicated they had increased knowledge about using improved NUE practices and were likely to use these methods. Crop outcomes were measured, and when in-season N fertilizer applications were recommended, there was an average yield increase of 28% (~1500 lb/ac) (p = 0.01, n = 6). Yield increase at these sites ranged from 14%, or 1,088 lb grain/ac, to 75%, or 3,672 lb grain/ac. When no fertilizer application was recommended, yields in the grower field were equal to the control (p = 0.80, n = 4).

INTRODUCTION

Small grains are grown throughout the state of California (CA) on approximately 500,000 acres annually. They are generally fall-sown and grown during the winter months when most precipitation occurs. However, because precipitation and irrigation patterns and timing vary across the geography of CA, there is a strong interaction between total water and plant available nitrogen (N). Determining fertilizer N application recommendations is particularly challenging in this cropping system.

Recently, fertilizer price volatility, irregular access to water for irrigation, and increasingly strict regulatory orders for protecting groundwater from leached nitrate have all made N use efficiency (NUE) improvement in CA small grains an increasingly urgent matter. One of the biggest improvements growers can make is to shift the majority of their N fertilizer application budget to an in-season application as opposed to applying all of it pre-plant. To do this, growers and crop consultants engaged in N fertilizer management applications must be able to navigate and evaluate several variables strongly influencing NUE in small grains. Considering all the variables involved, this must be done on a field-by-field and year-by-year basis. To address the need to improve NUE in CA small grain production, a multifaceted method for determining site-specific fertilizer N application is needed. This method and an associated decision support tool were utilized at 16 commercial farm demonstration sites over the course of three growing seasons between 2019 and 2022, in cooperation with farmers and crop consultants.

METHODS

Our objectives in this demonstration project were to 1) establish field-scale improved NUE demonstration sites, 2) host field days to view and discuss the results of using new decision support tools, 3) measure learning outcomes among participants, and 4) measure crop productivity as a result of using improved NUE methods.

Establishing sites

Between 2019 and 2022, we implemented a total of 16 demonstrations of improved small grain NUE practices on commercial farms spanning the northern CA intermountain region (3 sites), the Sacramento Valley (8 sites), the Delta region (2 sites), and the San Joaquin Valley (3 sites). At each of these sites, one to four replications of N-rich reference zones (NRZ) were established to serve as *in situ* positive controls for plant nitrogen status within the growing season. These NRZs were created by applying a known quantity of N fertilizer near planting time in multiple plots chosen to represent the variability of the given demonstration field (https://tinyurl.com/NRZdemos). Collaborating growers were asked to commit to adjusting their N fertilizer plans to accommodate shifting at least 50% of their planned seasonal N fertilizer budget to one or more in-season applications. Growers were then asked to maintain all other typical farming practices for the given fields.

The soil and plant N status was repeatedly measured to inform a decision support model using a web-based user interface with the purpose of generating site-specific N fertilizer recommendations which we call the "Nitrogen Fertilizer Management Tool for California Wheat" or Nitrogen Fertilizer Web Tool for short (https://tinyurl.com/WebTooldemo). Additional common crop management and environmental variable information were also collected to inform this model. Measurements of pre-plant soil nitrate were conducted using a unique quick test method with water quality testing strips (https://tinyurl.com/SNQTdemo). When site teams observed opportunities for in-season N fertilizer application approaching, plant N status was measured using canopy reflectance. Measurements were made using various hand-held (https://tinyurl.com/Devicesdemo) and aerial devices to determine common indices such as normalized difference vegetation index (NDVI) and normalized difference red edge (NDRE). These measurements were made in the NRZs as well as in the adjacent parts of the field area, and the quotient of the reflectance in the normal grower practice area divided by the NRZ area was used to generate a plant N sufficiency index. Previous empirical research (Lundy, et al. 2017) determined plant and soil sufficiency thresholds indicating the degree of crop N deficiency and likelihood of response to applied N fertilizer.

Methods described above for soil and plant N status measurement were repeated throughout the growing season at the demonstration sites at each opportunity to apply N fertilizer. When soil and plant N status were determined, this information along with management and environment information including planting date, crop variety, site location, crop growth stage, N fertilizer management, irrigation management, and yield and protein estimates were entered into the Nitrogen Fertilizer Web Tool to help generate a site-specific N fertilizer recommendation. These recommendations were vetted with the site teams then shared with the grower with the goal of informing their N fertilizer application decisions.

Field days and educational events

Due to in-person meetings and travel restrictions imposed during peaks in the COVID-19 pandemic, no field days were held in the first year. In the second and third years, we held small in-person gatherings as well as hosted webinars to disseminate the outcomes of the demonstrations. At these events, we presented current results from the ongoing demonstration sites. These results focused on soil and plant status measurements, fertilizer N management decision-making, and crop productivity outcomes. We also took time to refine teaching on the methods critical to this improved NUE decision support system through hands-on demonstrations, lecture presentations, and provisioning web-based resources for further information. Finally, we facilitated discussion among farmers and crop consultants to elicit feedback about what worked, what failed, and what would be pertinent to explore further or try differently.

Measuring learning outcomes

At five of the live events we hosted, we disseminated surveys to participants asking about what they had learned and which practices they intended to use in the future. We asked participants to rate their level of knowledge prior to and after the event about soil N testing, plant N status measuring, how to use the Nitrogen Fertilizer Web Tool, and how to deploy N-rich reference zones. We also asked about their likelihood to use the above practices in their small grain N management decisions after participating in our events. Finally, we asked about their need for further training in any of the above practices. Surveys were provided either on-paper or electronically depending on the nature of the event. In all, 45 participants answered questions pertaining to NRZs and associated methods and 41 participants answered questions about the Nitrogen Fertilizer Web Tool.

Measuring crop outcomes

At 10 of the 16 demonstration sites, site teams implemented alternative management zones to demonstrate the effect of the grower’s fertilizer N decision. That is, if a grower decided not to fertilize with N, we added a small plot of N fertilizer and vice versa. At the end of each crop season, we hand-harvested representative sub-plots within the NRZs, the broader grower-managed fields, and any alternative management zones implemented within the season. Yield and N content were measured to estimate grain protein and total N uptake by the crop. Grower-reported yields for the whole field were then used to normalize and calibrate the hand-harvested yield estimates.

RESULTS AND DISCUSSION

Learning and behavior outcomes

Participants in the education events we hosted indicated an average increase in knowledge about NRZs and associated methods ($n = 45$) as well as about the Nitrogen Fertilizer Web Tool ($n = 41$). After the events, participants stated their knowledge level about NRZs and associated methods increased from 2.4 ± 1.3 to 3.9 ± 0.8 (mean ± standard deviation) on a scale of 1-5 where 1 = “none” and 5 = “high.” At the same time, participants stated their knowledge level about the Nitrogen Fertilizer Web Tool increased from 2.8 ± 1.3 to 4.2 ± 0.7 on the same scale. When asked about how likely participants were to use the NRZs and associated methods and the Nitrogen Fertilizer Web Tool, they responded 4.0 ± 1.1 and 4.0 ± 1.0, respectively, on a scale of 1-5 where 1 = "not likely" and 5 = "very likely" (Figure 1)

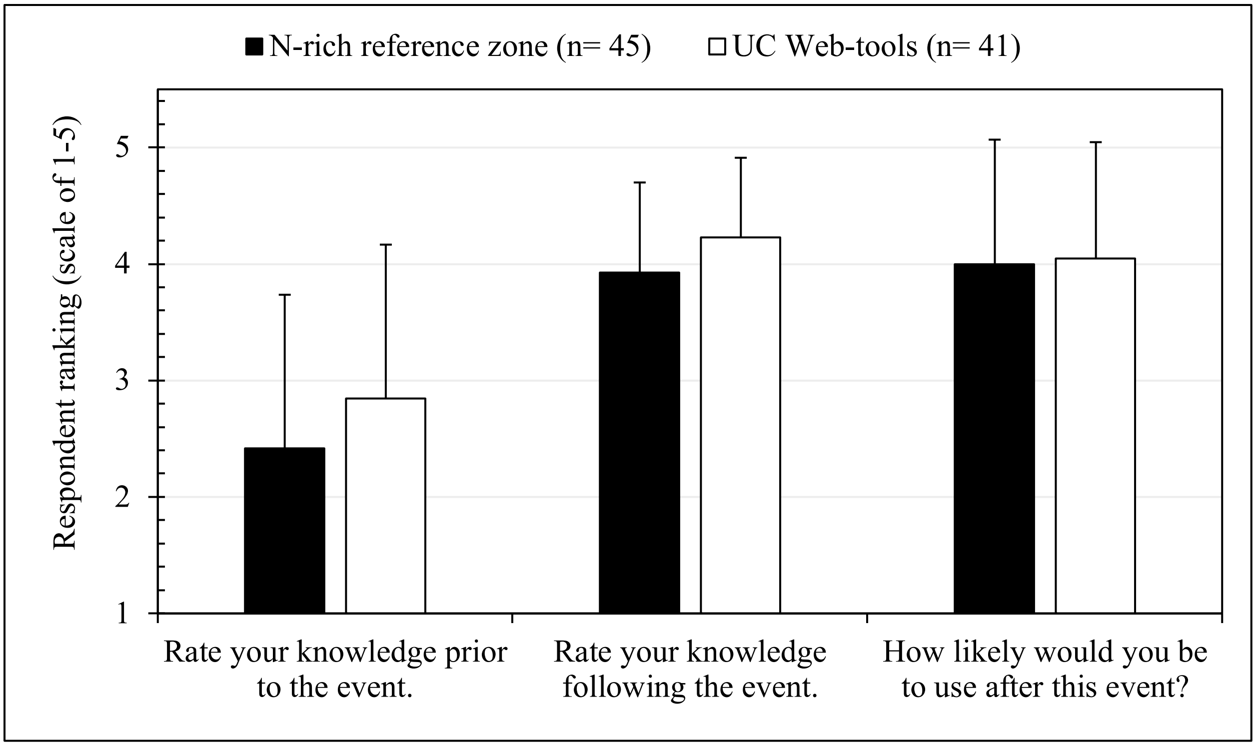

Figure 1. Change in knowledge and likelihood of adoption recorded after outreach events explaining N-rich methods and tools (1 = none/not likely; 5 = high/very likely). Bars represent 1 standard deviation.

Crop outcomes

When in-season N fertilizer applications were recommended, there was an average yield increase of 28% (~1500 lb/ac) compared to an in-field control ($p = 0.01$, $n = 6$). The range of yield increase at these sites was from 14%, or 1,088 lb grain/ac, to 75%, or 3,672 lb grain/ac. When monitoring indicated crop response to N fertilization was unlikely and no fertilizer application was recommended, yields in the grower field were equal to the control ($p = 0.80$, $n = 4$) (Table 1). We estimated an average savings of $40/ac in fertilizer costs for these sites. Furthermore, across all sites, crop N removal was greater than fertilizer N application where total fertilizer N applied only accounted for 80% of the N removed in the harvested crop (Figure 2).

Table 1. Indicates whether in-season N fertilizer was recommended, the rate of N fertilizer applied, and the resulting changes in yield at sites where alternative management plots permitted comparison ("-" indicates that the effect was not measured).

Location	In-season N recommended	In-season N applied (lb/ac)	Yield change (compared to control, lb/ac)	Total N Applied (lb/ac)	Total N Uptake (lb/ac)
Solano 2019-20	N	0	no change	0	97
Yolo 2019-20	Y	50	-	76	30
Siskiyou 2019-20	Y	200	+ 3672 (75%)	200	181
Colusa 2019-20	Y	46	+844 (15%)	106	156
Kings 2019-20	Y	61	-	209	161
Sacramento 2019-20	N	0	-	60	148
Yolo 2020-21 (irrigated)	Y	50	+1119 (26%)	50	115
Yolo 2020-21 (rainfed)	N	0	no change	74	58
Colusa 2020-21	N	0	-	60	146
Kings 2020-21	Y	140	+ 1088 (14%)	140	177
Sacramento 2020-21	N	0	no change	60	163
Yolo 2021-22 (rainfed)	N	60	no change	110	41
Yolo 2021-22 (irrigated)	Y	30	-	139	130
Kings 2021-22	Y	80	-	210	164
Lassen 2021-22 (forage)	Y	92	+ 3548 (29%)	98	129
Lassen 2022 (barley)	Y	40	+ 604 (15%)	46	127

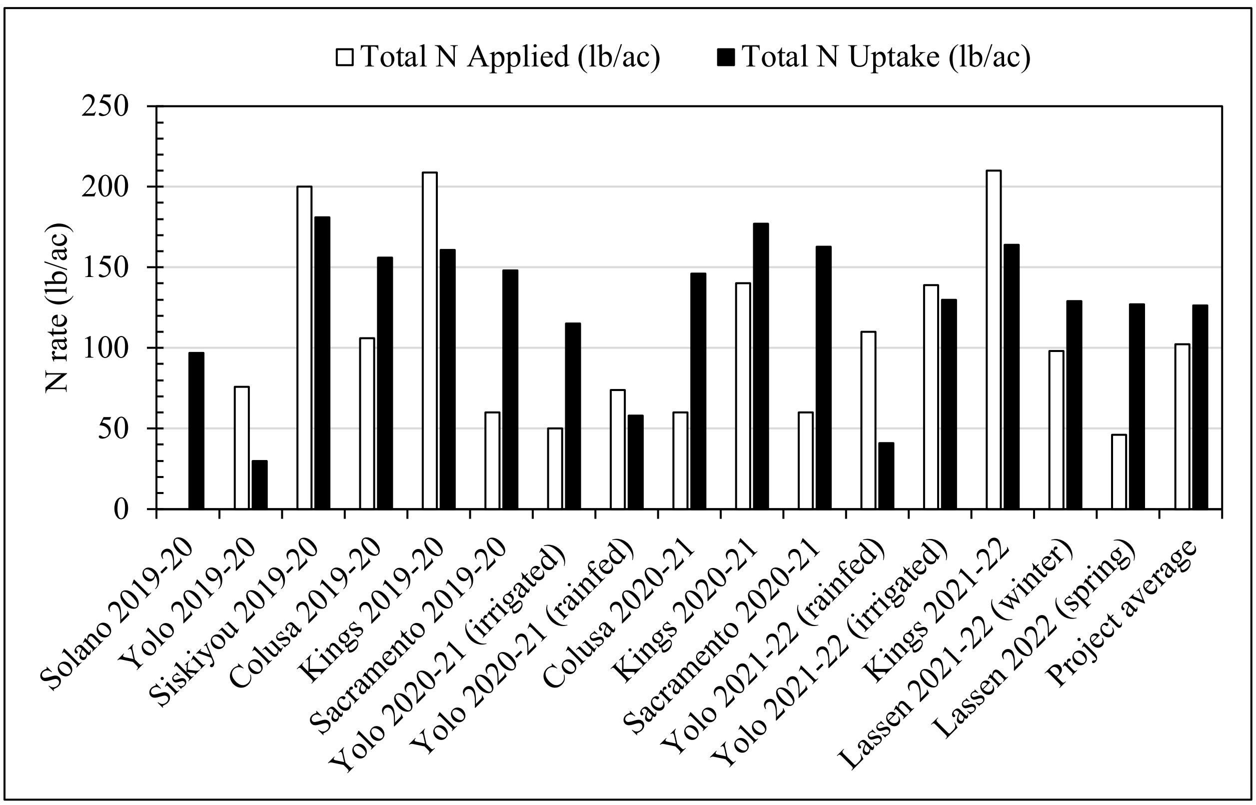

Figure 2. Crops at the demonstration sites removed 24 lb/ac more N than was applied as fertilizer for an average applied/removed ratio ≈ 0.80 (N fertilizer applied ≈ 80% of N fertilizer removed).

In summary, these tools and methods present an opportunity for improved N use efficiency in California small grain crops. Implementation will require more intensive observations and site-by-site adaptability from farmers and crop consultants. We continue to provide support and collaboration with growers and crop consultants to extend these tools to the agricultural community thereby increasing yields, reducing per-unit fertilizer costs, and improving stewardship of natural resources by small grains farmers and crop consultants in CA.

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HOW VARIABLE IS VARIABLE FOR PRODUCTION FIELDS IN SOUTHERN IDAHO

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ABSTRACT

Agricultural producers in Southern Idaho, just like many other regions, are tasked with managing irrigation water and soil fertility on large fields with spatial heterogeneity in a way that results in homogeneous crop production. Management practices implemented to the 'average' of the field limit the ability to attain maximum efficiencies of inputs, such as fertilizer and water. To better advise agricultural producers on precision agricultural practices, first spatial variability of typical production fields must be assessed and quantified. To this end, two 130-acre fields in Southern Idaho were sampled at a high spatial resolution for soil physical, chemical, and biological properties at multiple depths in fall 2019 and spring 2020. Initial results showed the presence of spatial variation in the soil properties like cation exchange capacity, pH, organic matter, total inorganic nitrogen, and phosphorus. However, the degree of the variation was different for each soil property. The presence of spatial variation in soil properties will serve as the basis for site-specific management to attain higher nutrient use efficiency and optimum crop productivity as supported by the potato yield and fall soil fertility data presented.

INTRODUCTION

Generally, agricultural research is conducted on small plots to reduce soil variability. While this is important for research purposes, scaling up of the results of research by producers can be a challenge in the presence of soil heterogeneity. With the increase in acreage from plot to field, the variability within the field also increases. Implementation of management practices, like fertilizer application and irrigation, tend to target the field average and do not necessarily account for field variability. Commercial crop production systems tend to adhere to homogeneous management of large acreage fields due to the efficiency of application of inputs. However, homogenous management practices applied over these large production fields does not necessarily result in the optimum use of inputs. Reduced input efficiency can be caused by the loss of applied input through leaching, runoff, volatilization, and evaporation, depending on the type of input. These input losses also incur economic losses. When crop inputs are optimized, the profitability from the agricultural commodity grown can be maximized.

In this regard, evaluating the variability of soil fertility and crop productivity is important. When the variability in the field is known, it can be better managed, such as dividing it into sections where each section has a similar response when subjected to optimized inputs. Site-specific crop management comes with advantages like better efficiency of inputs, reduced costs of inputs, and optimized crop productivity. There are many ways management zones can be defined, like based on individual soil properties or crop production properties.

The objective of this research is to evaluate the spatial and temporal variability of soil and crop properties of two Southern Idaho fields used for commercial crop production by evaluating soil nutrients and crop characteristics.

METHODS

The research was carried out at the Idaho Center for Agriculture, Food, and the Environment (Idaho CAFE) Sustainable Water and Soil Health Demonstration and Research site near Rupert, Idaho. The site extended from 42°48’28’’ N to 42°48’54’’ N and 113°40’5” W to 113°41’15” W. Site elevation ranged from 1309 m (4297ft) to 1331 m (4370 ft). The region is semi-arid with annual precipitation of approximately 24.2 cm (9.53 in).

Idaho CAFE was established as a new research and demonstration farm in 2019. As such, the initiation of research included site characterization. Historically, the cropping system of the southern fields was a four-year barley-sugar beet-barley-potato rotation. In 2019 and 2020, the fields were in barley and sugar beets, respectively, with the rotation continuing in 2021 and 2022. Each field was approximately 130 acres and irrigated with a center pivot using groundwater. Both fields are managed exactly the same, including the timing and amount of water application. The southwest field within the section (SW) was characterized after barley harvest in 2019 whereas the southeast field (SE) was sampled for characterization before planting in the spring of 2020; the large number of samples collected from each field inhibited the ability to characterize both fields at the same time. Between sampling events, fields were vertically tilled in fall and roller harrowed in the spring. Fertilizer was also applied at rates of 220 lb N ac^{-1}, 220 lb P ac^{-1}, and 165 lb K ac^{-1}. Each field was divided into 170 ft by 170 ft (0.66 acre) grids having a density of 180 points and 187 points for the SW and SE fields, respectively. At each location, the soil was sampled using a bucket auger at depths of 0-10 cm (0-4 in), 10-20 cm (4-8 in), 20-30 cm (8-12 in), 30-60 cm (12-24 in) and 60-90 cm (24-36 in), and depth to bedrock was recorded. All soil samples were air-dried and sieved (2 mm) before they were analyzed for soil chemical properties by a commercial laboratory.

Beginning in fall 2020, crop yield and quality were evaluated in 21 locations per field. The locations were selected to capture the crop variability of each field. Using 2018 satellite crop evapotranspiration (ET) data, each 2019/2020 sampling location was characterized as high (>34.6 inches), medium (31.0 – 34.6 inches), and low (<31.0 inches) ET. In 2018, temperatures were slightly above average in July, August, and September. Precipitation was well above average from January to early July and below average for the rest of the cropping year. For each ET zone, seven locations were chosen for temporal sampling. Soil fertility samples were taken in the spring before planting and in the fall after harvest. Crops were hand harvested for yield and quality analyses a few days before bulk harvest every year. Only a subset of data will be presented in this paper.

RESULTS AND DISCUSSION

Initially, descriptive statistics were used to describe soil properties (Table 1). Means for organic matter, pH, cation exchange capacity (CEC), and excess lime were similar for both fields while means of total inorganic N, total P, and total K were greater in the SE field due to fertilization between sampling the SW and SE fields. However, results seem to indicate that the SE field had higher P and K values prior to fertilization. Inorganic N also could have been higher in the SE field in the fall, but it’s impossible to say due to potential N leaching over winter. For total inorganic N, P, and K, there were wide ranges of values for both fields.

Table 1. Descriptive statistics of soil properties in total soil profile (0- 36 in) for both fields.

Property	mean	median	min	max	CV
SE Field					
OM (%)	1.51	1.48	1.03	2.21	12.54
pH	8.12	8.17	7.31	8.44	2.16
CEC (meq per 100 g soil)	19.4	19.44	14.8	23.39	7.38
Excess Lime (%)	9.41	9.91	0.36	17.02	43.78
Total Inorganic N (lb ac^{-1})	232.2	215.5	71.3	1066.5	47.14
Olsen P (lb ac^{-1})	668.2	666.6	93.5	2282.8	50.83
K (lb ac^{-1})	1306.6	1184.7	496.2	3707.5	39.16
SW Field					
OM (%)	1.6	1.58	1.17	2.29	12.21
pH	8.2	8.22	7.74	8.48	1.31
CEC (meq per 100 g soil)	17.62	18.33	8.33	24.54	17.73
Excess Lime (%)	10.75	11.66	1.49	16.38	32.69
Total Inorganic N (lb ac^{-1})	96.4	93.3	37.5	230.6	30.61
Olsen P (lb ac^{-1})	103.2	93.4	43.4	520.0	42.84
K (lb ac^{-1})	789.1	728.6	268.0	2592.5	46.02

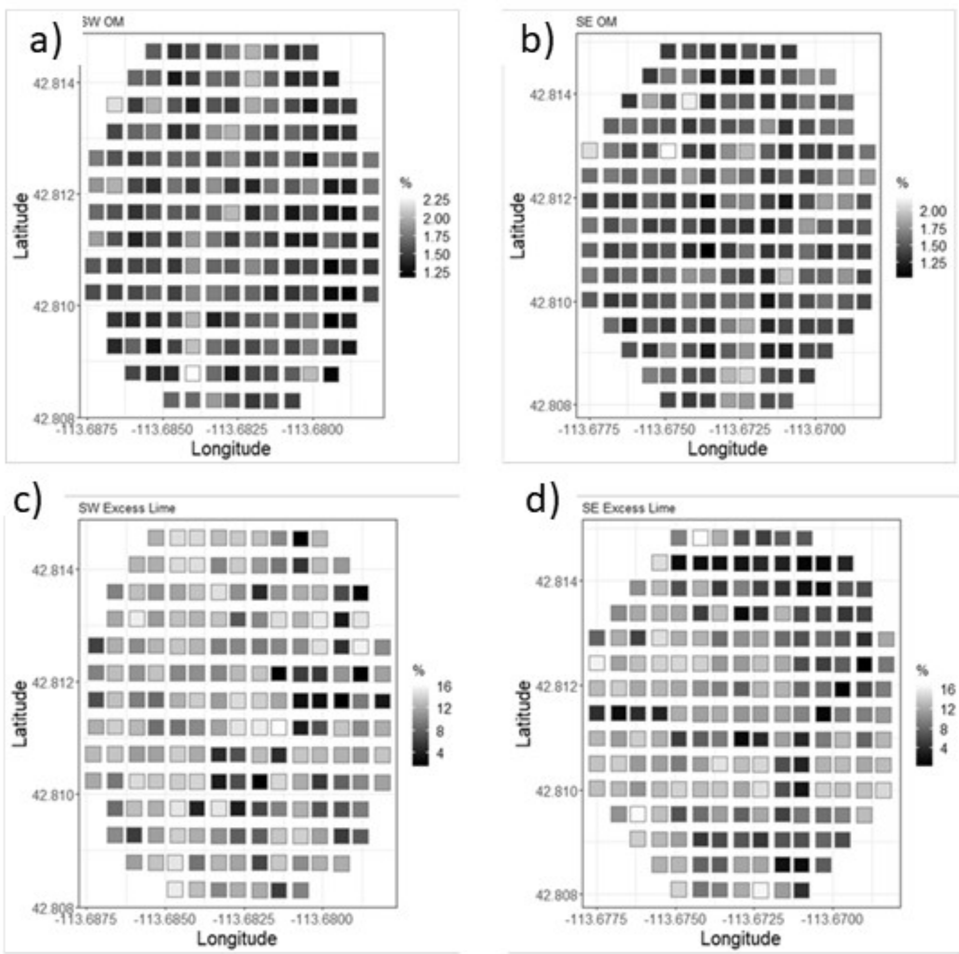

Figure 1. Total soil profile for organic matter (OM) (a,b) and excess lime (c,d) in southwest (SW) and southeast (SE) fields

A CV of 0-15% is generally considered minimally variable, 15-35 % moderately variable, and more than 35% is highly variable. The analyses show that even for the same soil properties in adjacent fields there was a difference in variability. For example, CEC was minimally variable in the SE field but moderately variable in the SW. Excess lime and total inorganic N were moderately variable in the SW field but highly variable in the SE. For the SW field, which was sampled prior to fertilization after barley harvest, soil P and K were highly variable while total inorganic N was moderately variable. All three properties were highly variable in the SE field when it was sampled the following spring after fertilization.

Figure 1 shows the variation of one of the least variable properties (OM) and one of the most variable properties (excess lime) across the sampled fields. The locations of the high and low OM values are somewhat random across both fields. For the excess lime, most of the locations have high values with a prominent area of lower values in the N and NW corner of the SW field.

Table 2 shows correlation coefficients between some selected soil properties. There was variable soil depth in the fields due to the presence of $CaCO_3$ layer as well as shallow bedrock in some areas. Thus, the major soil chemical properties were correlated with soil depth. For both fields, OM was negatively associated with soil depth (i.e. the shallower the soil the higher the OM) while inorganic N, P, and K were all positively correlated. For the SW field, elevation was negatively correlated with soil depth where the higher elevation areas had shallower soils. In the SE field, OM was not correlated with elevation but in the SW field, higher elevations had statistically higher OM. For the SE field, OM was negatively correlated with P while it was negatively correlated with K in the SW field. For both fields, higher concentrations of inorganic N were correlated with higher concentrations of P and K.

Table 2. Correlation coefficient (r) between the major soil properties with elevation and soil depth to impenetrable layer in the SE and SW fields. Negative (-) before r indicates negative correlation. Presence of '*' (0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1) indicates statistically significant correlation.**

	pH	CEC	Excess Lime	OM	Total IN	P	K	elevation
SE Field								
CEC	0.13							
Excess Lime	0.82***	-0.01						
OM	-0.84	-0.07	0.07					
Total IN	0.13	0.19***	0.14	0.01				
P	-0.37***	-0.22*	-0.38***	-0.19**	0.40***			
K	-0.62***	0.02	-0.60***	-0.02	0.23***	0.71***		
elevation	0.20**	0.02	0.20**	0.01	0.23***	-0.10	-0.1	
depth	−0.10	0.13	-0.03	-0.39***	0.27***	0.65***	0.31***	-0.1
SW Field								
CEC	0.00							
Excess Lime	0.41***	-0.21**						
OM	-0.05	0.07	-0.03					
Total IN	-0.13	0.13	0.18*	-0.07				
P	-0.13	0.01	-0.11	-0.11	0.24***			
K	-0.21***	0.44***	-0.46***	-0.17*	0.32***	0.44***		
elevation	0.00	-0.36***	0.31***	0.34***	0.17*	0.04	-0.34***	
depth	0.13	-0.01	0.14	-0.51***	0.48***	0.36***	0.47***	-0.16*

Burbank russet yields in 2022 ranged from 49 to 534 cwt acre^{-1} in the SE field and from 149 to 480 cwt acre^{-1} in the SW field (figure). The SE field averaged 352 cwt acre^{-1} and the SW averaged 330 cwt acre^{-1}. Both fields fell short of their 400 cwt acre^{-1} yield goals.

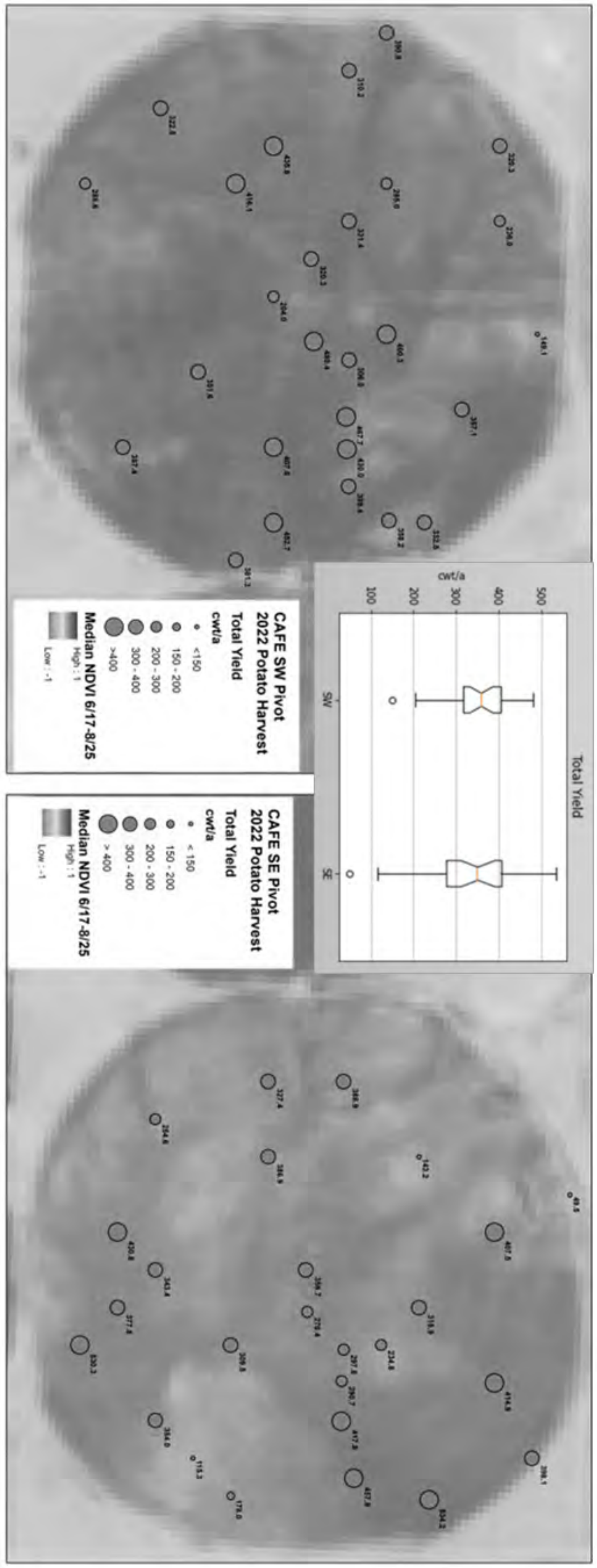

Figure 2. Spatial variability of potato yields (cwt acre^{-1}) in 2022.

Residual fall inorganic nitrogen was also variable both within field and between fields (Figure 3). Average N within the soil profile was slightly higher for the SE field compared to the SW field. However, the SW field had higher soil inorganic N in the upper 12 inches compared to the SE field. Much of this residual N will likely be lost over winter to leaching or other processes.

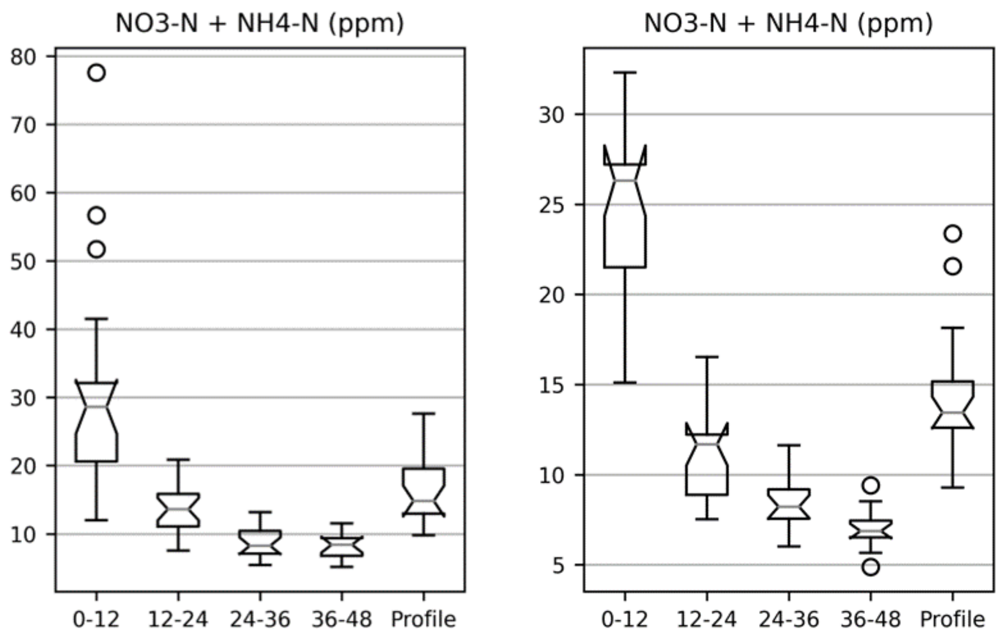

Figure 3. Box plots representing residual fall total inorganic nitrogen in 2022 after potato harvest for 0-48 inches of soil depth for the SW (left) and SE (right) fields.

In summary, while the two fields were managed the same by a commercial farmer, there are notable differences in soil variability among properties. Most notably, the SE field has a higher excess lime content variability and lower variability of CEC. Unfortunately, due to logistical challenges, both fields were not characterized at the same time. However, even with fertilization of the SE field prior to sampling, it is apparent that there is high persistent variability in this field. The CV values support this. There were also differences in correlation coefficients between the two fields. The presence of spatial variation in soil properties will serve as the basis for site-specific management to attain higher nutrient use efficiency and optimum crop productivity as supported by the potato yield and fall soil fertility data presented. These fields would be good candidates for variable rate application of fertilizers and further investigation into the drivers of variability as well as the impact on crop variability.

VARIABLE RATE FERTILIZATION: SOIL MOISTURE IMPACTS

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ABSTRACT

Variable Rate Fertilization (VRF) fertilization is a means of potentially applying nutrients more efficiently. Variable Rate Irrigation (VRI) is increasingly evaluated. However, these are generally studied in isolation, which seems contrary to the principles on which each are founded. Potential benefits of VRF, especially for N, are often confounded or repressed as a result of soil moisture variability due to runoff losses/accumulation and/or total water applied. Similarly, VRI results are impacted with interactions with biophysical chemistry when nutrients are applied uniformly to inherently variable field sites. Whole-farm Variable Rate Nitrogen (VRN) cropping systems were evaluated, including: 1) silage corn-alfalfa in Utah during 2010-2017, 2) lettuce-sweet corn-bean-onion-sweet corn-pea in Washington during 2015-2020, 3) potato-sugarbeet-wheat in Idaho during 2004-2020 and 4) potato-wheat-wheat in Idaho during 2003-2019. Each field included at least two N rate zones with optimum vs. deficit and/or excess soil moisture zones. Replication was variable with 3-5 management zones at each site. Yields increased an average of 8% when additional N was applied to zones with high yield potential when soil moisture was optimal. Yields were not negatively impacted in the optimal soil moisture zones with low yield potential when less N was applied. The effect of VRN was negated if soil moisture was excessively wet or dry, with significantly decreased yields in both. Overall, the effect was generally similar across crops. However, an orthogonal comparison of the high-yield potential zones showed the greatest response for non-legumes with minimal residual N for zones with optimal soil moisture. In-season N deficiencies were prevalent in excess soil moisture zones with reductions in Normalized Difference Vegetative Index and tissue N. Post season residual nitrate (NO_3-N) was significantly higher in most fields in deficit soil moisture zones (20 lbs. N/acre increase). These results show that the potential benefits of VRN can be completely overshadowed by variable soil moisture and that zonal management adjustments and/or VRI should be considered to maximize efficiency.

INTRODUCTION

Providing the food, fuel, and fiber for the eight billion people on the planet is a critical need Hopkins, 2020). Doing so requires that nutrients and water be managed carefully for maximum economic yield (Hopkins, 2020; Hopkins et al., 2020). However, water and the geological deposits of nutrient minerals and fossil fuels required to manufacture and transport fertilizers are resources that need conservation. Additionally, the misuse of these resources results in environmental problems related to air, water, and soil quality, as well as water quantity. Applying the correct rate and managing these appropriately is essential.

Variable Rate Fertilization (VRF) is a means of more efficiently applying nutrients, especially for nitrogen (N) as Variable Rate Nitrogen (VRN) fertilization. A minimum of two basic approaches should be used when employing VRF. First, residual nutrient availability can inform varying fertilizer needs. This is particularly important for nutrients, such as phosphorus (P) and potassium (K), which tend to be stored effectively in the soil and which have a reasonably high correlation of soil test concentrations to yield response. Second, yield potential can impact the rate of nutrient need, which is particularly important for N. The N can and should be analyzed in soil, but the soil test is relatively less reliable as it is easily transformed and lost to the environment. This nutrient is the most important fertilizer that is applied to non-legume crops, making up approximately half of the fertilizer used globally due to N making up the greatest concentration of mineral nutrients in most crop canopies (~3-5%). Our research shows that yield potential is an effective approach to fertilization but, admittedly, this is disputed by some.

Variable Rate Irrigation (VRI) is relatively rare, but ours and others' work shows great potential to improve the amount of crop produced per drop of water applied (Smith et al., 2021; Svedin et al., 2021; Woolley et al., 2021). The use of VRI requires an understanding of both crop needs and the soil's ability to store and supply water.

However, VRI and VRN are generally managed and studied in isolation, which seems contrary to the principles on which each are founded. Potential benefits of VRF, especially for VRN, are often confounded or repressed as a result of soil moisture variability due to runoff losses/accumulation and/or total water applied. Similarly, VRI results are impacted with interactions with biophysical chemistry when nutrients are applied uniformly to inherently variable field sites. The objectives of this research were to evaluate VRN studies at four multi-year, multi-crop sites by parsing the data into areas of deficit, optimal, and excessive soil moisture.

METHODS

Whole-farm VRN cropping systems were evaluated near: 1) Provo, UT with silage corn (2010, 2017) and alfalfa (2011-2016); 2) Pasco, WA with lettuce (2015), sweet corn (2016, 2019), navy bean (2017), onion (2018), and pea (2020); 3) Blackfoot, ID with potato (2004, 2007, 2010, 2013, 2016, 2019), sugarbeet (2005, 2008, 2011, 2014, 2017, 2020), and wheat (2006, 2009, 2012, 2015, 2018); and 4) Idaho Falls, ID with potato (2003, 2006, 2009, 2012, 2015, 2018) and wheat (2004-5, 2007-8, 2010-11, 2013-14, 2016-17, 2019-20). Replication was variable with three to five management zones at each location.

Fields were initially divided into management zones based on: previous crop yield history, bare soil imagery, in-season visual and Normalized Difference Vegetative Index (NDVI) imagery, topography, and grower knowledge. For purposes of the analysis, these zones were merged into two to three zones of average and below or above-average yield potential. Field edges and areas with significant problems not directly related to water or N nutrition were discarded from the analysis.

Each zone in each field had a customized N rate unique for each crop in the rotation, with 2 to 3 N rates per field. Nitrogen rates were determined based on yield potential, residual inorganic soil N, crop residue, previous crop, and irrigation water nitrate-N concentration. In general, the N rates followed typical fertilizer recommendations customized for the crop and the region. The average yield potential zones received 250 lbs. N/acre on average with a range of 180-330 lbs. N/acre for most crops, excepting legumes and crops grown after other crops with shallow and/or inefficient root systems (potato, lettuce, and onion) which received 50 lbs. N/acre. The N applied to legumes was fertigated during the middle to the later part of the season and crops following shallow crops received a concentrated band. In all cases, the low and high-yield potential zones received 50 lbs. N/acre less or more, respectively.

Each field was further evaluated during or after the season for areas with at least 0.5 acres of deficit or excess soil moisture as compared to areas with optimum soil moisture. Only sub-zones that clearly had deficit, optimal, and excess soil moisture were included in the analysis (marginal areas were excluded). The cause of deficit or excess soil moisture sub-zones was caused by problems with irrigation equipment (eg. incorrect sprinkler packages, malfunctioning regulators, leaks, etc.) and/or natural variations in field properties (slope, aspect, soil depth, soil texture, etc.). Each N zone was parsed into these soil moisture zones as determined with in-season aerial imagery, previous field history, in-field site assessment, and, in some instances global positioning system (GPS) tracking of in-season field equipment with the operating notating areas that were clearly moisture stressed or with excessive soil moisture.

For statistical analysis purposes, all combinations of three N rates and three soil moisture concentrations were analyzed by normalizing the yields against the optimal soil moisture with average yield potential and, thus N rate. As the number of zones were not balanced evenly, a General Linear Model (GLM) analysis was performed with mean separation using a Tukey-Kramer test.

RESULTS AND DISCUSSION

Yields increased significantly (8%) when 50 lbs. N/acre was applied to zones with high yield potential having near-optimal soil moisture (Fig. 1). Yields did not decrease significantly with 50 lbs. N/acre less applied to zones with low yield potential with optimal soil moisture. This resulted in increased N use efficiency (NUE), as a similar yield was produced with less N.

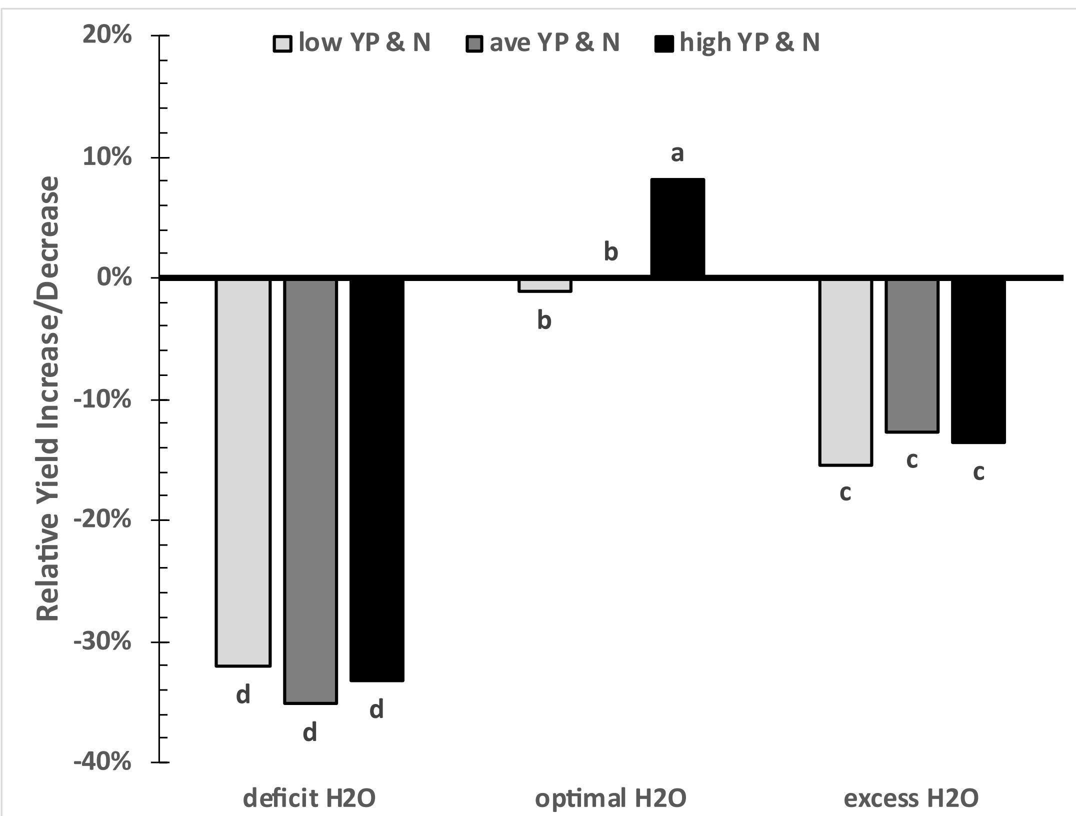

Fig. 1. Relative yield averaged across years and crops for a variable rate nitrogen (N) study. The N varied based on yield potential (YP), with yields evaluated across soil moisture levels [deficit, optimal, or excess water (H2O)]. Averages sharing the same letter are not statistically different than one another. *P* = 0.05

However, the positive benefits of VRN in zones with soil moisture deficits or excesses were overshadowed by the impact on soil moisture. Yields significantly decreased in deficit or excess subzones compared to optimal soil moisture, regardless of yield potential driven N rate (Fig. 1). In subzones with deficit soil moisture, the lower yields would have resulted in lower N demand. This was also likely at least part of the cause of yield reductions with excess moisture but, additionally, leaching and denitrification likely resulted in less N availability in all zones.

Overall, the effect was generally similar across crops. However, an orthogonal comparison of just the high yield potential/N rate compared to the average yield potential/N rate with optimal soil moisture showed a differential response across crops (Fig. 2). Not surprisingly, the legumes (navy bean, alfalfa, and pea) were relatively less responsive to additional N.

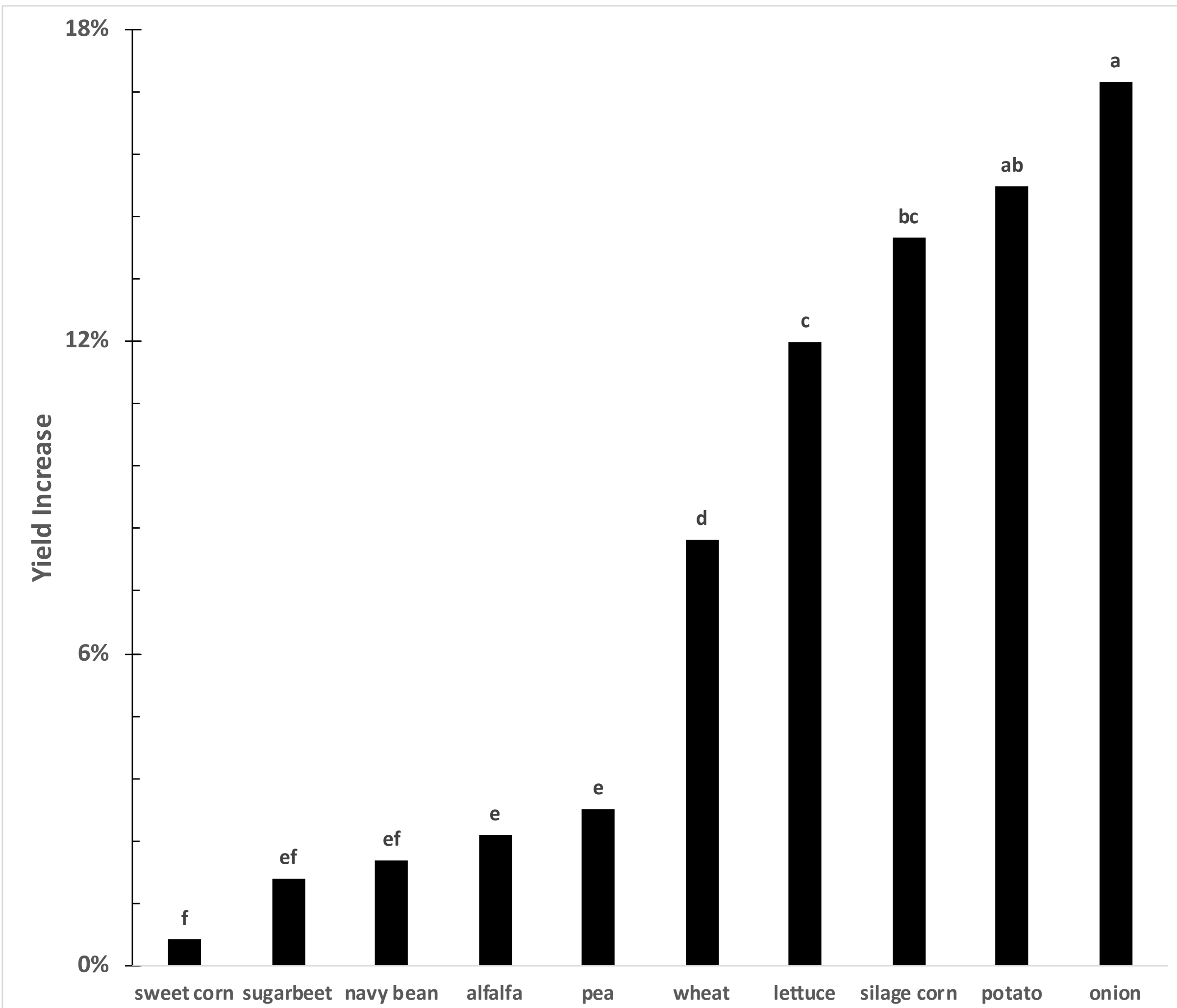

Fig. 2. Yield increase with an additional 50 lbs. N/acre in high yield potential zones compared to average yield potential zones when both have <u>optimal</u> soil moisture. Averages sharing the same letter are not statistically different than one another. *P* = 0.05

Additionally, deep-rooted species (wheat, sweet corn, and sugarbeet) tended to not respond to N fertilizer (Fig. 2) when these were grown in the year another crop that has inefficient/shallow rooting (potato, lettuce, and onion). Although the average increase for wheat was significant (Fig. 2), six of the 17 sites were following potato with a 0% average yield increase in these instances (comparing high yield potential/N rate zones to the average in the optimal soil moisture zones). However, in areas of excess moisture, the additional N did positively impact yield in these instances (Fig. 3).

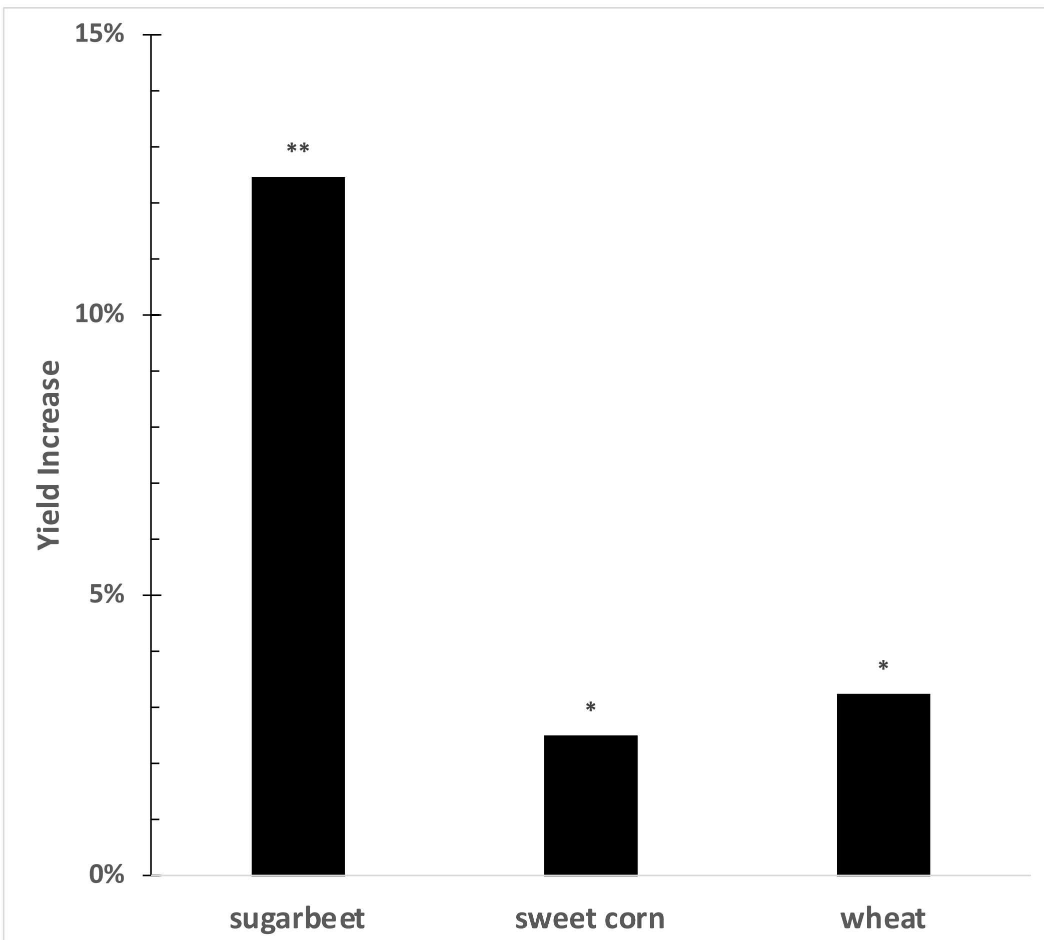

Fig. 3. Yield increase with an additional 50 lbs. N/acre when grown in soils with <u>excessive</u> moisture for deep-rooted crops grown after crops with shallow and/or inefficient rooting systems (sugarbeet grown after potato, sweet corn after lettuce or onion, and wheat grown after potato).

Not surprisingly, in-season N deficiencies were prevalent in excess soil moisture zones as identified through significant differences in Normalized Difference Vegetative Index (NDVI; 0.11 average decrease) and tissue analysis (0.35% average decrease). Post-season residual nitrate (NO_3-N) was significantly higher in most fields in deficit soil moisture zones (5 ppm increase =

~20 lbs. N/acre in the top 2 feet of soil). Furthermore, field areas where alfalfa was repeatedly and severely moisture stressed had 74% stand/yield reductions with the net effect of an estimated 105 lbs./acre reduced N credit to the subsequent corn crop (data not shown).

Finally, consistently lower yields generally resulted in increased residual soil test phosphorus (4 ppm bicarbonate extractable P) and, in some instances, potassium (15 ppm bicarbonate extractable K). These results suggest a further interaction requiring adjustment to other nutrients in addition to N. No other nutrients seemed to be consistently impacted, although there was a confirmed sulfur deficiency in potato in zones in a field with grossly excessive water accumulation.

These results show that the potential benefits of VRN can be completely overshadowed by variable soil moisture and that zonal management adjustments and/or VRI should be considered to maximize efficiency. The technology is readily available, relatively easy to access and use, and generally affordable, especially for VRF and increasingly with VRI. It is a best management practice to variably manage water and nutrients in harmony with each other.

With the increasing negative impacts of a mega drought plaguing the Western USA, it is critical that growers individually, and society generally, strive for increased water use efficiency. We need to not decrease agricultural production to support the earth's population into the future, but rather we do need to increase the amount of "crop per drop" (personal communication, Neil C. Hansen; Brigham Young University).

One aspect of this is an effort to increase soil moisture uniformity across fields. Often, this can be done through proper irrigation system design and maintenance. This was observed in a majority of the fields studied herein. In some instances, steep slopes resulted in water runoff to lower elevations, which can be at least partially corrected with practices such as increased surface residues, reservoir tillage, and application of water penetrants that break the surface tension and increase water infiltration. In some cases, such as our WA location, soils with vastly different water holding capacity (eg. sands vs. loams) in the same field may need adjustments in fertilizer and other inputs due to low yield potentials with minimal opportunity for improvement. If water parity is achievable, VRF should be considered in an effort to maximize efficiency and reduce waste and environmental contamination.

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ECONOMICS OF ALFALFA FERTILIZATION UNDER INFLATED HAY AND FERTILIZER PRICES

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ABSTRACT

Knowing critical alfalfa nutrient levels in-season improves recommendations and applications, while at the same time saves producers time, expense, and effort since many growers take samples for hay quality. Inflation has doubled hay and fertilizer prices which brings into question how current fertility decisions are made. From 2019-2020 detailed information on phosphorus and potassium response was conducted. Two experiments were designed as follows: 1) Phosphorus (P) rate study with differing rates of P_2O_5 using monoammonium phosphate (MAP); including 0, 30, 60, 120, 240 lb P_2O_5 acre^{-1} on a low testing P soil <10 ppm (Olsen P method); 2) Potassium (K) rate study with differing rates of K_2O using potassium sulfate: 0, 40, 80, 160, 240, 320 lb K_2O acre^{-1} on an <100 ppm K soil (ammonium acetate method). The second and third years of production (2019-2020) were used for determining P and K rates and yields. Alfalfa was harvested at the mid-bud stage for all cuttings. Fall phosphorus soil test levels were 6.7 and 5.7 ppm at the beginning of 2019 and 2020, respectively. Spring soil test levels for the potassium study were 86 and 79 ppm at the beginning of 2019 and 2020, respectively. Failing to apply fertilizer in this experiment reduced yields by 15% for phosphorus and 11% for potassium. The lb P_2O_5 acre^{-1} that maximized gross income after fertilizer costs varied from 166 to 69 lb P_2O_5 acre^{-1} and from 307 to 0 lb K_2O acre^{-1} depending on the price of hay and fertilizer. The optimum P level in the harvested hay was 0.41% prior to 2020. Potassium tissue levels were not found to be helpful recommending K rates as dilution of the nutrient occurred as yields increased. Optimized fertilizer rates guidance must consider both hay value and nutrient costs. Inflation adjustment factors in our examples ranged from 1.14 to 0.47 for phosphorus and 1.30 to 0.00 for potassium.

OBJECTIVE

To develop and calibrate phosphorus (P_2O_5) & potassium (K_2O) nutrient recommendations for irrigated bud stage alfalfa in the PNW using tissue testing for maximum profit and yield influenced by prices of fertilizer and hay.

STUDY DESCRIPTION

Plot Layout: Two alfalfa research studies (P Study, K Study) were grown near Prosser, WA in South Central WA in initial low P (add test and P ppm) & K (add test and K ppm) testing soil from 2019-2020.

P Study: Differing rates of P_2O_5 using MAP; including: 0, 30, 60, 120, 240 lb. acre^{-1}.

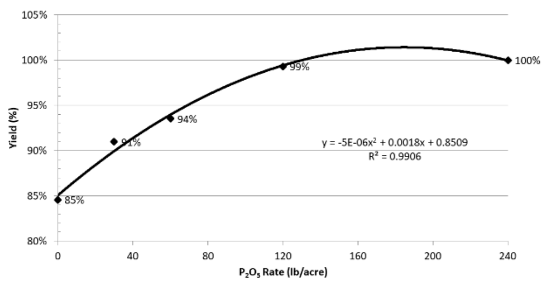
K Study: Differing rates of K_2O using potassium sulfate: 0, 40, 80, 160, 240, 320 lb. K_2O/acre

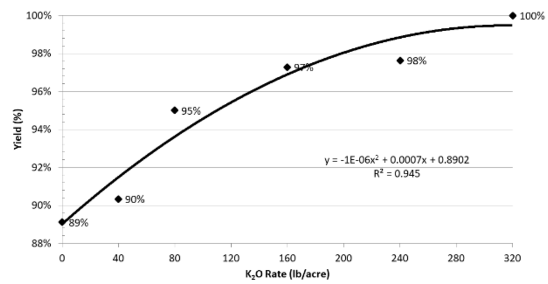
Analysis: Dry matter was analyzed for yield, P or K content (ICP method).

Funded: Three years of funding were received from the National Alfalfa and Forage Alliance and one year of funding from the Washington State Hay Growers Association.

RESULTS FOR PHOSPHORUS AND POTASSIUM STUDIES

Fall phosphorus soil test levels were 6.7 and 5.7 ppm at the beginning of 2019 and 2020, respectively (Figure 1a and 1b). Spring soil test levels for the potassium study were 86 and 79 ppm at the beginning of 2018 and 2019, respectively. Failing to apply fertilizer in this experiment reduced yields by 15% for phosphorus and 11% for potassium (Figures 1a & 1b). Results were similar for both years, so they were combined over years for each nutrient.





Figures 1a and 1b. The influence of P_2O_5 (Fig 1a) and K_2O (Fig 1b.) on the yield of alfalfa averaged over the 2nd and 3rd years (2019 & 2020) of production at the Irrigated Research and Extension Center located near Prosser, WA.

The lb P_2O_5 acre^{-1} that maximized gross income after fertilizer costs varied from166 when P_2O_5 acre^{-1}when hay prices were \$300 ton^{-1} and fertilizer was \$0.54 lb P_2O_5 to as low as 69 lb P_2O_5 acre^{-1} when alfalfa hay was \$150 ton^{-1} and fertilizer was \$1.56 lb P_2O_5 (Table 1). This shows that in the new world of inflation prices for both hay and fertilizer need to be put into fertilizer recommendations.

The increased price of fertilizer can be so high when hay prices are low that no amount of potassium would pay for itself, even in this responsive soil, which is the situation when alfalfa

Table 1. Influence of phosphorus fertilizer price on optimal economic rate (P_2O_5) and optimal phosphorus concentration of second cut harvested alfalfa forage at Prosser, WA from 2019-2020.

Fertilizer Price Of MAP (11-52-0)	**Hay Price \$150 per Ton**	**Hay Price \$225 per Ton**	**Hay Price \$300 per Ton**
Opt. Fert. Rate (lb P_2O_5/acre) / % of Base Price / Opt. % P Conc.			
Base Price \$ 560/Ton of MAP (\$0.54 lb P_2O_5)	146/(100%)/0.41	159/(100%)/0.42	166/(100%)/0.43
95% increase in Fert. Price \$1090/Ton (\$1.04 lb P_2O_5)	107/(73%)/0.38	134/(84%)/0.40	147/(89%)/0.41

189% Increase in Fert. Price $1620/Ton ($1.56 lb P_2O_5)	69/(47%)/0.34	109/(69%)/0.38	129/(78%)/0.40

Table 2. Influence of potassium fertilizer price on the optimal economic rate of K_2O based on research at Prosser, WA from 2019-2020.

Fertilizer Price Of KCl-(0-0-60)	**Hay Price $150 per Ton**	**Hay Price $225 per Ton**	**Hay Price $300 per Ton**
	Optimum Fertilizer Rate (lb K_2O/acre) / (% of base price rate)		
<u>Base Price</u> $ 446/Ton KCl^- 0-0-60 Or $0.37 lb K_2O	204/(100%)	246/(100%)	265/(100%)
122% increase in Fert. Price $990/Ton KCl^-, $0.83 lb K_2O	44/(22%)	144/(59%)	191/(72%)
244% Increase in Fert. Price $1534/Ton KCl^-, $1.28 lb K_2O	0/(0%)	43/(17%)	116/(44%)

hay is $150 ton^{-1} and the price of potassium is $1.28 lb K_2O (Table 2). Return on fertilizer is even more difficult if your goal is to maximize yield or replace nutrients removed (Table 3). When the 0-0-60 price is increased from $0.37/lb of K_2O to $1.27/lb of K_2O, the increased cost of the application over the optimum return on fertilizer went from $34 to $307 acre^{-1}. Farmers are already struggling so this increased cost may make it economically unsustainable for fertility to replace all the nutrients harvested and hauled off the field. Only the 120 and 240 lb P_2O_5 acre^{-1} treatments maintain or increased P fertility and only the 320 lb K acre^{-1} rate maintained the K soil fertility (data not shown).

Of the yearly increase in yield by fertilizer type, the percent of the yield increase for the year by applying the fertilizer primarily occurred in the first two cuttings with it accounting for 79% P yield increase and 80% K yield increase, with the first cutting providing 55% P and 54% K of the yield increases (data not shown).

Table 3. Impact of fertilizer price on optimum potassium fertilizer rate and cost per acre depending on the agronomic goal.

Goal	**Optimum Fertilizer Rate with Fertilizer Price (0-0-60)**		
	$446/ton of Fert. ($0.37/lb of P_2O_5)	$990/ton of Fert. ($0.83/lb of P_2O_5)	$1,534/ton of Fert. ($1.27/lb of P_2O_5)
Optimizing Annual Profit	265 lb acre^{-1}	191 lb acre^{-1}	116 lb acre^{-1}
Total K Replacement Rate <u>or</u> Maximizing Yield	356 lb acre^{-1}	356 lb acre^{-1}	356 lb acre^{-1}

Increased Fert. Cost $/acre	$34 acre^{-1}	$137 acre^{-1}	$307 acre^{-1}

Table 4. Impact of misapplying phosphorus to alfalfa at two scenarios, before inflation and after inflation. Different levels of second cut alfalfa tissue phosphorus concentration with 0.41% being optimum.

2nd Cut Harvest P Conc. (%)	Lbs of P_2O_5 to reach this from previous 0.01 %	Amount of P_2O_5 required to reach Optimum %	Dollars lost acre^{-1} year^{-1} for misapplying P when P is $0.54 lb of P_2O_5 and Alfalfa is $150 ton^{-1}	Dollars lost acre^{-1} year^{-1} for misapplying P when P is $1.04 lb of P_2O_5 and Alfalfa is $300 ton^{-1}
0.27	8	133	119	251
0.29	8	118	94	199
0.31	8	102	71	149
0.33	8	85	49	105
0.35	9	67	31	66
0.37	10	47	15	33
0.39	11	25	4	10
0.41	13	0	0	0
0.43	16	-29	5	10
0.45	20	-65	27	54

Recent global inflation has more than doubled the cost of misapplying phosphorus from both under and over-applying fertilizer (Table 4). Interestingly, since both hay price and fertilizer price have increased the optimum of 0.41% P concentration in the harvested hay at the second cut mid-bud stage remains the same. The second cutting was used as the data was less variable in the samples taken. Table 4 also shows the amount of P_2O_5 needed to increase forage content by 0.01%. This amount will likely vary based on yield potential in other fields. Potassium tissue levels were not found to be helpful in recommending K rates. This may have occurred as dilution of the nutrient occurred as yields increased. In the new inflationary times, we must adjust fertilizer rates to consider both hay and nutrient costs.

MANAGEMENT RECOMMENDATIONS FOR ADJUSTING FERTILIZER RATES:

Phosphorus

- First, gather any hay tests that you have taken for <u>second-cut hay</u> that has a % P of the hay. If you have no P content values from hay tests, use the adjustment factor in Table 5 and multiply this number by your soil test number to get an adjusted soil test for inflation.
- Second, do your best to estimate the cost of P fertilizer and the value of alfalfa hay and determine the box in Table 1 that best matches your condition.
- Third, determine if your hay tests %P are similar to the suggested P concentration and determine the difference.
- Fourth, use Table 4, second column, to add or subtract lb. P_2O_5 to get to the desired P concentration in the hay in Table 1. Remember, the number in each row is for a 0.1% increase or decrease for that tissue content. For instance, to get from 0.35 to 0.41% P. The difference is 0.6 increase needed. On average it takes about 11 lb per 0.1% increase (Avg of 10,11,13). So 6 times 11 would be an increase of 66 lb. **Add or subtract this amount from last year's application amount.**

Potassium

- Do your best to estimate the cost of K fertilizer and the value of alfalfa hay and determine the box in Table 2 that best matches your condition and use the rate in the box in Table 6. For instance, if you think at your next application you will have fertilizer price at \$990 ton^{-1} KCl^- (0-0-60) which is \$0.83 lb K_2O and alfalfa hay will be \$300 ton^{-1}. That box has 0.94 in it.
- Take your recommended soil test rate from your soil sample and multiply it by 0.94 and this is your new adjusted rate for inflation.

Alternative - Request an excel spreadsheet that you can put the numbers into and get a recommendation based on our results. Contact Steve Norberg at s.norberg@wsu.edu .

Table 5. Adjustment factors for phosphorus fertilizer rates for different hay and phosphorus prices.

Fertilizer Price Of MAP (11-52-0)	Hay Price \$150 per Ton	Hay Price \$225 per Ton	Hay Price \$300 per Ton
Opt. Fert. Rate (lb P_2O_5/acre) / % of Base Price / Opt. % P Conc.			
Base Price \$ 560/Ton of MAP (\$0.54 lb P_2O_5)	1.00	1.09	1.14
95% increase in Fert. Price \$1090/Ton (\$1.04 lb P_2O_5)	0.73	0.92	1.01
189% Increase in Fert. Price \$1620/Ton (\$1.56 lb P_2O_5)	0.47	0.75	0.88

Table 6. Adjustment factors for potassium fertilizer rates for different hay and phosphorus prices.

Fertilizer Price Of KCl^- (0-0-60)	Hay Price \$150 per Ton	Hay Price \$225 per Ton	Hay Price \$300 per Ton
	Optimum Fertilizer Rate (lb K_2O/acre) / (% of base price rate)		
Base Price \$ 446/Ton KCl^- 0-0-60 Or \$0.37 lb K_2O	1.00	1.21	1.30
122% increase in Fert. Price \$990/Ton KCl^-, \$0.83 lb K_2O	0.22	0.71	0.94
244% Increase in Fert. Price \$1534/Ton KCl^-, \$1.28 lb K_2O	0.00	0.21	0.57

OPTIMIZING FERTIGATION FOR HIGH VALUE CROPS

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ABSTRACT

In irrigated farming systems, soluble and mobile fertilizers, such as sources of nitrogen, are often applied to crops through irrigation water. Fertigation presents both opportunities and challenges. Potential opportunities include better synchronization of available nutrients with crop demand through the growing season, reduced soil compaction or crop damage, and energy and labor cost savings. Challenges include having the right infrastructure for the injection of nutrients into irrigation delivery and distribution systems, having the tools to forecast crop demand, and having the management guidelines to optimize uniformity and efficiency. This presentation will briefly summarize models and algorithms we have developed to optimize fertigation in surface and sprinkler irrigation systems, present the analytical framework for the evaluation of fertigation events, and present a case field study showing the implementation of a successful fertigation program.

INTRODUCTION

In irrigated farming systems, soluble fertilizers are often applied to crops through fertigation. Fertigation offers both benefits and limitations. Potential benefits include better synchronization of nutrient availability with crop demand through the growing season and reduced costs. Limitations consist of the need for the additional investment in infrastructure for nutrient injection into the irrigation conveyance and distribution system and the development and maintenance of management tools (including models for demand forecasting and guidelines to optimize fertigation performance). This presentation will focus on tools (i.e., mathematical models and performance evaluation methods) developed over the last two decades for optimal management of fertigation systems in surface and sprinkler-irrigated fields. The fertigation models addressed here can be used to simulate fertigation events where water-soluble fertilizers are applied. These models are not intended for direct use by growers but to allow advisors to make customized system operation recommendations via simulations across varying scenarios.

MODEL DEVELOPMENT AND PERFORMANCE EVALUATION SCHEMES

Surface Fertigation

Approximate advective transport fertigation models were developed by Boldt et al (1994), Playan and Faci (1997), and Strelkoff et al. (2007). These models were based on plug flow type conceptualization of the movement and distribution of nitrate fertilizers over surface irrigated fields. A physically based coupled surface-subsurface hydraulic and solute transport model capable of simulating the longitudinal and subsurface distribution of soluble fertilizers and water in irrigation basins was developed by Zerihun et al. (2005a,b,c). The subsurface component of the model can compute the redistribution of water and fertilizer in the soil profile, as a function of time, between irrigation events and over a cropping season. A capability that allows for a dynamic approach to the partitioning of soil water and fertilizer into crop available, deep percolated, and surplus fractions and hence for a more accurate determination of seasonal fertigation system performance. The model was calibrated and validated using field data collected in agricultural production fields (Figure 1). Following this work, other physically based s surface fertigation models were developed based on alternative numerical solutions to the advection-dispersion equation (e.g., Bautista and Schelgel, 2020; Burguette et al., 2009a,b; Perea et al., 2010; Zerihun et al., 2014).

A surface fertigation performance evaluation method (consisting of a set of equations and solution techniques) was developed for determining the efficiency, uniformity, and adequacy of fertigation events (Zerihun et al., 2003). The method can be used to determine the performance of real-world fertigation events using field-measured data or can be integrated into a fertigation model to assess the performance of simulated scenarios.

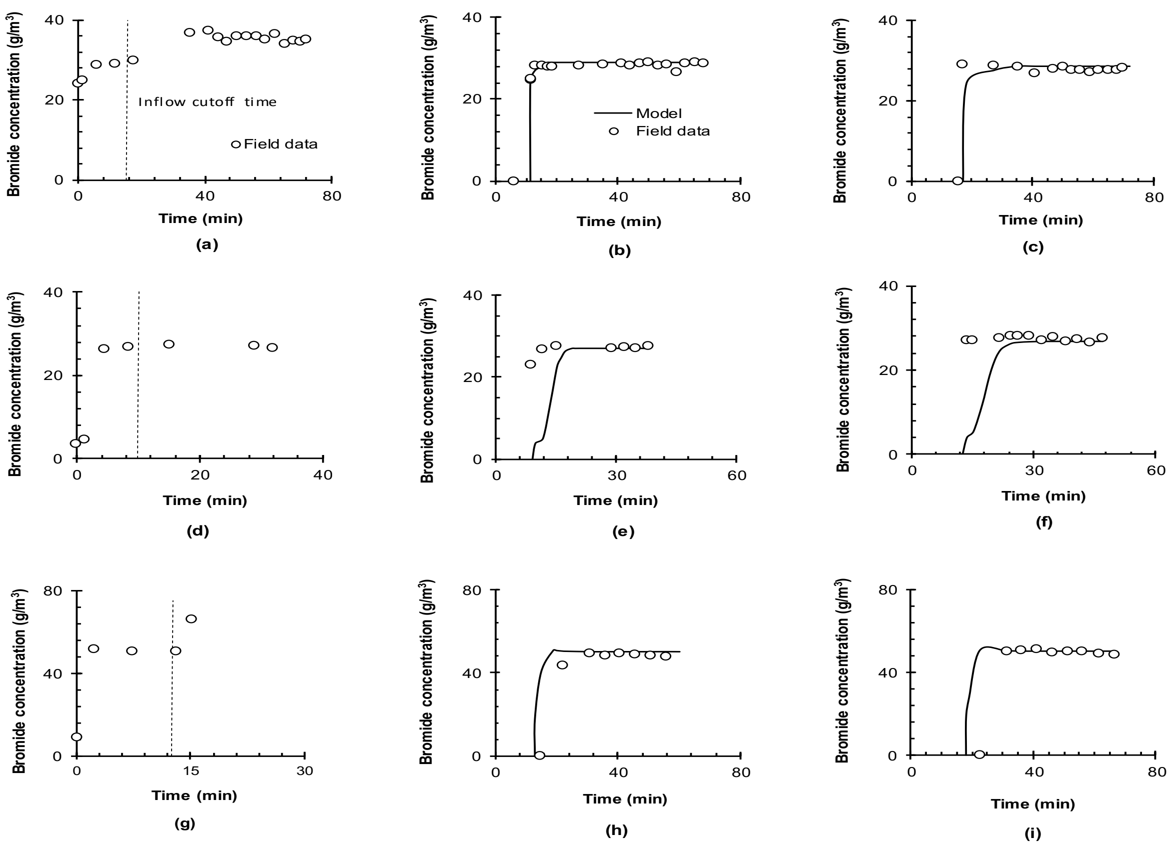

Figure 1. Comparison of model-predicted and field-observed bromide breakthrough data collected in the Yuma Mesa: First row, level basin: (a) basin inlet, (b) 100m from the basin inlet, and (c) 142m from basin inlet; Second row, graded basin: (d) basin inlet, (e) 107m from basin inlet, and (f) 142m from basin inlet; Third row, free-draining border: (g) border inlet, (h) 120m from border inlet, and (i) 160m from border inlet

Sprinkler Fertigation

Recently, a model for simulating the transport of solutes, in a sprinkler irrigation lateral was developed and evaluated by Zerihun et al (2023). The model is designed to simulate the time- and distance-evolution of the concentration of a nonreactive solute in an irrigation lateral over a chemigation event, given the hydraulic condition, the solute input function specified at the lateral inlet, and the initial concentration profile along the lateral. For modeling purposes, a lateral is conceptualized here as a hydraulic network consisting of a series of connected pipes, each delimited by outlet nodes. At the pipe-scale, flow is deemed steady and uniform and solute transport is modeled as an advective process in which the equation governing advection, in a hydraulic conduit, is solved with a quasi-Lagrangian integration scheme. Solutions to the transport problem, in a pair of consecutive pipes, are coupled through a nodal condition, which can be stated as: the concentration computed at the downstream-end node of a pipe constitutes the upstream boundary condition for the advective transport problem in the pipe just downstream.

The model was evaluated in two phases. First, the soundness of the formulation and programmatic implementation of the numerical solution, to the pipe-scale advective transport problem, was tested through a comparison of model outputs with an analytical solution. Evaluation of the predictive capacity of the lateral-wide model, in the context of a real-world application, was then conducted by comparing computed breakthrough curves of a nonreactive tracer with data measured along a pair of laterals. The results suggest that model performance is satisfactory (Figure 2).

A methodology (consisting of a field protocol and equations) for evaluating the uniformity of fertigation events under sprinkler irrigation systems were proposed by Zerihun et al. (2017). Irrigation uniformity indices are adapted for use in fertilizer application uniformity evaluation. Fertilizer application rate, given as a function of irrigation depth and fertilizer concentration, is identified as the appropriate variable to express fertilizer application uniformity indices. The results of the study show that the spatial overlap patterns between depth and concentration data sets are the main determinants of test-plot scale fertilizer application rate uniformity (Figure 3). The study also shows that often the uniformity levels of irrigation and fertilizer concentration data sets cannot be uniquely related to the uniformity of the resultant application rate data. However, some practically useful qualitative interrelationships between the uniformity of irrigation depth, solute concentration, and application rate data sets were identified.

Application

Legislative mandated "Best Management Practices" has prompted us to seek avenues for enhancing N use efficiencies, and fertigation management is among the practices currently being evaluated, where practical. Synchronizing applications with anticipated crop uptake creates opportunities for enhanced efficiencies (Sanchez and Doerge, 1999). However, high-value vegetable crops in the desert are planted daily from the middle of September through late February, the growth period varies, and days from planting is not a reliable prediction of the crop growth stage. Therefore, we have implemented growth-tracking based on growing degree days (GDD) or normalized difference vegetative index (NDVI) from satellite imagery. The use of GDD and NDVI to track above-ground N accumulation by baby spinach is shown in Figure 4. Data we have collected show N fertilizer use can be reduced by 50% for baby spinach using fertigation system operation protocols specified from models and the generalized N accumulations curves. This approach is being expanded to other sprinkler-irrigated crops.

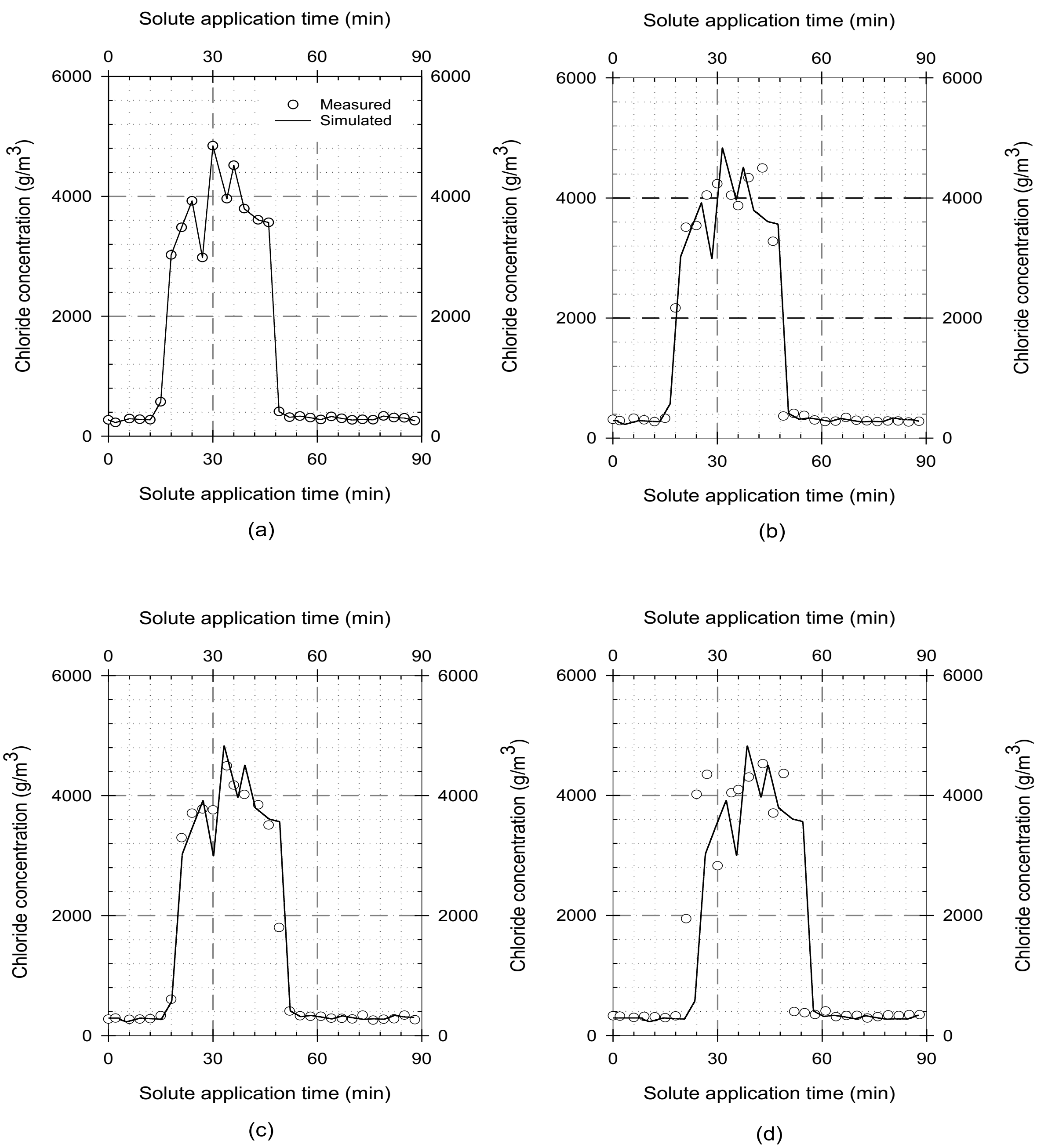

Figure 2. Comparison of measured and simulated solute (chloride) concentrations breakthrough curves sprinkler lateral a, input, b 91.4 m, c 173.7m and d 310.8 m from lateral inlet

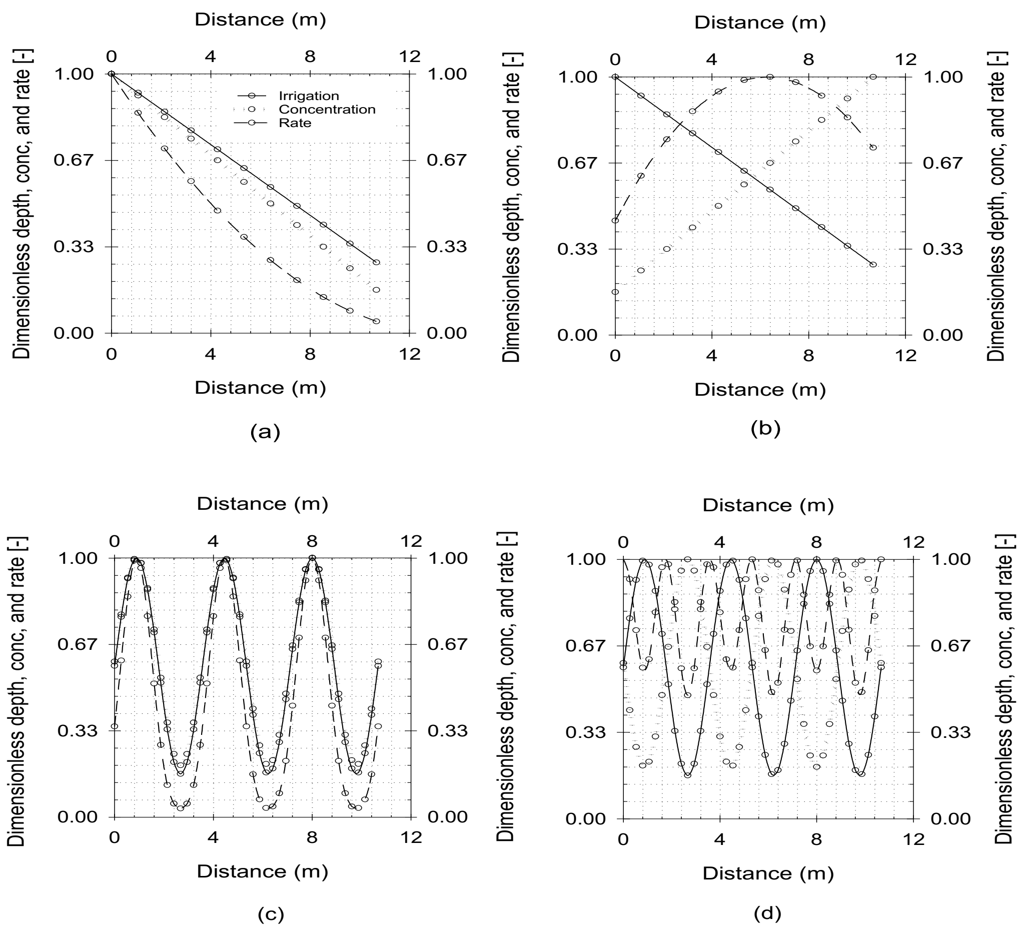

Figure 3. The relationship between spatial trends in irrigation depth, fertilizer concentration, and the spatial variability of the resultant fertilizer application rate. Scenarios where dominant spatial trend spanning the test–plot exists and depth and concentration show: (a) same monotonicity, (b) opposite monotonicity; and Scenarios where local spatial trends dominate and depth and concentration show: (c) same monotonicity, (d) opposite monotonicity.

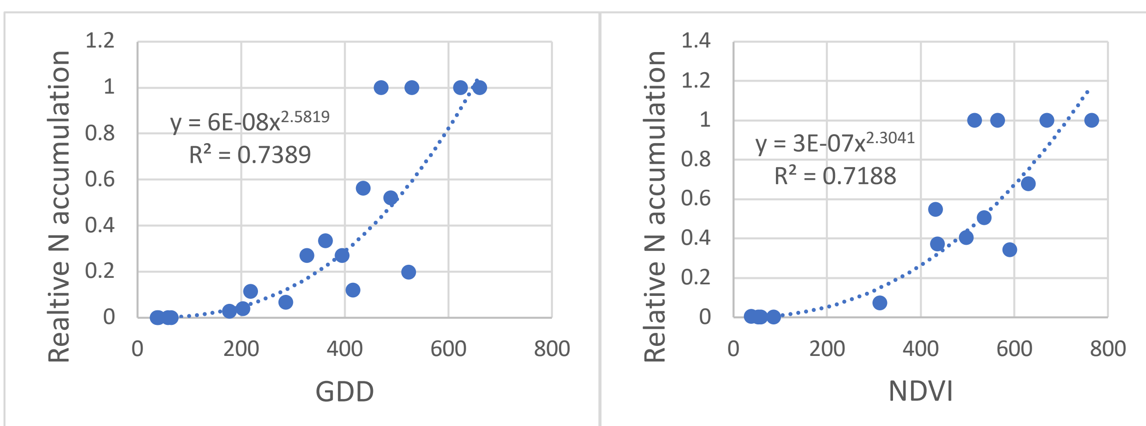

Figure 4. Generalized above ground N accumulation for baby spinach by GDD or NDVI derived from field experiments (unpublished data of Sanchez).

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MONITORING SOIL NITRATE TO ESTIMATE COVER CROP NITROGEN CONTRIBUTION IN ORGANIC VEGETABLE PRODUCTION FIELDS

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ABSTRACT

Organic vegetable growers rely on legume cover crops as an economical source of plant-available N. This research evaluated N contributions to summer vegetable crops by cover crops (CC) residues by monitoring soil nitrate (NO_3-N) concentrations during the summer crop growing season. Replicated field plots were established with three CC mixes: solo common vetch (V), phacelia + V (PV), and cereal rye + V (RV), plus a winter fallow (F) control in grower fields in the north Willamette Valley OR. Soil textures were silt loam (7 sites) and sandy loam (2 sites). Cover crops were seeded in a randomized complete block design in mid-October and killed in April (vegetative) or in early May (just prior to flowering). Cover crop biomass was incorporated by tillage 1-3 wk. after CC kill. Soil samples (0-12 in depth, 4 in beside the row) were collected on 2-4 wk. intervals, beginning at summer crop planting (Year 1 sites) and at cover crop kill (Year 2 sites). Net soil NO_3-N contribution from CC in the field was estimated by difference in soil test nitrate concentrations (CC treatment minus winter fallow control). Summer crops monitored included winter squash (3 sites), lettuce (2 sites), and table beet, snap bean, kale and popcorn (1 site each). All sites received overhead sprinkler irrigation. Phacelia did not establish reliably as a winter cover crop. It emerged in fall, but did not survive the winter at most sites. At time of cover crop kill in spring, phacelia biomass exceeded 25% of total CC biomass (phacelia + V) at only 2 of 7 sites where it was seeded. Maximum net soil NO_3-N contribution was observed near time of crop planting for lettuce, kale, snap bean and table beet, and just prior to the first heavy irrigation for corn and winter squash. Across 9 sites, median net soil NO_3-N contribution (treatment minus control) was 28 lb/acre (range = 3 to 95) for RV and 46 lb/acre for V (range = 9 to 130). Soil nitrate monitoring had the most practical value for adjustment of organic fertilizer input rates for crops that receive limited early season irrigation (corn and winter squash), or for short season crops (lettuce and kale) planted in July. Median net soil nitrate contribution in the field was 50 to 80% of that measured in 10-wk laboratory incubation at 22°C. This suggests that N credits based on measuring soil nitrate (0-12 inches) following a cover crop will usually underestimate actual plant-available N supplied by a cover crop.

INTRODUCTION

Legume cover crops provide plant-available N for the succeeding crop. Predicting the amount and timing of plant-available N provided from a winter cover crop is critical to choosing appropriate rates of supplemental organic fertilizers. The present research was conducted to evaluate three cover crop seed mixtures for the timing and amount of plant-available N released in vegetable cropping systems in western Oregon. In this paper, we primarily address the measurement of soil nitrate in the field as an indicator of soil N status following cover crop kill. To provide additional context for the field soil nitrate data, we also briefly discuss the relationship between soil nitrate concentrations measured in the field vs. those measured for the same cover crop residues incubated in soil at constant temperature and soil moisture in the laboratory.

Timing and depth of soil nitrate sampling is important for test interpretation. Extension guidance for irrigated vegetable crop in western states that soil nitrate concentrations (0-12 inch depth) exceeding 20 mg/kg at seeding, or 30 mg/kg at 4-6 wk. after seeding are considered adequate for many vegetable crops Oregon (OSU Extension EM 9221).

Interpretations of preplant or midseason soil nitrate tests (0-12 inches) are imperfect because they do not 1) account for plant-available NH_4-N, 2) forecast N mineralization that happens after the soil nitrate sample is collected, 3) assess crop root distribution and crop N uptake capacity below 12 inch depth, or 4) forecast the timing and amount of nitrate loss via leaching.

Table 1. Field site descriptions and date of maximum soil nitrate contribution from cover crop treatments. Willamette Valley, OR on-farm cover crop trials.

Summer crop yr	Farm	Soil mapping unit (NRCS) [a]	Cover crop kill	Summer crop	Summer crop planted	CC kill to planting (days)	Date of maximum net soil NO_3-N [b]
2009	MF	Canderly sal	9-Apr	table beet	10-May	31	18-May
	MSF	Amity sil	20-Apr	winter squash	28-May	38	10-Jun
	PMF	Aloha sil	30-Apr	winter squash	25-May	25	1-Jul
	SSF	Chehalis sil	21-Apr	lettuce	6-Jul	76	2-Jul
	WUG	Aloha sil	24-Apr	winter squash	30-May	36	30-Jun
2010	MF	Canderly sal	19-Apr	snap bean	18-May	29	25-May
	MSF	Amity sil	14-Apr	lettuce	5-May	21	25-May
	SSF	Chehalis sil	19-Apr	kale	25-Jun	67	8-Jul
	NWREC	Willamette sil	12-May	popcorn	22-Jun	41	9-Jul

[a] sal = sandy loam, sil = silt loam soil texture.

[b] Date listed for maximum net NO_3-N within each site-yr is based on soil NO_3-N data presented in Figure 1. At specified date, maximum net soil NO_3-N = [(soil NO3-N for CC treatment) - (soil NO_3-N for control winter fallow treatment)]. Table 3 estimates maximum net soil NO_3-N contribution in units of lb/acre.

MATERIALS AND METHODS

Field experiments were conducted over 9 site-yr (Table 1). Field sites were located in the north Willamette Valley (WV) of Oregon near Canby (MF and PMF), St. Paul (MSF), Clackamas (SSF), North Plains (WUG) and Aurora (NWREC). Commercial farms in the study grew a wide range of fresh market vegetables in rotation, with some historical use of cover crops. At NWREC, conventional wheat was grown for several years before the study and the field was being transitioned to organic management. Summer crops (Table 1) were direct seeded except for lettuce and kale. Weeds and insects were controlled by organically approved methods except at WUG and

MF. Overhead sprinkler irrigation as supplied via solid set irrigation systems and handlines, with 100% overlap at operating pressure. Irrigation timing and amount was determined by growers. All farms except WUG and MF used certified organic production methods; WUG used synthetic fertilizers in combination with yard debris compost. Preplant soil test values (0-12 in) indicated sufficiency for pH (6.1-6.6; 1:2 soil:water), P (69-160 ppm; Bray P1) and other nutrients, relative to OSU Extension guidance.

Cover crop species included common vetch (*Vicia sativa*), cereal rye (*Secale cereale*) and phacelia (*Phacelia tanacetifolia*). Cover crop trials were seeded by OSU personnel in small plots within larger grower-managed fields. Previous crop residues were mowed and incorporated by discing. Common vetch was seeded at 60 lb/acre in both solo and mixed species treatments. Vetch seed was treated with inoculum just prior to seeding (*Rhizobium leguminosarum* inoculant group C for peas and vetch). In mixed species treatments, cereal rye was seeded at 30 lb/acre and phacelia was seeded at 10 lb/acre. Experimental design within each field site was a randomized complete block with 4 replications. Cover crop subplots were 20-25 ft wide and 70-80 ft long within each replication. Cover crops were seeded in early to mid-October using a Gandy drop spreader, incorporated with a ring roller, then irrigated once or twice with overhead sprinklers on hand lines (if needed) before the onset of fall rain. Cover crop stands were good to excellent at all sites in November.

Just prior to cover crop kill in the spring, above-ground cover crop biomass and species composition were determined by harvesting four 4ft^2 quadrats within each plot (16 ft^2 per plot; method in PNW Extension publication 636, p. 6). After biomass determination, cover crops were killed by mowing (if needed) and then incorporated with a disc or moldboard plow. In the field, soil samples were collected 4 inches beside center rows to a depth of 12 inches using a 0.75 inch diameter push probe. Five to 10 cores were collected per composite sample. Soil samples were refrigerated (5 ^oC) on day of collection, and were oven-dried within 48 h of sampling.

Laboratory incubation. Cover crop biomass was incubated aerobically in moist soil to determine net CC contribution to soil nitrate after 4 and 10 wk. at constant temperature (22^oC). Between the date of field cover crop harvest and the start date for laboratory incubation, cover crop biomass samples were held in a kitchen freezer (-18^oC). Prior to mixing with soil, cover crop samples were defrosted, chopped into small pieces (1 to 2 inch length), then immediately added to soil at a rate of 25 g moist biomass per 500 g of moist soil, for an approximate incorporation rate of 1% w/w on a dry weight basis. To determine actual N added, CC dry matter was determined at 60 ^oC and soil dry matter at 100^oC. During the incubation, gravimetric soil moisture was monitored and maintained at 20 to 25% (200-250g H_2O/kg dry soil).

Analyses of C and N in cover crop biomass was performed by the Oregon State University Central Analytical Laboratory (CAL) using a combustion analyzer equipped with an infrared detector. Nitrate in 2M KCl soil extracts was determined by an automated cadmium reduction method at CAL. Soil NO_3-N (lb/acre) was estimated as soil nitrate-N (mg/kg) x 3.5. This conversion factor assumes a soil bulk density of 1.3 g/cm^3 in soils at all sites.

Table 2. Cover crop species composition, nitrogen and carbon analyses, biomass and above-ground N uptake[a].

Year	Farm	Cover Crop (CC)	Legume	Phacelia or cereal rye	Total N		C:N ratio		CC biomass		CC N uptake	
			% of CC dry wt.		% of CC dry wt.		lb/acre					
2009	MF	PV	90	1	3.6	(0.2)	11	(0.1)	2670	(390)	94	(12)
		RV	44	56	2.7	(0.2)	15	(0.8)	4950	(570)	135	(23)
		V	95	0	3.7	(0.1)	11	(0.4)	4450	(470)	164	(20)
	MSF	PV	62	7	2.9	(0.3)	14	(1.3)	3660	(480)	111	(24)
		RV	40	46	2.3	(0.2)	19	(1.8)	5560	(360)	128	(18)
		V	59	0	2.9	(0.1)	14	(0.6)	3880	(380)	114	(12)
	PMF	PV	32	34	2.4	(0.1)	16	(0.6)	5100	(410)	125	(11)
		RV	36	33	2.3	(0.1)	18	(0.7)	5230	(500)	124	(17)
		V	61	0	2.9	(0.2)	15	(0.7)	4660	(380)	137	(16)
	SSF	PV	12	2	2.0	(0.2)	20	(2.8)	2520	(350)	53	(13)
		RV	11	66	2.3	(0.1)	18	(0.7)	5860	(290)	137	(7)
		V	62	0	3.4	(0.1)	12	(0.5)	4000	(310)	137	(13)
	WUG	RV	5	90	2.0	(0.0)	21	(0.3)	8330	(490)	164	(9)
		V	56	0	3.7	(0.1)	11	(0.3)	3570	(150)	132	(10)
2010	MF	PV	56	27	3.0	(0.1)	13	(0.3)	3470	(270)	104	(10)
		RV	44	34	2.9	(0.2)	14	(1.0)	2660	(220)	76	(5)
		V	69	0	3.1	(0.1)	13	(0.6)	2650	(110)	82	(3)
	MSF	PV	62	13	2.6	(0.1)	15	(0.7)	2600	(340)	67	(6)
		RV	50	31	2.1	(0.0)	19	(0.4)	3060	(280)	64	(5)
		V	52	0	2.4	(0.3)	16	(1.4)	2170	(160)	53	(10)
	NWREC	RV	26	67	1.9	(0.1)	22	(1.3)	8490	(610)	163	(22)
		V	75	0	3.8	(0.2)	11	(0.7)	5750	(300)	221	(24)
	SSF	PV	69	0	3.0	(0.1)	13	(0.3)	2700	(100)	82	(4)
		RV	20	61	2.1	(0.1)	19	(0.5)	6700	(200)	141	(4)
		V	66	0	3.1	(0.1)	13	(0.3)	3320	(380)	101	(12)
	Median	PV	62	2	2.9		14		2700		94	
		RV	36	56	2.3		19		5560		135	
		V	62	0	3.1		13		3880		132	

[a] Values in parenthesis are standard error of the mean (n=4). Weed dry matter (%) = 100-CC dry matter (%).

RESULTS AND DISCUSSION

Median values for RV and V biomass and above-ground crop N uptake (Table 2) were in a typical range for our region, based on monitoring data from other farms and years. The median C:N for RV (19) was slightly above the "breakeven" value listed in literature for zero N mineralization/immobilization (15), suggesting a brief period of N immobilization for RV in soil. At a few sites (WUG in 2009; NWREC and SSF in 2010), values for RV biomass were very high (8330, 8490, 6700 lb/acre, respectively), because rye dominated cover crop biomass, and cover crop was allowed to grow until late April or May. Phacelia did not establish reliably as a winter cover crop. It emerged in fall, but did not survive the winter at most sites. At time of cover crop kill in spring, phacelia biomass exceeded 25% of total CC biomass (phacelia + V) at only 2 of 7 sites.

Soil NO_3-N concentrations following cover crop incorporation in the field (Figure 1;Table 3) were affected by: 1) amount and quality of cover crop biomass, 2) soil temperature and rainfall, 3) N uptake by the summer crop, and 4) leaching by rainfall + irrigation. Examples: In 2010, declines in soil nitrate were observed at most sites in early June (MF, MSF SSF), associated with unusually cool, wet weather. The seasonal peak in soil nitrate occurred just prior to the period rapid crop N uptake for corn (NWREC in 2010) and for winter squash (MSF and PMF in 2009), suggesting that a combination of crop N uptake and nitrate leaching may have been responsible for declining soil NO_3-N concentrations in July. Cover crop NO_3-N contribution was < 10 lb/acre for a lettuce crop seeded at MSF on 5-May 2010, associated with limited CC biomass and cool soil temperatures after CC incorporation.

Maximum net soil NO_3-N contribution was observed near time of crop planting for lettuce, kale, snap bean and table beet, and just prior to the first heavy irrigation (3-5 wk. after planting) for corn and winter squash (Table 3). Across 9 field sites, median net soil nitrate contribution (treatment minus control) was 28 lb/acre (range = 3 to 95) for RV and 46 lb/acre for V (range = 9 to 130). At all sites, the timing of net soil nitrate contribution was similar for RV and V.

Maximum net soil nitrate contribution (0-12 inches) in the field was generally lower than that measured in laboratory incubations (Table 3). Median net soil nitrate contribution in the field was 50 to 80% of that measured in 10-wk laboratory incubations at 22°C. This suggests that N credits based on measuring soil nitrate (0-12 in) following a cover crop will usually underestimate actual plant-available N supplied by a cover crop.

We conclude that soil nitrate monitoring has the most practical value for adjustment of organic fertilizer input rates for crops that receive limited early season irrigation (e.g. corn and winter squash), or for short season crops (e.g. lettuce and kale) planted in July following an extended fallow period.

Table 3. Net soil nitrate contribution as estimated by laboratory incubation of cover crop residue (4 and 10 wk. at 22°C) and maximum net soil nitrate contribution in field soil samples (0-12 inches)[a].

Year	Farm	Lab Incubation (4 wk. @ 22°C)			Lab Incubation (10 wk.)			Field				Ratio: Field/(10-wk incubation)		
		PV	RV	V	PV	RV	V	Date of max NO_3-N contribution	PV	RV	V	PV	RV	V
		------------Net soil nitrate contribution from cover crop residue (lb NO_3-N/acre)------------------												
2009	MF	44	48	74	54	71	87	18-May	16	13	26	0.3	0.2	0.3
	MSF	37	29	31	59	49	47	10-Jun	48	28	46	0.8	0.6	1.0
	PMF	28	35	46	40	53	74	1-Jul	34	21	25	0.9	0.4	0.3
	SSF	14	46	67	15	61	81	2-Jul	29	66	124	1.9	1.1	1.5
	WUG		20	49		37	42	30-Jun		95	130		2.6	3.1
2010	MF	36	28	36	55	45	51	25-May	28	24	23	0.5	0.5	0.5
	MSF	25	20	12	43	33	23	25-May	4	3	9	0.1	0.1	0.4
	NWREC		25	62		83	106	8-Jul		52	85		0.6	0.8
	SSF	18	26	32	38	82	69	9-Jul	30	40	48	0.8	0.5	0.7
Median		28	28	46	43	53	69		29	28	46	0.8	0.5	0.7

[a] Soil nitrate-N conversion from ppm to lb/acre based on a soil bulk density of 1.3 g/cm^3 for all sites and incubations.
PV treatment was omitted from experiment at WUG in 2009 and at NWREC in 2010.
In the field, net NO_3-N contribution was estimated at listed sample date within each field site-yr where maximum CC treatment response (CC treatment minus winter fallow treatment,"F") was observed. Figure 1 shows soil NO_3-N concentrations across time.

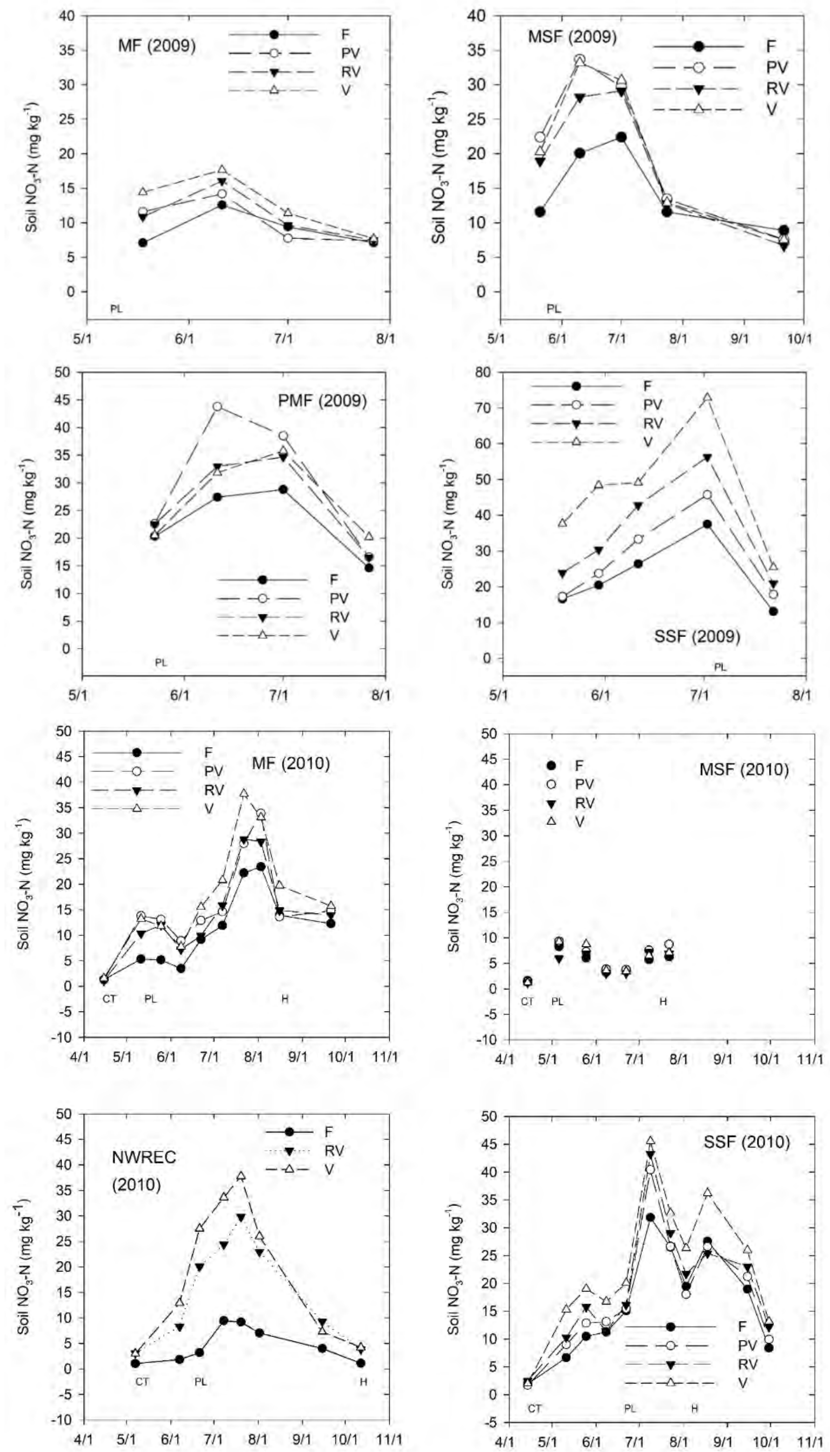

Figure 1. Effect of winter cover crop on soil nitrate-N (0-12 inches). Crop management events: CT = cover crop termination, PL = planting of summer crop, H = crop harvest. Zero cover crop control treatment = F (winter fallow). Summer crops present at each field site are listed in Table 1.

CRYSTAL GREEN® – THE MOST EFFICIENT GRANULAR PHOSPHATE FERTILIZER

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ABSTRACT

Over 80% of applied conventional phosphate is lost to soil fixation or the environment and leaves crops hungry for nutrients when they need them the most. Not only are crops missing out on proper plant nutrition, but nutrients lost to the environment are responsible for harmful algae blooms. At Ostara, we're fixing this industry challenge by producing Crystal Green (CG) granule phosphate fertilizers. Crystal Green fertilizers provide critical nutrients throughout the growing season to maximize yield and quality while also protecting the environment. By combining concentrated ammonium phosphate with other proprietary ingredients, Crystal Green is produced as a magnesium ammonium phosphate hexahydrate. The result is an industry-leading granular fertilizer that is sparingly water-soluble and eliminates nutrients lost due to soil P tie-up, runoff, and leaching. Nitrogen, phosphate, and magnesium released by Crystal Green are over 90% weak organic acid-soluble and 100% plant available. Unlike conventional phosphate fertilizer sources, Crystal Green will only release nutrients in response to crop demand as plant roots naturally exude organic acids. Due to its unique weak organic acid solubility, Crystal Green can be applied in the fall or spring with the assurance that the fertilizer will be there when crops need it. Research conducted in the U.S. and Canada proves farmers can reduce phosphate application rates by choosing Crystal Green over other phosphate fertilizers and continue to receive positive yields and ROI. When Crystal Green fertilizers are applied, farmers maximize phosphate efficiency and take significant strides to reduce nutrients released into the environment.

INTRODUCTION

Crystal Green is the first commercially available struvite-based fertilizer (5-28-0 with 10% Mg) to harness the power of nutrients as a root-activated phosphate fertilizer. Composed of magnesium ammonium hexahydrate, Crystal Green performs differently than conventional water-soluble phosphate fertilizers because it is only sparingly water-soluble. Crystal Green is the first Root Activated™ nutrient technology that releases in response to weak organic acids such as those produced by growing roots and soil microbes. Crystal Green's mode of action delivers plant-available nitrogen (N), phosphorus (P), and magnesium (Mg) when the plant needs it most. Nutrients released to plant demands mean improved nutrient efficiency, reduced nutrient losses, the potential for greater yields, more uniform growth, and improved quality. Crystal Green excels when it is placed in the root zone because it stays where it is applied. Over a decade of university and third-party field trials and laboratory evaluations prove high-yielding results in a wide range of soil types and crops. It is seed safe, easy to blend, and a proven complement to traditional phosphate fertilizer programs for season-long availability. Crystal Green is the next generation of highly effective sustainable phosphate fertilizer that can reduce the amount of phosphate needed per acre.

Potatoes have a high demand for phosphorus (P) but also have a shallow inefficient root system which often requires high phosphate application rates on acid or calcareous soils. Studies on the effect of Crystal Green (5-28-5 with 10% Mg) on potato (Solanum tuberosum L) were conducted in 2014 and 2017 by Dr. Byran Hopkins (BYU-Provo).

METHODS

2014 – Russet Burbank potatoes were planted in research plots near Rupert, Idaho May 2014. Plots were 6 rows wide (36-inch width) by 50 feet in length in a randomized complete block design with 5 replications. Phosphate treatments were applied as a broadcast application and incorporated prior to bedding. Phosphate treatments included 1) 0 P control, 2) MAP (11-52-0) at 100 lb. P_2O_5/acre, 3) 38% CG + 62% MAP at 100 lb. P_2O_5/acre, 4) 38% CG + 62% MAP at 75 lb. P_2O_5/acre, and 5) 65% CG + 35% MAP at 75 lb. P_2O_5/acre. Nitrogen was balanced across all treatments. The soil type was a sandy loam with excellent drainage. Thirty-foot row length from the center two rows was mechanically harvested and used to determine yield and quality.

2017 – Russet Burbank potatoes were planted at the Brigham Young University research facility near Provo, Utah on May 14. Phosphate treatments were applied 6 inches below the soil's surface prior to planting. Phosphate treatments included 1) 0 P control, 2) MAP (11-52-0) at 150 lb. P_2O_5/acre, 3) 25% CG + 75% MAP at 150 lb. P_2O_5/acre and 4) 50% CG + 50% MAP at 150 lb. P_2O_5/acre. Nitrogen was balanced across all treatments. Plots were arranged in a randomized complete block design with 5 replications. Plots were 4 rows (30 inch) by 30 ft. in length. Cut potato seed was planted 6 inches below the soil surface. The soil was a sandy loam with a 1% slope, low soil fertility, and excellent drainage. Eighteen-foot row length from the center two rows was hand harvested and used to determine yield and quality.

RESULTS AND DISCUSSION

There was a significant response of Russet Burbank potatoes in 2014 when Crystal Green granular phosphate fertilizer was included as part of the preplant phosphate application (Figure 1). Marketable yields (US#1 + US#2) significantly increased compared to the same phosphate rate as MAP alone. A 25% reduction in P_2O_5 rate (75 lb. P_2O_5) significantly outyielded 100 lb. P_2O_5 as MAP. Treatments containing CG had higher petiole P concentrations than the MAP-only treatment for the first petiole sampling date and treatments containing CG had higher Mg concentrations (data not shown). CG increased the US#1 compared to only MAP and 0 P treatments. There was no difference in internal quality or specific gravities resulting from any of the phosphate treatments.

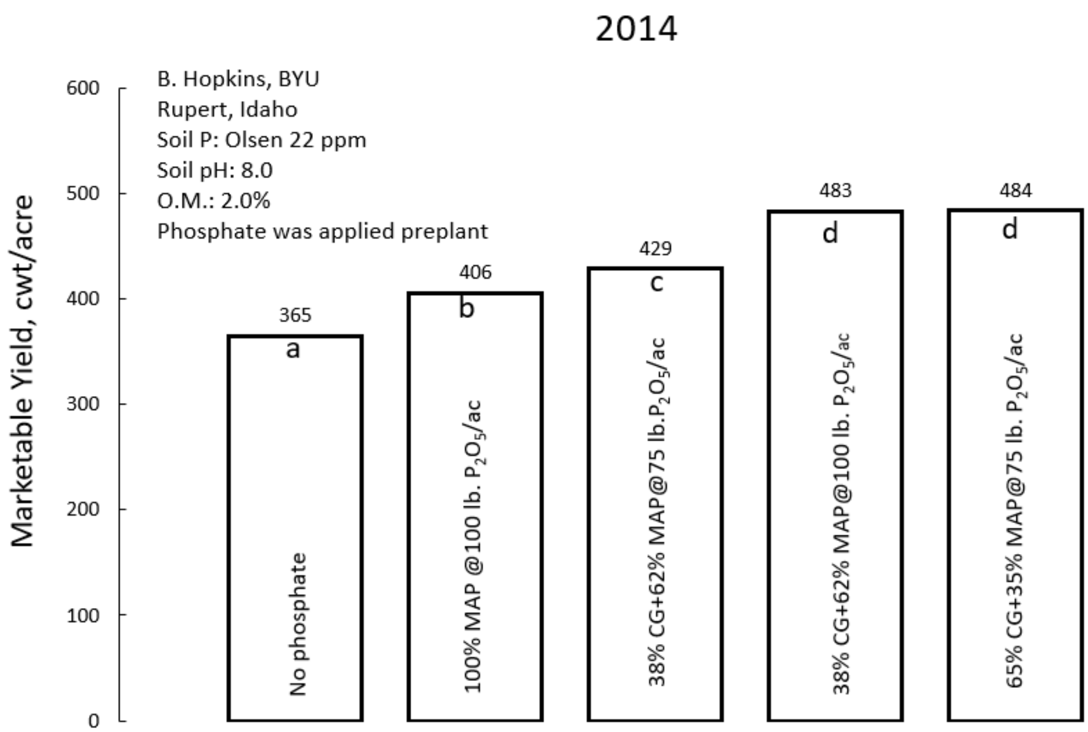

Figure 1. Effect of Crystal Green on Russet Burbank potato production near Rupert, Idaho in 2014

In 2017, phosphate fertilization resulted in greater shoot, root, and tuber biomass. Marketable yield of MAP at 150 lb. P_2O_5 per acre was similar to the untreated control. There was a tendency for potatoes receiving only MAP to have larger tubers with poorer quality. Crystal Green (38%) blended with MAP at 38% and (62%) out yielded 100% MAP applied at the same rate (Figure 2). CG (50%) plus MAP (50%) had the highest numerical yield and greater US#1 tuber yield than all the other treatments. There was no difference in internal quality or specific gravities resulting from any of the phosphate treatments.

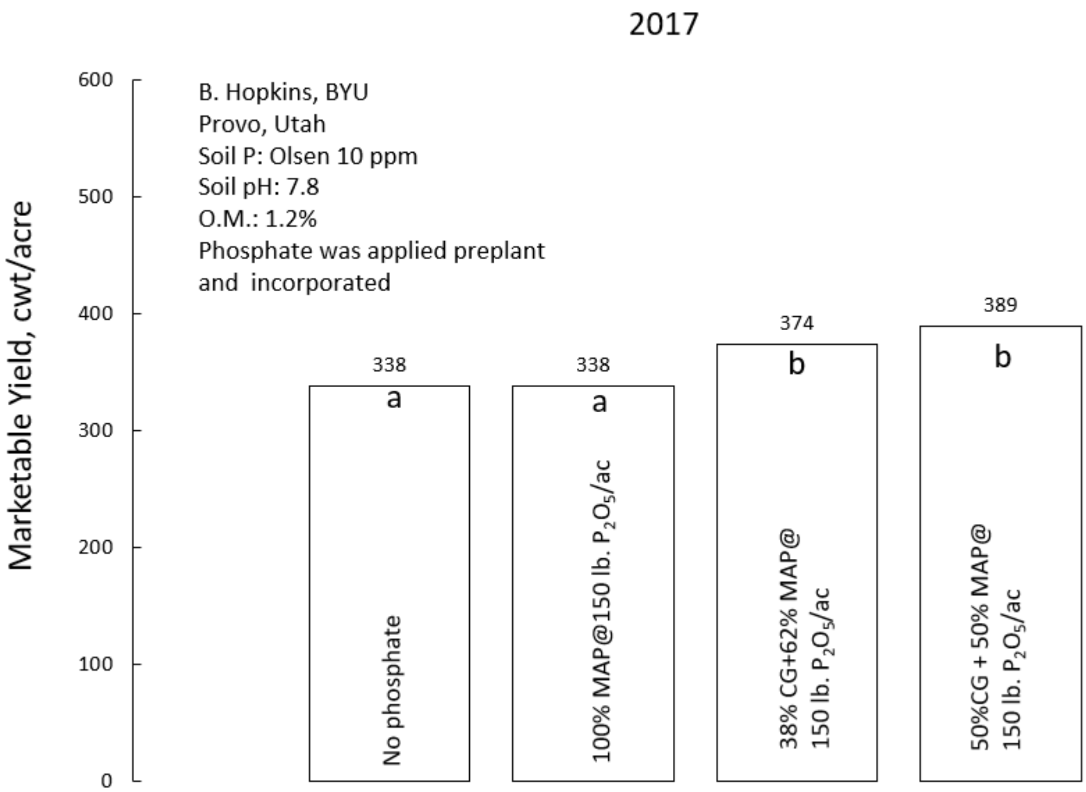

Figure 2. Effect of Crystal Green on Russet Burbank Potato production near Provo, Utah in 2017

CONCLUSIONS

This data along with numerous other research and field trials with Crystal Green granular fertilizer demonstrates that replacing a portion of the water-soluble phosphate with Crystal Green can improve crop yields with Root-Activated™ season-long phosphate uptake.

HELPFUL OR NOT? – BIOSTIMULANT USE IN CORN SILAGE PRODUCTION

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ABSTRACT

There has been a recent increase in both the availability and marketing of biostimulant products to local producers, particularly to dairymen, in southern Idaho. These products claim to increase yield and nutrient use efficiency while improving soil health in agricultural fields. The objective of this study was to assess four commercially available products and one locally produced one on their impact when applied to corn grown for silage. Measurements included corn silage yield, quality, and changes to soil health properties. Initial results from this two-year study indicate that none of the products tested increased corn silage yield or moisture, crop uptake, or soil health properties, such as infiltration characteristics, microbial biomass carbon, microbial respiration, active carbon, or penetration resistance. There were statistical differences in dairy feed quality between treatments, but the results are mixed. Individual products may have benefits in certain fields under certain conditions, but overall, these products do not seem to have a robust impact on corn silage or soil health in Southern Idaho.

INTRODUCTION

There has been a recent increase in both the availability and marketing of biostimulant products to local producers, particularly to dairymen, in southern Idaho. These products claim to increase yield and nutrient use efficiency while improving soil health in agricultural fields. If these claims are true, the use of these products would ultimately aid in promoting the overall sustainability of Idaho farms. However, there is a lack of objective data to support these claims, leaving producers uncertain as to if and how these products may benefit their operation. Further, these products contain nutrients, like phosphorus, that may not be accounted for in nutrient recommendations.

On a nearly weekly basis, agricultural extension personnel are asked by agricultural producers and their advisors about whether one of the hundreds of biostimulants on the market is a worthwhile investment. To provide robust, scientifically justifiable recommendations for Southern Idaho, products need to be tested in a controlled, well-designed study. Thus, the objective of this study was to assess four commercially available products and one locally produced one on their effectiveness to increase corn silage yield and quality and soil health properties.

METHODS

A two-year study was launched in 2021 at the University of Idaho Kimberly Research and Extension Center. There were 6 treatments with 4 replicates each for a total of 24 plots arranged in a completely randomized complete block design. Plots measured 20 ft wide to accommodate 8 rows of corn silage by 35 ft long. Blocks were separated by a 35 ft buffer of winter wheat; the same field and study design was used in year 2 to assess the effect of multiple years of product application. The study was sprinkler irrigated. Prior to planting, the field was fertilized using the University of Idaho recommendations based on a spring soil sample. Between years 1 and 2, the field was lightly tilled with a chisel plow and harrow to break up compaction and incorporate residue without transporting soil between plots.

Treatments included a control with no biostimulant added and five biostimulant products: Amend, PS-Foundation, Bactifeed, Lalrise Max, and compost tea. The biostimulant products were chosen based on feedback from stakeholders to represent locally available and marketed products. In addition, each product represented different types of biostimulants; their rates and description (type) are shown in table 1. Briefly, the compost tea was brewed using dairy compost from a local provider and brewed aerobically for a minimum of 24 hours before being filtered to remove the large particles. Biostimulant treatments were applied according to instructions at suggested manufacturer rates. For the biostimulants applied at planting, products were applied in the seed furrow with the planter. Water was applied in-furrow for the control plots. The products tested are generally applied in-season using an irrigation system. To simulate this, a backpack sprayer was used to spray the center four rows of corn with the appropriate product. Immediately after biostimulant application, irrigation for the entire field containing the study was initiated.

Table 1. Biostimulant product information

Product	Manufacturer	Description	Total Product Applied Annually	Application Timing
Amend	Paradigm Ag Solutions	8-26-0	640 oz per acre	In-furrow at plant 3x in-season
PS- Foundation (BMZ)	BMZ Biological	Nutrient concentrate w/ humates, kelp, trace minerals, organic acids, and enzymes	24 oz per acre	In–furrow at plant Optional 1x in-season
Bactifeed	Bactifeed Soil Treatment	Bacteria-based inoculant	Pre-measured powder activated in water	In-furrow at plant 3x in-season
Lalrise Max	Lallemand	mycorrhizae-based inoculant	1.5 oz (dry powder) per acre of seeds	Seed treatment
Compost Tea		Locally produced	64 oz per acre	In-furrow at plant 3x in-season

The soil was sampled for soil health properties late in the vegetative stage every year. Briefly, three samples 0-6 inches were collected and composited per plot from the center four rows and sent to the Soil Health Testing Laboratory at Oregon State University. Analyses completed included microbial biomass carbon, microbial respiration (24 and 96 hours), β-glucosidase activity, and active carbon. Soil compaction with a penetrometer and infiltration characteristics with a single ring were assessed at the same time. In year 2, infiltration was inhibitively slow despite multiple attempts due to crusting. The center four rows of each plot were harvested with a plot harvester and weight was recorded. Subsamples of silage were sent to Stukenholtz for nutrient analyses of crop uptake (N, P, and K) and Dairyland Laboratories for NIR analyses of feed quality and moisture. The soil was sampled soon after harvest in each plot at 0-12 inches for ending soil fertility and sent to Stukenholtz.

RESULTS

The biostimulants tested tout a wide variety of effects on cropping systems. Amend is marketed to prevent crusting and increase water infiltration, water retention, crop health and growth, and increased nutrient density in crops while mitigating high K and sodium salts in the soil. PS-Foundation (BMZ) is marketed to improve crop vigor by promoting root growth and improving soil nutrient utilization. Both Bactifeed and Lalrise Max are inoculants, applying either bacteria or fungi, respectively, to the soil. Both claim to increase yield as well as improve water infiltration and soil structure. Compost tea contains humic acids and plant-soluble nutrients. It is often used to improve crop yield, promote soil microbial activity, and improve soil structure.

Corn silage yield, when corrected to 68% moisture, was not significantly different between treatments in either year (Figure 1). Yield averaged 34.6 ton ac^{-1} in 2021 and 31.9 ton ac^{-1} in 2022. Silage moisture at harvest was also not statistically different. Average moisture was 67.0% and 63.7% in 2021 and 2022, respectively.

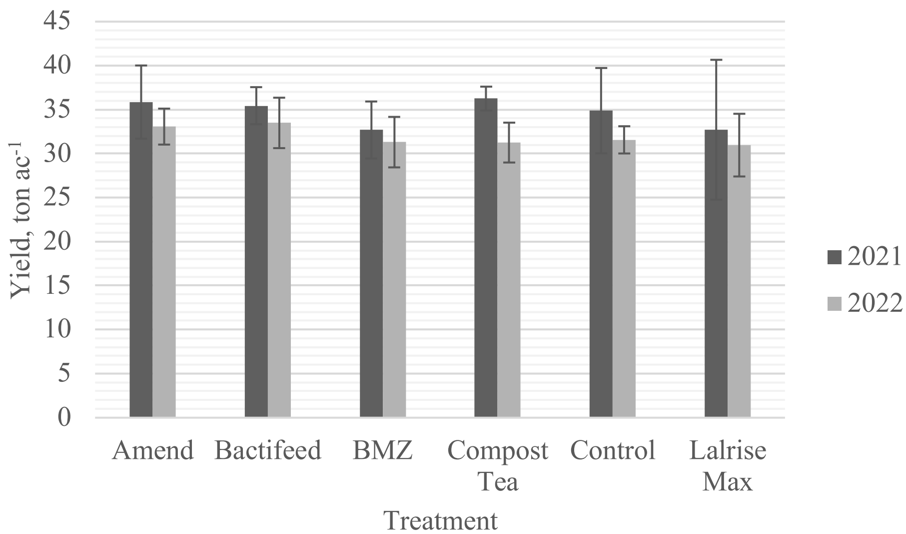

Figure 1. Corn silage yield in 2021 and 2021. Bars represent standard errors.

In terms of feed quality, there were some treatment differences by year (Table 2). For crude protein, the Bactifeed treatment had 0.7% less in 2021 while the Amend treatment had 0.5% higher crude protein in 2022 when compared to the control. For both ADF and NDF, lower values indicate better forage. BMZ (PS-Foundation) and Bactifeed had 2.8% and 3.2% higher NDF when compared to the control in 2021 while the compost tea treatment had 3.1% higher NDF in 2022. For ADF, BMZ and Bactifeed were greater in 2021 compared to the control while all treatments except Bactifeed were greater in 2022. In general, the results of this study are mixed in terms of forage quality. There were statistical differences, but they were inconsistent between years. The Bactifeed treatment resulted in lower NDF and ADF values but also lower protein while Amend had the opposite effect. There were no statistical differences between treatments in plant uptake in terms of total N, nitrate, P or K.

Table 2. Average crude protein, neutral detergent fiber (NDF), and acid detergent fiber (ADF) via NIR by treatment for 2021 and 2022. Treatments not connected by the same letter within column are statistically different (p<0.05).

Treatment	Crude Protein, %DW		NDF, %DW		ADF, %DW	
	2021	2022	2021	2022	2021	2022
Amend	6.6bc	7.8a	36.6bc	37.0ab	21.5b	21.3a
Bactifeed	6.0d	7.6ab	39.3a	33.8c	23.5a	18.5b
BMZ	6.3bcd	7.5ab	38.9ab	36.abc	23.3a	20.4a
Compost Tea	6.3bc	7.6ab	38.3abc	37.8a	22.9ab	21.8a
Control	6.7ab	7.3b	36.1c	34.7bc	21.3b	19.4b
Lalrise Max	7.1a	7.7ab	36.4c	36.7ab	21.4b	21.0a

There were also no significant treatment differences in any of the microbial soil health properties in either year or over both years. Microbial biomass C, β-glucosidase activity, and active C were all greater in 2022 when compared to 2021 while microbial respiration rates were higher (Table 3). There were also no differences between treatments infiltration in 2021 and penetration resistance at depths of 3, 6, or 12 inches in 2021 or 2022. Penetration resistance was significantly greater in 2022 than in 2021. This is what likely inhibited the ability to do infiltration testing in 2022.

Table 3. Average soil health properties for 2021 and 2022 for 0-6 inches of soil depth.

	Microbial Biomass C	β-glucosidase activity	CO_2 24 hr burst	CO_2 96 hr burst	Active C
	μg biomass per g dry soil	nmol B-gluc per g soil per hour	μg CO_2-C per g soil per day		ppm
2021	1733.9	94.3	27.4	15.1	116.7
2022	3041.4	290.3	21.1	11.5	193.5

While there were no differences between treatments in fall soil total N or Olsen P, there were significant differences in soil K (Table 4). The control had significantly higher soil K concentrations after harvest than Lalrise Max, compost tea, and PS-Foundational (BMZ). Interestingly, the Amend treatment was not significantly different even though higher K utilization is one of its key marketing claims.

Table 4. Average soil nutrient concentrations after harvest by treatment for 0-12 inches of soil depth.

	Total N	Olsen P	K
	------------ppm------------		
Amend	8.2	15.6	166.0ab
Bactifeed	8.1	15.8	161.6ab
BMZ	8.2	14.0	148.6c
Compost Tea	8.7	15.1	154.4bc
Control	7.9	16.5	170.5a
Lalrise Max	9.8	14.6	157.3bc

In summary, initial results from this two-year study indicate that none of the products tested increased corn silage yield or moisture, crop uptake, or soil health properties, such as infiltration characteristics, microbial biomass carbon, microbial respiration, active carbon, or penetration resistance. There were statistical differences in dairy feed quality between treatments, but the results are mixed. Individual products may have benefits in certain fields under certain conditions, but it would be impossible to test every scenario. Overall, these products do not seem to have a robust impact on corn silage or soil in Southern Idaho. Producers and advisors interested in trying these products should have clear goals in mind and a well-designed plan to test them for their scenario. Large, replicated strip trials are the best way to do this. These products can be pricey and even if they are effective for one year, they should be re-evaluated often to ensure they are positively impacting profitability and meeting expectations.


WESTERN NUTRIENT
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BARLEY YIELD AND PROTEIN RESPONSE TO NITROGEN AND SULFUR RATES AND APPLICATION TIMING

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ABSTRACT

The introduction of new barley varieties, as well as changes in management practices, necessitate a re-evaluation of nitrogen (N) and sulfur (S) nutrient management guidelines. Nitrogen has a significant impact on barley grain quality and yield. Overapplication of N can result in lodging, groundwater pollution, and high protein content, resulting in lower end-use quality of barley, while underapplication of N results in reduced grain quality and yield. Sulfur promotes N utilization in barley plant tissues, resulting in increased yield and end-use quality. This research aims to provide barley growers with an accurate diagnosis of nutrient deficiencies as well as estimates of appropriate supplemental fertilizer rates in order to improve yields and grain quality. Three barley classes were grown: malt (Moravian 179), feed (Claymore), and food (Julie). At planting, we applied five urea N rates ranging from 0 to 180 kg ha^{-1} in 45 kg ha^{-1} increments. Additional treatments included 45 kg N ha^{-1} applied at heading and top-dressed with 23, 45, or 90 kg ha^{-1}. At planting, three S rates of potassium sulfate were applied in 17 kg ha^{-1} increments from 0 to 34 kg ha^{-1}.

We investigated fertilizer rates for N and S, but S had no effect on yield, yield components, or protein content. Increasing the N rate increased lodging, while splitting the N rate reduced lodging by approximately 10% across all barley classes. Claymore produced the most grain, while Julie produced the least, because Claymore has more heads per meter of row (124) than Moravian 179 (109) or Julie (94). A single N application increased yield over a split application by about 5% across all barley classes and locations. Split applications increased Moravian 179's grain protein content to near maximum levels of acceptability for malt barley protein content (12.5%), and Julie had the highest grain protein content.

EVALUATING ZINC REQUIREMENTS OF CORN, SMALL GRAINS, AND ALFALFA

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ABSTRACT

Many growers and crop advisors in the Intermountain west have recently reported Zn deficiencies in major cereal and forage crops. Further, many common fertilizer blends now include Zn. Most Zn fertilizer guidelines indicate that 5-10 lbs of Zn per acre should be applied when critical soil test Zn levels are less than about 0.8 ppm Zn. These guidelines in Utah and many other states in the region were developed decades ago and need to be reassessed. Therefore, we established Zn response and rate trials at 9 locations in Utah in 2021-2022 to evaluate current Extension Zn guidelines. It was difficult to find fields with less than 0.8 ppm Zn. Thus, we selected several fields with some of the lowest soil test Zn we could identify. In all of our trials, other required macronutrient and micronutrient besides Zn were applied according to Utah State University guidelines. Three Zn rate trials were established in corn in 2021 with treatments including a control, granular Zn SO4-S at 5 and 10 lbs Zn/acre, and liquid Zn chelate at 5 lbs Zn/acre applied near the V4-V6 leaf stage. Soil test Zn ranged from 1.1 to 1.7 at these sites and no silage corn yield or quality response to Zn treatments were detected. Another Zn response trial was conducted at 19 site-years in Utah in 2021-2022 with treatments including 0 or 5-10 lbs Zn/acre as Zn SO4-S or Zn chelate. These sites included nine alfalfa, five small grains, and five corn trials with soil test Zn levels of 0.8-3.0, 0.9-3.0, and 0.4-1.3 ppm, respectively. Preliminary results indicate that forage yield and quality were not impacted by Zn applications at any site. These results suggest that critical Zn soil test levels do not need to be raised and that Zn responses are rare and likely can be diagnosed and corrected in-season rather than as an integral part of a soil-based fertilizer program.

SOIL HEALTH IN AMERICAN SPORTS FIELDS AND GOLF COURSES

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ABSTRACT

Healthy soils are essential for sustaining the world's ecosystems and maintaining human lifestyles. The adoption of biological, chemical, and physical analyses to assess soil health is a relatively new concept with a paucity of scientific work assessing how well these tests can predict and influence soil health. Golf and sports turf are arguably the most intensively managed soil systems in the world, including fertilizer and pesticide use. Excess fertilizer and pesticide application can cause extreme environmental degradation, with concerns regarding soil health. Soil samples (105) were collected between September 2021 and April 2022 from various golf courses and sports fields, as well as farm fields, non-sport urban, and undisturbed native soils (forests, deserts, beaches, and golf sand traps). The samples were then analyzed for chemical, biological, and physical properties, including pH, micronutrients, electroconductivity, aggregate stability, potentially mineralizable nitrogen, autoclave-extractable protein, beta glucosidase, and texture. General linear statistical models were then used to evaluate these differences in soil properties based on field type. Sport, golf, farm, and urban lawn soils were microbially active as indicated by reasonable levels of PMN; which is in contrast with sand soils with no plants that had very low PMN. However, football, baseball, intermural, and urban lawn had somewhat lower PMN than forest soils; while soccer, softball, and golf were not lower. Sport, golf, and urban lawn soils had significantly higher soil test P (STP) than non-fertilized sand and forest soils. Sport (other than softball) and urban lawn soils had significantly higher STP than farm soils. Sport, golf, farm, and urban lawn soils did not have lower stable aggregates than forest soils, although farm, urban lawn, and intermural did have a lower fraction of stable to unstable aggregates. The data collected, and comparisons made, will add to scientific and community understanding of soil health as a function of land management.

NITROGEN FERTILIZER RATE AND TIMING IMPLICATIONS FOR MALT, FOOD, AND FEED BARLEY PRODUCTION IN SOUTHERN IDAHO

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ABSTRACT

Nitrogen is an essential nutrient required to produce high-yielding barley. Nitrogen strongly impacts barley yield, grain protein, tillering, and lodging potential. Unlike other crops such as corn, available nitrogen must be carefully managed for producers to achieve both optimal yield and grain quality for malt, food, and feed barley. Excessive nitrogen availability increases grain protein concentration that may be unsuitable for malting but may be ideal for feed or food barley. The objective of this study was to evaluate the effect of single (at planting) and split (at planting and tillering) nitrogen applications at five nitrogen rates for spring planted barley in southern Idaho. This study evaluated the effect of nitrogen rate and timing on grain yield and protein concentration, lodging, and tillering.

In this study, grain yield and harvest height typically increased with increasing nitrogen application rates, except at Aberdeen 2021 when residual soil N was high. Soil samples should be collected prior to planting to adjust fertilizer N rates. Although not statistically significant, split-applications had a trend of reducing grain yield and plant height relative to a single fertilizer application at planting. Delaying supplemental N applications past early tillering likely limited barley yield potential. Within site-year, test weight, tiller number, and grain moisture was typically non-responsive to N rate and application timing.

IMPACTS OF IRRIGATION TECHNOLOGY, DEFICIT IRRIGATION, AND GENETICS ON ALFALFA PHOSPHORUS AND POTASSIUM USE

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ABSTRACT

Alfalfa is exceptional at obtaining nutrients from the soil with its deep tap root. However, with its ability to consume vast amounts of phosphorous and potassium more is used than what is made available each year. This results in the need of nutrient management plans. With the continuing of the drought, nutrient management becomes more difficult. Irrigation management, drought tolerant genetics, and sprinkler technology can play an important role in nutrient management and affect financial outcomes of producers. Generally, there are two ways to increase profits which are, maximize yields, or reduce input cost. Deficit irrigation almost always leads to yield loss in alfalfa, which means a loss of income. That leads to a plan to reduce input cost. Fertilizer cost can be a large portion of a producer's budget.

This study looked at the possible effects of sprinkler irrigation technology, deficit irrigation, and drought tolerant genetics, on alfalfa uptake of phosphorous and potassium. Sprinkler technologies consisted of mid elevation sprinklers (MESA) and the following low elevation sprinklers, Nelson Advantage (LENA), precision application (LEPA), and spray application (LESA). Also tested was a mobile drip irrigation system (MDI). Deficit irrigation rates were full irrigation or 100% of ET, a 25% reduction, and a 50% reduction. Ladak II was chosen as the drought tolerant variety of alfalfa with a common "conventional" variety to compare.

At two sites in Utah full irrigation led to the highest uptake of potassium and phosphorous with relatively no little reduction in uptake in with a 25% reduction of applied water. Genetics were not consistently affecting the uptake of nutrients at different sites. Cedar City 2021 conventional variety had a higher uptake of potassium but no effect on phosphorus. Logan 2020 conventional variety had a significantly higher uptake of phosphorus but not potassium. The MDI sprinkler technology consistently had the lowest uptake of phosphorous and potassium in all site years.

Full irrigation tends to cause the most uptake in alfalfa. When applying deficit irrigation strategies, it would be beneficial to reevaluate fertilizer plans to meet what would be uptake by the plant. Sprinkler technology (MDI) is also significant enough to considers when making fertilizer applications based on sprinkler technology.

NITROGEN MANAGEMENT TO INCREASE COTTON PRODUCTION IN CONSERVATION CROPPING SYSTEMS

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ABSTRACT

The use of conservation management practices, like cover crops and no-tillage, is common in semi-arid cropping systems to reduce wind erosion. However, the use of these practices can also reduce cotton lint yield. The purpose of this study was to determine the impact of nitrogen (N) management in conservation cropping systems to increase cotton lint yield. Two experiments were conducted at the Agricultural Complex for Advanced Research and Extension Systems in Lamesa, TX, USA. The first experiment utilized litterbags in 2020 and 2021 to determine cover crop decomposition rates following termination. In 2020, approximately 75% of the cover crop biomass remained 128-d following termination while approximately 25% of the biomass remained 128-d after termination in 2021. The differences in decomposition rate between 2020 and 2021 are likely the result of significant differences in biomass production between the two years. Cover crop herbage mass production in 2020 resulted in significantly greater N immobilization compared to 2021. The second experiment utilized four N fertilization timings to determine the impact of supplemental N fertilization on cotton yields following cover crop termination to minimize potential N immobilization. Three supplemental N fertilization timings were compared to a traditional farm practice of 138 kg N/ha fertigated at 30% preplant and 70% applied at pinhead square following cover crops, the current Texas A&M AgriLife Extension recommendation. The three applications consisted of applying a supplemental 34 kg N/ha at (1) pre-plant, (2) post-emergence + three weeks, and (3) pinhead square + two weeks. An early-season application of N either pre-plant or post-emergence resulted in significantly greater cotton lint yields following cover crops in 2018 and 2019, but not 2020. Supplemental N did not increase cotton lint yield in the traditionally grown cotton or a cotton-wheat-fallow rotation. Nitrogen use efficiency was significantly greater in pre-plant and post-emergence systems following a cover crop but not in the conventional system. Averaged across years and cropping systems, pre-plant and post-emergence N applications resulted in a 22 and 24% increase in economic return compared to the conventional system, respectively. These results demonstrate that N management practices that account for potential N immobilization following cover crops can significantly increase cotton lint yield and decrease the potential yield loss associated with conservation management practices in semi-arid regions.

USING HYDROXIDE FOR LIME INCUBATION STUDIES AND MOISTURE EFFECTS ON LIMING CALCIUM

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ABSTRACT

Plant health and productivity are negatively affected by soil acidity. Soil physical properties such as soil texture, soil organic matter, and nutrient content help soils resist changes in their acidity (buffering capacity). Soils have different buffering capacities; agricultural producers need to know how responsive a soil is to lime and how much lime is required to modify a soil to a certain pH (lime requirement). One method to evaluate soil liming requirements and buffering capacity is to add varying levels of calcium carbonate ($CaCO_3$) to soil and incubate it for 90 days. This incubation method does not allow laboratories to provide timely feedback to agricultural producers. A shorter lab incubation method would be ideal. This experiment was conducted to investigate the possible use of calcium hydroxide {$Ca(OH)_2$} as a replacement for $CaCO_3$ for incubation studies. Calcium hydroxide is more water soluble and should react more quickly with the soil to neutralize soil acidity. The first study objective was to evaluate the response of $Ca(OH)_2$ to a 90-day $CaCO_3$ incubation.

While pure $CaCO_3$ allows researchers to compare lime requirement incubations across studies, Southern Idaho agricultural producers often use precipitated $CaCO_3$ (PCC), a byproduct from sugar beet sugar processing, as their lime source. The second objective was to evaluate if PCC had the same neutralizing capacity as pure $CaCO_3$ when applied at the same $CaCO_3$ rate. Finally, because soil moisture moderates soil chemical reactions, the third objective was to evaluate changes in soil pH when $CaCO_3$, PCC, and $Ca(OH)_2$ were incubated in air-dry soils, at 50% field capacity, or 90% field capacity.

To evaluate these objectives, a Marystown-Robinlee-Rexburg silt loam soil was collected in Ashton, Idaho, dried, and homogenized. 100 grams of soil was weighed out into cups and $CaCO_3$, $Ca(OH)_2$, and PCC were added at rates of 0, 1, 2, or 4 tons $CaCO_3$ equivalent per acre. Deionized water was added to bring the soil moisture to 90% field capacity. Soils were incubated for 3 days, 7 days, 2 weeks, 1 month, 2 months, and 3 months. Additional treatments were done by adding $CaCO_3$, $Ca(OH)_2$, and PCC at rates of 0, 1, 2, and 4 tons $CaCO_3$ equivalent per acre. Soil moisture content was either air dry, 50%, or 90% of field capacity and soils were incubated for 90 days.

SOIL GREENHOUSE GAS DYNAMICS IN RESPONSE TO DAIRY MANURE COMPOST IN AN ALMOND ORCHARD

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ABSTRACT

Application of dairy manure compost in soils under almond production may confer benefits such as increased carbon sequestration, improved crop nutrient use efficiency, and reduction of greenhouse gas emissions. Elucidating the mechanisms of greenhouse gas emissions and mitigation is a primary concern in the management of agricultural soils and it is directly linked to nutrient management. Presently, agricultural soils account for 11.2% of U.S. greenhouse gas emissions. Of particular concern is how agricultural management influences CO_2, CH_4, and especially N_2O emissions. Indeed, there is greater demand for soils to mitigate climate change and increase food production while also reducing negative impacts on the environment. This is especially relevant to management of agricultural soils in intensive Mediterranean climates, such as the growing almond industry in California. Though it is generally understood that N_2O production is largely constrained by microbial activity, the specific drivers of N_2O emissions are also dependent on season, N inputs, soil moisture content, and available carbon sources. Therefore, we ask, to what extent can compost application mitigate N_2O emissions? To investigate the effects of dairy manure compost on greenhouse gas dynamics in almond orchards, we split an orchard into four blocks, each with a control of no compost or fertigation (T1-0N), compost only (T9-0N: 7 tons wet weight per acre), compost with fertigation (T9-+N: 7 tons wet weight per acre and 90 lb N/acre with UAN32), and fertigation only (T1-+N: 90 lb N/acre with UAN32). Four rows for every block were randomly assigned one of the four treatments. Static flux collars were randomly assigned a tree within the treatment row and all collars were installed 140 cm from the target tree (halfway between micro sprinkler and tree). Data was collected in duplicate for each experimental unit. Preliminary analysis of flux dynamics shows that there are compost effects on N_2O flux. A strong decoupling is apparent between T1-+N and the other treatments, including the control. This is most apparent by the third fertigation event, where N_2O flux of T1-+N was three times higher than T9-+N, both of which received the same rates of UAN32 fertilizer. CO_2 flux was variable, but patterns were consistent across treatments. CH_4 flux was consistently negative, indicating methane oxidation and aerated soils. There was an expected delineation in NO_3-N concentrations between fertilized rows and non-fertilized rows. However, an inverse relationship between NO_3^--N and NH_4^+-N emerged by the second fertigation event. This may indicate immobilization processes where trees may compete with microorganisms for inorganic nitrogen, possibly explaining the lower nitrous oxide flux in the compost treatments. There was also an expected increase in DOC concentrations in the compost treatments relative to T1-0N and T1-+N. NH_4^+-N concentrations across treatments eventually stabilized to comparable levels. Initial results indicate that compost application can mitigate net N_2O emissions. Future directions will involve further flux measurements for the next 4 growing seasons and determination of microbial/enzymatic activity response.

THE EFFECTS OF CALCIUM SOURCE AND PLACEMENT ON SOIL ACIDITY PARAMETERS AND WHEAT PERFORMANCE

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ABSTRACT

Wheat production is a critical component of U.S. Pacific Northwest agriculture, with approximately 80% of the global soft white wheat grain supply originating from this region. Ammonium-based nitrogen fertilizers are widely used on typically alkaline soils in Eastern Oregon dryland production areas by wheat growers. However the nitrification process that biologically converts ammonium to nitrate increases the soil concentration of H+. This process ultimately creates acidic soil conditions, which can lead to aluminum toxicity from solubilized aluminum. While incorporation of calcium carbonate (lime) is generally recommended to combat soil acidity issues, the majority of dryland wheat growers in Eastern Oregon incorporate no-till or reduced till management practices. Alternative strategies for surface applied lime applications in recently acidified no-till wheat production systems is needed to maintain optimal grain yields. The project objectives are to investigate the effects of calcium source and placement on root and above ground biomass, grain yield, and yield components, soil pH, soil extractable Al, and soil base saturation. The study will take place as a greenhouse study using an aluminum sensitive spring wheat variety. The soil type is Walla Walla silt loam collected from a dryland, no-till wheat field located in Southeastern Washington. The tentative calcium source treatments include a control (no application), gypsum, fluid lime, agricultural lime, prilled lime, and micronized lime. The tentative calcium placement treatments include an incorporated agricultural lime, surface applied and banded agricultural lime, prilled lime, and micronized lime. The greenhouse study will begin in fall of 2023 and the treatment effects and results will be evaluated and summarized in 2024.

DEVELOPMENT OF A CONSTRAINED RESOURCE MODEL TO SUPPORT INTERCROPPING DECISIONS

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ABSTRACT

Crop producers are interested in intercropping due to its potential to increase profitability, yield stability, and sustainability. Our objective was to extend a simulation model to forecast crop yields (PRS® CropCaster®) to pulse-oilseed intercrops. This tool would provide crop producers with forecasts of yields of each crop component under different management and environmental conditions.

Field trials were conducted for three years at two locations in southern Alberta and for one year at one location in Washington. When intercropped with lentil, oilseed crops took up more than 80% of soil and fertilizer N even when outnumbered 10:1. When intercropped with pea, canola was still more competitive for fertilizer N, but mustard and pea had similar competitiveness (Figure 1). In comparison, pulse crops were more competitive for water and light due to the sufficiency of symbiotic N_2 fixation. Accounting for the partitioning in these resources in the model was sufficient to reasonably forecast partial yield and land equivalent ratio (LER) in pulse-oilseed intercrops. Values of LER increased with N deficiency of the oilseed crop and were highest when competitiveness for soil and fertilizer nitrogen favored the oilseed crop. Reduced heat stress and harvest losses also contributed to intercropping benefits for pea.

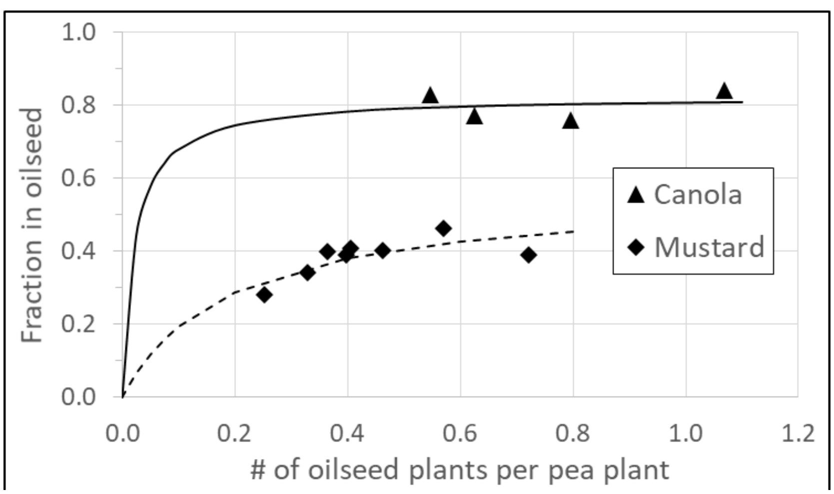

Figure 1. Recovery of fertilizer N (^{15}N-enriched UAN) in an intercropped oilseed crop as a fraction of total plant recovery in pea-oilseed intercrops grown in field trials in southern Alberta from 2018 to 2020.

A SINGLE NUTRIENT SOURCE HYDROPONIC SOLUTION: MANAGING PH WITH A BIOLOGICAL BUFFER

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ABSTRACT

MES (2-[N-morpholino]ethanesulfonic acid) is a biological buffer that can be used to stabilize pH in a hydroponic system. It can, however, be toxic to plants, including soybeans. Hydroponic systems are efficient for studying plant nutrition. It is often desirable to adjust individual nutrients for unique species' needs and/or to create multiple nutrient deficiencies within the same study. However, this is challenging to do with traditional solutions as nutrients are generally added as dual nutrient salts. Such as when using ammonium phosphate as the phosphorus (P) source in a study with varying P concentrations, which would result in an undesirable interaction as the nitrogen (N) concentration would vary as well. This can create unintended consequences with nutrients other than those intended for adjustment. A new hydroponic system has been created to allow for nutrient deficiencies using single nutrient sources, including ammonium nitrate; phosphoric, sulfuric, hydrochloric, and boric acids; potassium, calcium, magnesium, zinc, and copper carbonates; manganese acetate; sodium molybdate; iron EDDHA; and with HEDTA as an additional chelate. However, previous studies have resulted in problems with excessive pH fluctuation. The objective of this study was to evaluate a biological buffer (MES) at various concentrations to evaluate solution pH levels and soybean [*Glycine Max* (L.) Merr] health in an attempt to further refine this new hydroponic solution and investigate its effectiveness in providing a way to introduce single nutrient deficiencies. This new solution proved effective, as soybean was grown to maturity with no signs of nutrient deficiencies. The MES concentrations at or above [BH1] 0.060 M proved to be toxic for soybean and concentrations below 0.060 M showed no significant negative impact on plant health. The MES concentrations were: 0.000, 0.006, 0.008, 0.012, 0.060, and 0.080 M, which resulted in average pH of: 8.5, 7.4, 6.8, 6.2, 5.0, and 4.9, respectively. According to the data, the optimal concentration for MES is 0.008 M if the desired pH is near neutral and 0.012 M or 0.006 M if an acid or alkaline solution is desired, respectively.

ALFALFA FERTILITY SURVEY OF OREGON, WASHINGTON, AND IDAHO

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ABSTRACT

Understanding alfalfa nutrient status in plants and soils allows researchers and growers to identify the greatest nutrient needs for this important crop. A survey of PNW alfalfa fields is being conducted to accurately summarize alfalfa nutrient uptake and biomass yield potential in response to soil agronomic properties to address this question. Forty alfalfa fields throughout alfalfa production regions in Oregon, Washington, and Idaho were selected for the 2022 survey. The number of fields collected from each region is as follows: Klamath Basin (KB) (n=9), Treasure Valley (TV) (n=10), Magic Valley (MV) (n=11), Willamette Valley (WV) (n=4), and Columbia Basin (CB) (n=6). Soil, above-ground plant biomass, and plant tissue samples of the top 15 cm of each plant were collected at each site from June to August of 2022 regardless of the cutting period. The cutting period was recorded and will be included in the evaluation in case the cutting stage had an impact on nutrient status or yield. The soil will be analyzed for OSU recommended soil agronomic tests. Plant tissue collected from the top 15 cm of the plant will be analyzed for total agronomic nutrients. Yield samples were weighed, dried, and reweighed to calculate the single-cutting dry matter biomass yield. The dry matter yield means and standard error for a single cutting were as follows: KB = 3,792 (647) kg/ha, MV = 3,699 (468) kg/ha, TV = 2,991 (663) kg/ha, CB = 2,779 (510) kg/ha, and WV = 1,704 (276) kg/ha. Single-cutting dry matter yield may be impacted by factors including growing degree days, cutting stage, water availability, and soil acidity, although further analysis is needed for validation. Correlations between soil properties and plant nutrient status will be summarized over the winter of 2022/2023. The field survey will continue during the 2023 growing season to provide a more accurate representation of alfalfa field conditions in the PNW, with final findings to be presented and published in 2024.

FIRST-YEAR EVALUATION OF PRECIPITATED CALCIUM CARBONATE AS A LIME AMENDMENT IN EASTERN IDAHO

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ABSTRACT

The natural process of soil acidification has become a rising issue in soil sustainability and affects approximately 30% of the world's surface. Soil acidification is enhanced by the application of ammonium- and elemental sulfur-containing fertilizers, the removal of base cations (Ca, Mg, K, and Na) at harvest, and the leaching of base cations and their conjugate bases such as nitrate. Even though most of southern Idaho soils are alkaline with a pH of around 7.0 to 8.5, there are several regional acidic areas. Periodic applications of locally available precipitated calcium carbonate can help neutralize soil acidity and maintain the productivity of acidic soils in eastern Idaho, including Fremont, Bonneville, Caribou, and Oneida counties. Precipitated calcium carbonate is a byproduct of sucrose extraction during the processing of sugar beet roots, primarily produced in Idaho and Oregon. There is limited information about the specific effect of precipitated calcium carbonate on Idaho soils. Most trials have been done in Oregon soils that may or may not correlate well with the chemical and physical properties of Idaho soils. Four on-farm field trials were conducted in eastern Idaho to assess the effect of precipitated calcium carbonate lime rates (0, 2, 4, 6 ton ac^{-1}) on the modification of soil pH by soil depth and small grain yield. Soil samples were collected at 0-2, 2-4, 4-6, 6-8, and 8-12" depths by replication in the fall of 2022 immediately before lime application and by plot in May-June and post- wheat or barley harvest in 2023. Grain yield was collected by hand harvesting a 5x5' section of each plot. Initial soil pH measurements before liming (0-2") at the four field sites were 4.6, 4.8, 5.0, and 5.6 and soil pH increased with increasing sampling depth to 5.7-6.2 (8-12"). Following liming, soil pH increased at all soil depths, but the greatest increase occurred in the top 6" of the soil profile. Across the four sites, the 6-ton ac^{-1} lime rate increased soil pH (0-2") 0.7 to 1.5 pH units by the May-June sampling event relative to the non-fertilized check. Averaged across lime application rates, liming did not significantly improve grain yield over the non-limed treatment at two sites but increased wheat yield by 8 bu ac^{-1} at one location. We will continue to monitor these sites to evaluate how long a lime application lasts before soils acidify to yield-limiting levels.

OPTIMIZING NITROGEN FERTILIZER RATES FOR ANNUAL CEREAL FORAGE PRODUCTION

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ABSTRACT

Nitrogen fertilizer provides one of the greatest returns on investment but also one of the highest operating expenses for annual cereal forage production. It is important to know the total nitrogen required by a crop to optimize yield and quality and to minimize nitrogen losses to the environment. It is also possible that annual cereal forage species and cultivars will have varying responses to nitrogen availability. The objective of this study was to determine the optimal nitrogen fertilizer rate for three forage barley varieties (Hayes, Haybet, Lavina) and three forage oat varieties (Monida, Otana, Ajay).

The study was conducted in 2021 at the University of Idaho Aberdeen Research and Extension Center and Brigham Young University – Idaho (BYUI), Rexburg and only at BYUI in 2022. The treatment design was a split plot design where nitrogen rate (0, 39, 78, 117, 156 kg ha^{-1}) was the main plot and forage cereal variety was the subplot, replicated four times. Soil samples were taken immediately before planting and after the harvest (0-1' and 1-2' depths) and analyzed for nitrate content. Each plot was harvested at approximately boot stage and a representative grab sample was taken to determine sample moisture content and forage quality (using NIR).

The interaction between the effect of variety and N rate had no significant effect on yield. At the BYUI location, yield increased with increasing N rate but there was no difference between the 78 kg N ha^{-1} rate and higher rates. The lack of a significant response to the N rate at Aberdeen may be due to 141 kg N ha^{-1} in the top 60 cm of the soil at planting. Tissue moisture content increased with increasing N rate, although there was no significant difference between the 78 kg N ha^{-1} rate and greater N rates.

At the Rexburg location, the optimal nitrogen fertilizer rate was 78 kg N ha^{-1} for all varieties. At Aberdeen location, the higher nitrogen level at planting makes the response to fertilizer statistically insignificant.

RESPONSE OF SOIL N CYCLING, NITRIFYING ORGANISMS, AND WINTER WHEAT TO NITRIFICATION INHIBITORS IN NORTHERN IDAHO

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ABSTRACT

Leaching of fertilizer nitrogen contributes to environmental pollution and is an economic loss for agricultural producers. Leaching of inorganic nitrogen fertilizers is intensified when applied to areas of high rainfall zones in excess of crop requirements. Reduction of this nitrogen loss may be achieved through the application of nitrification inhibitors at the time of planting to prevent the transformation of ammonia to more leachable nitrate by nitrifying organisms. Much research on nitrification inhibitors has been done in the areas of the Midwest for corn production but is lacking in the Pacific Northwest for winter wheat production. To help address the lack of research in this area, two research trials were conducted in northern Idaho during the 2019-2020 and 2020-2021 growing seasons. Two varieties of winter wheat, soft white winter wheat LCS Hulk and hard red winter wheat LCS Jet, were tested separately at each trial location. For each variety and trial location, five nitrogen treatment rates of UAN 32 (0, 50, 100, 150, 200 lbs N/A) were mid-row banded with and without the nitrification inhibitor, nitrapyrin (Instinct® II). Soil was sampled at four intervals during the growing season. Extractable soil ammonium in the mid-row band of the control treatment remained elevated until late spring but soil nitrate declined by early spring. Application of nitrapyrin increased extractable ammonium and reduced extractable soil nitrate by up to 6%. Soil samples were also obtained in early winter and early spring to quantify the abundance of ammonia-oxidizing bacteria and archaea. Nitrifying archaeal populations did not respond to the nitrification inhibitor treatment. However, bacterial populations were significantly decreased by 7% in the Instinct® II treated samples compared to the control. Winter wheat yield and associated measurements were not impacted by nitrapyrin treatment. The limited agronomic benefit of nitrapyrin in this study may be due to 25% of UAN 32 fertilizer already being in the nitrate form and toxic concentrations of ammonia in the mid-row band limiting nitrification and thus benefits of reduced nitrification due to nitrapyrin. Greater agronomic benefits from nitrification inhibition may be attainable in sandy soils or with broadcast fertilizers.

SUS-TERRA ENHANCED EFFICIENCY PHOSPHORUS FERTILIZER ON POTATO GROWN IN CALCAREOUS SOIL

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ABSTRACT

Potato (*Solanum tuberosum* L.) has a relatively high demand for phosphorus (P), especially on calcareous soil where the availability of P is hindered by poor solubility. Sus-Terra is claimed to be an enhanced efficiency fertilizer compared to other P sources. The objective of this trial was to evaluate the differences in uptake efficiency and yield for multiple P sources compared to a no P control applied to Russet Burbank potato. Field trials with six replications in a RCBD were performed in calcareous loamy sand soil in Provo, Utah during 2021 to evaluate various rates and blends of Sus-Terra fertilizer (The Mosaic Company, Tampa, FL, USA) compared to traditional P sources and an untreated control. Traditional P sources included MAP and MES10 (The Mosaic Company). The residual soil test P was low (15 mg P kg^{-1}). Petiole P was measured four times in July and August and yields were measured in September. There was a significant increase compared to the untreated control for most parameters as a result of P fertilization, but there were no significant differences between any of the P fertilizer treatments. However, an orthogonal comparison of three combined Sus-Terra treatments to three combined monoammonium phosphate (MAP) treatments resulted in significant differences, with Sus-Terra resulting in highly significant increases in US No. 1 and Marketable (US No. 1 + 2) yields as compared to the untreated control. The MAP treatments resulted in a significant difference for US No. 1 yield, but not for Marketable yield. Both Sus-Terra and MAP treatments resulted in significant increases in total yield and highly significant increases for petiole P concentration over the control. Sus-Terra is an effective source of P fertilizer, with a slight advantage over MAP in this trial. An additional study was completed in 2022 with results pending.

POLYMER COATED UREA: MICROPLASTICS IN THE URBAN LANDSCAPE

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ABSTRACT

Polymer Coated Urea (PCU) in urban landscapes has recently become a controversial practice as some fear the repercussions of the polymer coatings left behind in soils and the environment to potentially be detrimental to land and water ecosystem health. The use of PCU has been beneficial in effectively supplying nitrogen (N) to plants with less leaching, denitrification, and volatilization losses to the environment. However, the pollution of microplastics may outweigh these benefits. The purpose of this study was to determine the magnitude that this threat poses from the use of PCU in urban landscapes. Treatments included a full factorial randomized complete block design of all combinations of four fertilizer approaches applied to three landscape types. The fertilizer approaches included: 1) untreated control, 2) uncoated urea, 3) liquid slow release (UFlexx), 4) PCU (Duration). The landscape types included: 1) Sod, 2) Mulched Bed, and 3) Xeriscape; which represent those commonly found in urban areas. Fertilized plots received a typical recommended N rate for cool season grasses at 3 lb N ft^{-2} (131 lb. N ac^{-1}). Each plot (3.3 ft. x 6.6 ft) had an approximate 1% slope. The slope ran the length of the plot, funneling towards a depression at the center end with a collection vessel for each plot. There were four simulated rainfall events, with significant runoff, over two years where 0.25 gal of runoff water was collected and subsequently analyzed for sediment, N concentrations, visible plastics, and microplastics (not visible to the naked eye) concentrations. There were highly significant differences for sediment and visible plastics (N concentration and ultra-small microplastics analysis are not yet complete). The Sod landscape resulted in the least amount of sediment loss and visible plastics found in the runoff water. In the Mulched Bed landscape, there was less sediment loss (26.9 lbs ac^{-1}) than Xeriscape (41.7 lbs ac^{-1}), but more than sod (19.3 lbs ac^{-1}). In the Mulched Bed landscape, there were more visible microplastics in the runoff water (0.00025 lbs ac^{-1}) than in Xeriscape (0.00008 lbs ac^{-1}) and Sod (0.00008 lbs ac^{-1}). It is evident that a vegetated landscape surface, such as a perennial sod, virtually eliminates soil and plastics erosion, while the Mulched Bed (especially for plastics) and the Xeriscape (especially for soil erosion) landscapes had significant losses.

NUTRIENT MANAGEMENT FOR SEMI-ARID CANNABIS PRODUCTION

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ABSTRACT

The industrial hemp (*Cannabis sativa* L.*)* industry rapidly emerged in Utah in 2019 with nearly 480 new hectares of hemp production. Production declined and stabilized during 2019-2022 due to low returns in a flooded pharmaceutical market. Though small and specialized, the hemp production industry is still viable in Utah and surrounding states. Many questions remain on optimal production practices for this new and potentially high-value crop. Research throughout the United States is limited on a large scale and regionally. One of the first Utah outdoor hemp research sites was established in 2020 near Logan, Utah (41.66N, -111.91W), looking at multiple production factors. One multi-year trial investigated fundamental fertility strategies. In 2020, there were three treatments of control, 100 lb N additional, and 100 lb P additional applied to three replications of plants and repeated for 2021. For 2022, the trial expanded to four P treatments, five N treatments, and a no applied nutrients control. Female hemp clones were transplanted in late May and harvested in September and October. Harvest index (leaf and flower biomass: total aboveground biomass), biomass yield, and stem yield for the three years. A complete cannabinoid analysis was measured on the 2020 and 2021 harvested plants to determine how these management factors influence the indices. Preliminary results will be presented.

STACKING 4R NUTRIENT MANAGEMENT: POTATO

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ABSTRACT

The 4Rs of nutrient management are research-based guidelines to improve the sustainability of major cropping systems and the environment without compromising crop yield and quality. The term '4R' represents fertilizer applied at the Right rate with the Right source, Right timing, and Right placement. The objective of this project is to evaluate the interactions of individual and combined 4R management practices. In 2020, potato (*Solanum tuberosum L.*) was grown in a calcareous loam soil in a field near Grace, ID, USA. Nitrogen (N) fertilizer treatments contained all combinations in an RCBD of two N sources [uncoated and polymer-coated urea (PCU)], two rates (84 and 100% of the recommended rate), and two placement/timings (emergence tilled into the soil or split application with 50% applied at emergence and 50% simulated fertigation) with all compared to an untreated control. Overall, potato was responsive to N for petiole nitrate (NO_3-N), Normalized Difference Vegetative Index (NDVI), and US No. 1 and total tuber yield. Notably, the PCU treatments resulted in significantly greater NDVI than the negative control by the end of August, while the uncoated urea treatments were not. For US No. 1 yield, despite large numerical yield increases for most treatments compared to the untreated control (2.2-7.5 Mg ha^{-1}), only the source x timing treatment showed a significant difference (8.22 Mg ha^{-1}) over the untreated control. Similar to NDVI, the PCU treatments for US No. 1 and total yield tended to be relatively higher yields even though most of the differences were not significant. Notably, this study revealed that a reduced rate of urea performs identically to the full rate of urea. Preliminary data from this one-year study reinforces the 4R principles and also indicates that certain treatment combinations may not be necessary. For instance, there was no statistically different benefit for split timing application, even at reduced rates, although there was a strong trend for this timing. This project is in a potato-wheat-wheat cropping system, with wheat evaluated similarly in 2021 and 2022, with a second year of potato planned for 2023. Further experimentation is planned to investigate the impacts of combined application trials on crop yield and quality.