WERA-103

Nutrient Management and Water Quality

WESTERN NUTRIENT MANAGEMENT CONFERENCE

MARCH 2-4, 2021

PROCEEDINGS

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ORAL PROCEEDINGS

REUSE AND RECLAMATION OF PHOSPHOGYPSUM

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ABSTRACT

Phosphogypsum (PG) is a gypsum byproduct of the phosphate fertilizer industry and is produced at a rate of five tonnes of PG per tonne of phosphate fertilizer. It is estimated that over 3 billion tonnes of gypsum have been accumulated in stacks worldwide. Although PG is classified as NORM (naturally occurring radioactive material), all evidence suggests that no restrictions on reuse are necessary and PG is being increasingly being reused worldwide in agriculture, construction and for roadbase. Phosphogypsum can also be used beneficially *in situ* to grow high value crops and concentrated tree plantations. Research has shown that mixing small amounts of soil into the gypsum creates a high performance Anthrosol that results in greater vegetation health and biomass over plants grown in soil alone. Concentrated woody plantations of willow and hybrid poplar have been established on 25 hectares of PG stacks at the Nutrien facility in Fort Saskatchewan, Alberta, Canada. These trees are sequestering carbon at a rate of 30 Mg CO2 eq/ha/year to combat climate change while producing woody biomass that can potentially be used for green energy. The woody plantations have been shown to be sustainable and environmentally protective while preventing water infiltration into the stacks.

INTRODUCTION

Phosphogypsum (PG) is produced when phosphate rock is treated with sulphuric acid during the manufacture of phosphoric acid, and is composed mostly of gypsum ($CaSO_4{\cdot}2H_2O$). In North America, the gypsum is traditionally stockpiled in stacks that can cover hundreds of acres and be over 100 feet high. In Canada, it is estimated that there are more than 100 million tonnes of stockpiled phosphogypsum, while there are nearly 2 billion tonnes of stacked PG in the United States. Phosphogypsum is typically acidic due to residual acid being present in the pore fluids. The major impurity is quartz sand carried through the process stream. Residual P and F, as well as trace components in the apatite rock may also be present. Although PG is classified as NORM, the reuse of PG is considered to be safe for most applications because of the low level of the radioactivity.

Nutrien spent some time examining PG reuse opportunities in the 80’s and 90’s. Among other things, PG was used as a soil amendment for sodic and heavy clay soils, as a calcium and sulfur fertilizer, as an additive in composting manure, and for oil sands tailing remediation. Phosphogypsum was never developed as a product at Nutrien and the focus of the company changed from PG reuse to PG reclamation in the early 2000’s. Nutrien still provides PG to local farmers for use in dairy barn bedding or for use as a soil amendment upon request but is not actively developing reuse markets in Canada at this time.

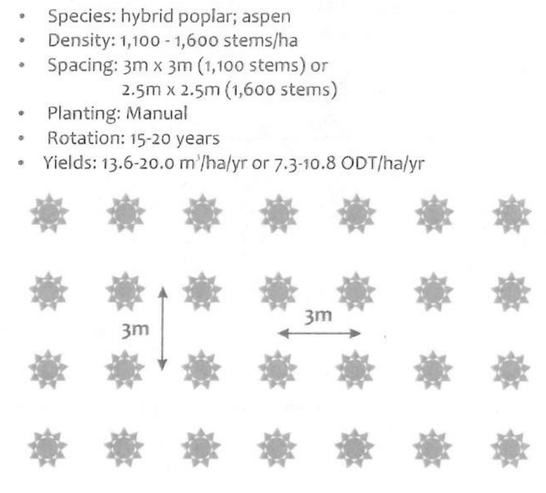
Nutrien has two phosphogypsum stacks in Canada. One is located in Fort Saskatchewan, Alberta where phosphate fertilizer was produced by a predecessor company between 1965 and 1991. Approximately 5 million tonnes of PG were produced during that period. Nutrien’s other Canadian PG stack is located near Redwater, Alberta. Phosphate fertilizer was produced in this location for 50 years, resulting in approximately 50 million tonnes of PG covering an area of approximately 275 ha. Phosphate fertilizer production was shut down in April 2019 and there is no longer any phosphogypsum production in Canada.

RECLAMATION AND BENEFICIAL USE OF PG *in situ*

Traditionally, gypsum stacks in North America are regarded as a waste by-product and reclamation involves contouring the piles, covering with soil or a synthetic liner and seeding to a grass mixture. Nutrien began conducting research into alternative methods of reclamation in 2005 in collaboration with the University of Alberta. In the last 15 years, seven students have earned their M.Sc. degrees working on different aspects of this project. Initially research projects examined the depth of soil needed to cover the PG stacks and what grasses to seed, but over time it became apparent that it was beneficial to mix soil into the gypsum to create an Anthrosol rather than using a barrier approach to reclamation. PG/soil mixes were shown to result in greater vegetation health and biomass over plants grown in soil alone. Once soil was mixed into the gypsum and the rooting depth of vegetation was no longer an important consideration, growing trees could be considered , creating the possibility of reducing long term maintenance costs and sequestering carbon dioxide to combat climate change.

Nutrien then partnered with the Canadian Wood Fiber Center, Natural Resources Canada (NRCAN) to test the possibility of establishing concentrated woody plantations on the PG stacks. Nutrien follows the protocols developed by NRCAN to develop high yield afforestation plantations that maximize biomass and carbon accumulation over the short to medium term. Typically, these types of plantations are established on moderate to high quality land across Canada but have proven to be very successful on the PG Anthrosol.

In the prairie provinces of Canada, the primary tree species to be considered for high yield and carbon sequestration afforestation is hybrid poplar (*Populus* spp). Hybrid poplar plantations of 1100 – 1600 stems/ha produce yields of 13.6 – 20 m^3 or 7.3 – 10.8 ODT (oven dried tonnes) ha/yr of above ground woody biomass. The preliminary assessments of below and above ground carbon budgets estimate potential carbon increase of 500-650 t CO_2 eq/ha over a 20-year rotation, or 25 – 32.5 Mg CO_2 eq/ha/y.



- Species: hybrid poplar; aspen
- Density: 1,100 - 1,600 stems/ha
- Spacing: 3m x 3m (1,100 stems) or
  2.5m x 2.5m (1,600 stems)
- Planting: Manual
- Rotation: 15-20 years
- Yields: 13.6-20.0 m^3/ha/yr or 7.3-10.8 ODT/ha/yr

Figure 1. NRCAN Hybrid Poplar Plantation Design

Hybrid willows (*Salix* spp) are also suitable for high yield and bioenergy development. Plantations of 15,625 stems/ha were designed to produce yields of 6 – 12 ODT (oven dried tonnes) ha/yr of above ground woody biomass. Preliminary assessments of below and above ground carbon budgets estimate potential carbon increases of 14 – 28 Mg CO_2 eq/ha/y over 6-7 three year rotations.

Natural Resources Canada has also designed a mixed wood afforestation plantation using hybrid poplar and white spruce that is designed to maximize biomass accumulation, carbon sequestration and fibre production over both the medium (20 years) and long term (70 years) through the development of both hardwood and softwood crops. Preliminary assessments of below and above ground carbon budgets estimate potential carbon increases of 644-820 Mg CO_2 eq/ha/yr over the 20 and 70 year rotations for the respective hardwood and softwood crops.

Establishing a forest on top of PG stacks has many positive impacts on the environment. The afforestation approach to PG stack reclamation will increase carbon sequestration and generate carbon dioxide offsets as well as produce biomass for energy production. Trees are also capable of phytoremediation of any excess nutrients and water within their rooting zone, thereby improving long term groundwater quality. Field observations indicate that there is little or no water infiltration into the gypsum stack under the concentrated tree plantations in the semi-arid climate of the Canadian prairies. Tree plantations have already been established on 20 ha of phosphogypsum (PG) at the Nutrien facility in Fort Saskatchewan, Alberta, Canada. The trees are growing extremely vigorously. As an example, between 2016 and 2017, the hybrid poplar cultivar *Tristis* grew from an average height of 85 cm to 280 cm, a gain of almost 2 meters height in a single year. Many trees are over 5 meters in height after three years of growth. Crown closure has been observed after less than three years. This inhibits vegetation growth beneath the trees, with the site essentially left in a free-to-grow state without any need for maintenance. Trees are observed to be growing much faster on the gypsum stacks than the same trees growing on regular soil. This is likely because the PG has excellent water holding capacity and some residual plant nutrients.

The tree plantations established at Nutrien are predicted to sequester 30 Mg CO_2 equivalents/ha/year. Thus, in 20 years, the gypsum stack area reclaimed to date will sequester 12,000 metric tonnes of CO_2 equivalents. This same area is also predicted to produce 10 ODT/ha/year of above ground woody biomass; therefore, it is estimated that 4000 green tonnes will be produced in this area over the next 20 years. These numbers will continue to increase as Nutrien continues to reclaim and establish concentrated woody plantations on their PG stacks.

The economic benefits of afforestation can be substantial. Carbon credits are worth $30/tonne in Alberta and therefore it is estimated that the 20 hectares of forested gypsum stack can potentially generate $360,000 in C credits in 20 years. The cost of establishing a short rotation woody crop is approximately $3800/ha, therefore afforestation pays for itself in a few years. If desired, woody biomass could also be sold. Woody biomass is worth approximately $50/tonne in Alberta. It is also important to consider that once the trees close canopy, maintenance is essentially eliminated, so the reduction in maintenance and mowing costs compared to a grassed PG stack can be significant.

Incorporating trees into the reclamation plan will also improve the long-term sustainability and ecosystem diversity of the gypsum stacks. Increased wildlife such as deer, rabbits, foxes, small rodents and many birds have been observed in the forested areas.

Figure 2. Willows planted on a PG filled pond five years after planting.

Figure 3. Hybrid poplars (4 years old) growing on the PG stacks

Figure 4. Some of the 2020 vegetable harvest from the PG Anthrosol research garden.

The phosphogypsum/soil Anthrosol can also be used to grow many other types of high value crops. Nutrien has established a small research garden on top of the PG stack and has tested various flowers, fruits and vegetables such as raspberries, potatoes, tomatoes and pumpkins. Analytical results for trace elements indicate that the quality of the vegetables is the same or better than plants grown on regular soil. Future research will include expanding pollinator habitat and working with local beekeepers to investigate other opportunities to create value *in situ*.

SUGAR BEET LIME EFFECTS ON HIGH pH SOILS AND CROPS IN THE NORTHWEST U.S.

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INTRODUCTION

Precipitated calcium carbonate (PCC) is a byproduct of sucrose extraction from sugarbeet (*Beta vulgaris* L.). To remove impurities from the sugarbeet sucrose liquid juice stream, calcium oxide and carbon dioxide are added to the stream to form calcium carbonate ($CaCO_3$) that precipitates out of the liquid juice stream with the impurities. The combination of the $CaCO_3$ and impurities form the PCC and is removed from the juice stream as a solid material.

Various lime materials are used in agriculture is to ameliorate the negative effects of soil acidification on crop production (Havlin et. al, 1999). An estimated 25 to 30% of world soils are acidic (Havlin et. al, 1999). In the Amalgamated Sugar Company growing area in Idaho, Oregon and Washington the pH of most soils range from 7.5-8.5 and do not require lime applications to adjust soil pH. Not only are lime applications not needed to correct soil pH, there are questions regarding potential negative effects of increasing salt concentrations with added PCC.

The Amalgamated Sugar Company LLC's major sugarbeet processing factories (Paul, ID; Twin Falls, ID; and Nampa, ID) produce approximately 387,000 tons of PCC annually. In 2018, PCC stockpiles at these factories totaled approximately 12.6 million tons. Without an offsite beneficial use or disposal method for the PCC, the stockpiles will continue to grow. The difficulty in finding more land to stockpile PCC due to availability issues and high land prices, and potential environmental issues have resulted in the need for Amalgamated Sugar Company LLC to find more offsite beneficial use or disposal methods. Agricultural land application is a practical method to dispose the PCC.

The objective of the study was to assess the effects of added PCC to a common alkaline soil on a sugarbeet-dry bean-barley rotation yields and soil chemical properties. The data will be used to help determine if PCC can be land applied on high pH soils.

MATERIALS AND METHODS

This study was conducted from 2014 to 2020 at the USDA-ARS Northwest Irrigation & Soils Research Lab in Kimberly, ID on a Portneuf silt loam soil. The treatments included four PCC application rate/timings. Table 1 outlines the treatments application details.

Table 1. PCC treatment annual rates and cumulative total amounts applied (in parentheses), crop grown, soil sample date, and lime application date.

Year	2014	2015	2016	2017	2018	2019	2020
Crop	--	Sugarbeet	Dry Bean	Barley	Sugarbeet	Dry Bean	Barley
	tons acre^{-1}						
Control	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
3A	3 (3)	3 (6)	3 (9)	3 (12)	0 (12)	0 (12)	0 (12)
10A	10 (10)	10 (20)	10 (30)	10 (40)	0 (40)	0 (40)	0 (40)
40T	40 (40)	0 (40)	0 (40)	0 (40)	0 (40)	0 (40)	0 (40)
Soil Sample Date	Oct. 19	Apr. 22	Apr. 18	Mar. 21	Apr. 3	Apr. 18	Apr. 9
Lime Application Date	Oct. 29	Nov. 18	Nov. 30	Nov. 24	--	--	--

The treatments were selected to: a) determine the effects of PCC on crop production and soil chemical properties (method: Control vs 3A, 10A, 40T); b) compare the effects of a "low" rate of PCC compared to a “high” rate of PCC (method: 3A vs 10A and 40T); and c) compare the effects of the same rate of PCC application applied differently over time (10A vs 40T). The treatments were arranged in a randomized block design and each treatment was replicated four times. Each plot was 22 ft wide and 60 ft long.

Soils were sampled in the spring and fall of each year from 0 to 12 in (Table 1). In the fall of each year the soil sampling was done before PCC application. The soil samples were analyzed for pH (Kalra, 1995), electrical conductivity (EC) (Rhoades, 1996), Total P , Bicarbonate Extractable P (Olsen P, 1954), NO_3-N and NH_4-N (Mulvaney, 1996), Total C and N using a FlashEA1112 CN analyzer (CE, Elantech, Lakewood, NJ). Due to the significant concentration of P in the PCC (Table 2) and the marginal concentrations in the soil over the study area, to eliminate the crop productivity responses to P, in spring 2015, 400 lbs P_2O_5/acre (mono ammonium phosphate fertilizer) was applied over the entire study area. Soil fertilizer recommendations were determined each year based on University of Idaho recommendations for each crop.

Following PCC applications each fall the entire study area was disked, moldboard plowed, and roller harrowed. The study area was planted to sugarbeet (BTS 21RR25), in 2015 and 2018, dry beans (Ruby Small Red) in 2016 and 2019, and barley (Moravian 69) in 2017 and 2020. The crops were furrow irrigated to meet estimated crop evapotranspiration (ET_c) rates (Wright, 1982). The harvest areas within each plot for each crop were 201, 275, and 275 ft^2 for sugarbeet, dry bean, and barley, respectively.

Analysis of variance was conducted for treatment main effects for selected production factors (sugarbeet root yield, sugarbeet ERS yield, sugarbeet root sucrose concentration, sugarbeet root brei nitrate concentration, barley grain yield, and dry bean yield) using a randomized block design model in Statistix 8.2 (Analytical Software, Tallahassee, FL). For significant (0.05 probability level) main effects, the LSD mean separation method were used to determine treatment differences.

RESULTS AND DISCUSSION

PCC Composition (Tables 2 and 3):

- PCC is a major source of P, a moderate source of K, and a minor source of other nutrients and elements.
- The PCC pH (8.5) was slightly higher than most soils in the study area. The control treatment (no PCC) pH levels ranged from 7.8 to 8.1 across all years.
- The calcium carbonate equivalency (CCE) is the acid neutralizing value of PCC compared to 100% calcium carbonate.

Table 2. Selected constituent contents and characteristics of the PCC used in this study.

CCE (%)	75
pH	8.5
EC (mmhos/cm)	2.5
NO_3-N (mg/kg)	183.8
NH_4-N (mg/kg)	8.5
P (mg/kg)	8114.6
K (mg/kg)	873.7
Cu (mg/kg)	17.2
Na (mg/kg)	1528.1

Table 3. Total cumulative rates of selected constituents applied from the PCC treatments. The cumulative amount of PCC added for the 3A, 10A, and 40T treatments were 12, 40, and 40 tons/acre.

Constituent	lbs/ton	3A	10A	40T
		Total lbs/acre		
NO_3-N	0.4	4.8	16	16
NH_4-N	0.02	0.24	0.8	0.8
P_2O_5	37	444	1480	1480
K_2O	2.1	25.2	84	84
Cu	0.03	0.36	1.2	1.2
Na	3.1	37.2	124	124

Crop Yield and Quality (Tables 4 and 5):

- The sugar beet production values and the mean separations for the 2018 sugar beet root yields are presented in Table 4. Yield data for dry bean and barley are presented in Table 5.
- The addition of PCC at all rates and timings did not affect crop production compared to no PCC. PCC raised soil pH but not significantly. For all crops, the only statistical differences of PCC effects on yield and production factors was sugar beet root yields in 2018 (Table 4). The significant differences in sugar beet root yields were not easily interpreted according to PCC application rates and timings. Increased root yields in 2018 with PCC could have been the result of increase P concentrations in the soil, but the control treatment soil P levels were sufficient based on soil test recommendations. Also, there were greater differences in soil P between PCC treatments and the control in 2015, with no differences in root yield. It is common in research studies to have significant differences between treatments that are not explained by the treatments.

Table 4. Sugarbeet production factors and analysis of variance (ANOVA) for treatment effects on production factors. Significance was determined at P<0.05. For significant treatment differences, LSD mean separations were performed. Within each production factor, study, and year values with the same letters are not different.

Year	Treatment	Cumulative Lime Applied Prior to Listed Year Sugarbeet Crop (tons/acre)[a]	Root Yield	ERS Yield	Sucrose	Root Nitrate	Root Conductivity
			tons acre^{-1}	lbs acre^{-1}	%	mg kg^{-1}	mmhos
2015	Control	0	41.2	12522	17.8	140.1	0.70
	3A	3	39.2	11949	17.8	139.4	0.69
	10A	10	39.3	11884	17.7	140.3	0.70
	40T	40	41.0	12447	17.7	135.8	0.68
	Mean		**40.2**	**12201**	**17.8**	**138.9**	**0.69**
			ANOVA (P value)				
			0.4359	*0.3007*	*0.9853*	*0.6994*	*0.9694*
2018	Control	0	28.6 b	9550	193	84.0	0.64
	3A	12	32.8 ab	10599	189	90.2	0.75
	10A	40	37.3 a	11744	184	129.3	0.73
	40T	40	31.9 ab	10281	188	78.8	0.71
	Mean		**32.7**	**10544**	**189**	**95.6**	**0.71**
			ANOVA (P value)				

0.0420	*0.0816*	*0.2361*	*0.4563*	*0.2555*

[a] As-Is Root Water Content (approx. 77% water)

Table 6. Dry bean and barley grain yields, and analysis of variance (ANOVA) for treatment effects on crop yields. Significance was determined at P<0.05.

Crop	Year	Treatment	Cumulative Lime Applied Prior to Listed Year Crop	Bean or Grain Yield [a]
			tons acre^{-1}	lbs acre^{-1}
Dry Bean	2016	Control	0	No Yield[b]
		3A	6	No Yield
		10A	20	No Yield
		40T	40	No Yield
Dry Bean	2019	Control	0	3851
		3A	12	3835
		10A	40	3557
		40T	40	3838
		Mean		**3770**
				ANOVA (P value)
				0.3166
Barley	2017	Control	0	5247
		3A	9	4933
		10A	30	4995
		40T	40	4621
		Mean		**4949**
				ANOVA (P value)
				0.3101
Barley	2020	Control	0	7341
		3A	12	7359
		10A	40	7309
		40T	40	7108
		Mean		**7279**
				ANOVA (P value)
				0.9053

[a] Oven Dry Yield

[b] Hail damage

Soil pH (Figure 1):

- Soil pH levels varied based on date of measurement. Base pH levels of the control varied between sample time; all other treatments following the same variation. These temporal variations may be the result of several soil factors such as temperature, soil water, microbial processes, etc.
- The important pH comparisons are between treatments within each sample date. The data shows that before lime applications (Fall 2014), all soils from the study had the same pH. Overtime, the plots with lime application showed a trend for increasing pH. However, the increase in pH was not great. Although the PCC was adding acid neutralizing anions, the amount of these ions in the soil were much greater than the amount added in the PCC. This is analogous to adding a few drops of water to a glass of water, the drops of water do not significantly increase the volume of water in the glass.

- The important take away from Figure 1 is that the increase in soil pH from the PCC is not likely to cause any negative effects associated with soil chemistry that would affect plant growth.

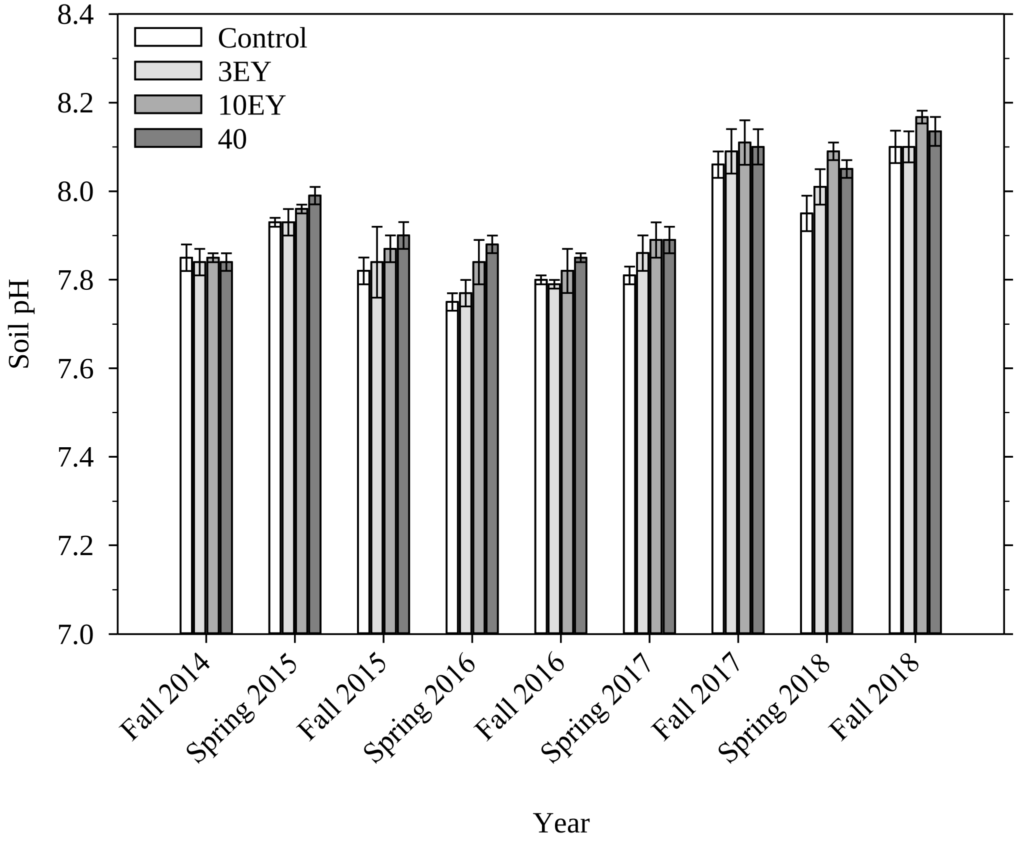

Figure 1. Soil pH for study treatments over time.

CONCLUSIONS

Application of PCC at rates up to 40 tons/acre did not negatively affect crop production in a silt loam soil and serves as a P fertilizer source.

Soil Test P (Figure 2):

- PCC increased plant available soil P.
- PCC has an added P fertilizer value.
- In soils that have high soil P, PCC can potentially increase negative environmental impacts. The extent of the environmental impacts will vary based on management practices that affects the amount of runoff that enters off-site water streams. Practices that reduce runoff will reduce risks.

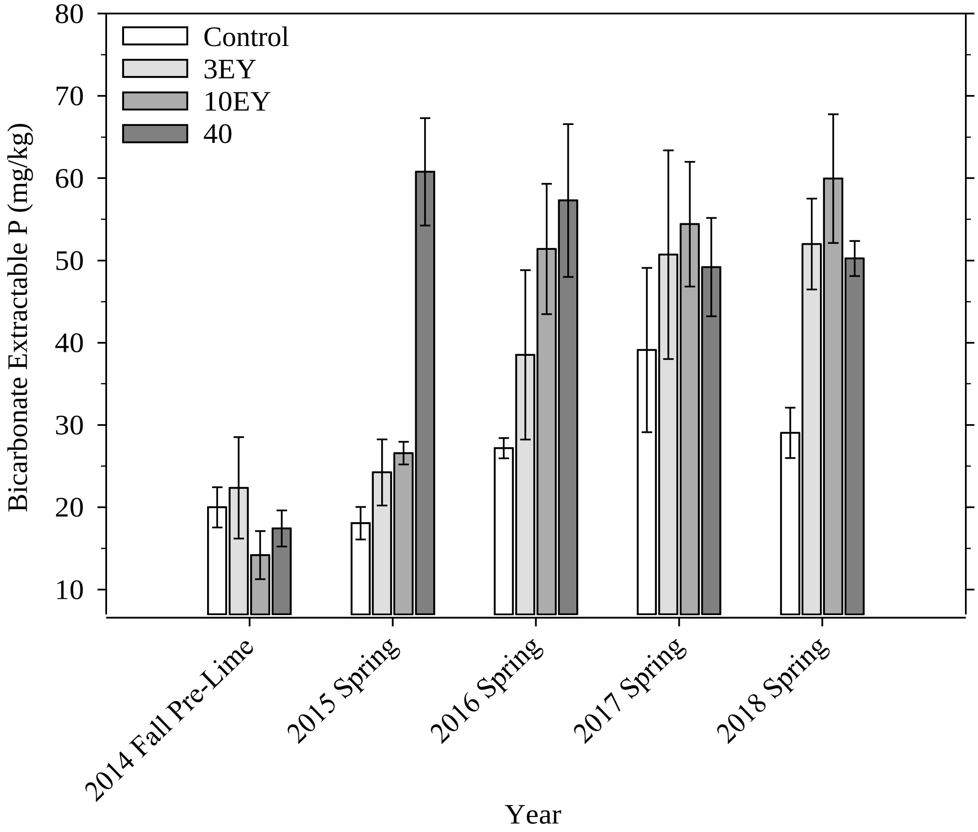

Figure 2. Soil bicarbonate extractable P (Olsen P) for study treatments over time.

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REPURPOSING ZINC FROM MINING TIRE WASTE TO A FERTILIZER RESOURCE

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ABSTRACT

Waste tires are a major environmental concern around the globe. Pyrolysis under high vacuum can be used to recover petrochemicals, steel, and recovered Carbon Black (CB) char that may have value as a zinc fertilizer and soil amendment. Our preliminary work with a by-product of mining tires, CB4000, showed significant increases in the Zn supplying power of soils using short term burials of PRS® probes. This confirmed that the Zn contained in CB4000 was in a bioavailable form. Further studies growing corn in pots showed a significant increase in Zn uptake from the CB4000 amended soils. This work shows repurposing the Zn from used tires to fertilizer can be highly successful.

INTRODUCTION

Waste tires have been a major environmental concern in Canada since the 1990 Hagersville, ON tire fire that burned for more than 2 weeks at the dumpsite with over 10 million scrap tires. Although many changes in the environmental footprint of vehicles have happened since this time, the global demand for tires has not slowed down. In fact, within the last 5 years, tire sales have increased by 4.1% per year with 2019 seeing over 3B tires sold.

Although giant mining tires make up a small fraction of this number, they do make up a significant mass as they can weigh over 6 tons each. These tires are commonly concentrated in their use and disposal around mining sites like the oil sands of Fort McMurray, AB. This close proximity to world-class expertise in optimizing oil recovery has provided a special opportunity in tire recycling in Alberta, Canada. Thermal Vacuum Recovery (TVR) of oils and gas from the waste tires is not new (Williams, 2013). However, using local expertise the Titan Tire Reclamation Corp. has perfected a proprietary system that results in a very efficient and complete separation with the remaining char or Carbon Black (CB) containing between 6-8% Zn. Although total elemental analysis shows significant quantities of essential plant nutrients, this does not mean that these elements will be bioavailable to the plant in the year of application.

Zinc (Zn) is the fifth most important human nutrient deficiency according to the World Health Organization. Within the broad acre field crops of North America, Zn deficiency in corn, barley, and wheat are common on soils with high pH, low organic matter, and high carbonate. This limit in Zn supply is often exacerbated by increased plant demand under high yielding hybrids and new semi-dwarf genetics.

Our goal was to assess the char derived from this proprietary TVR process (called CB4000) to supply bioavailable Zn and other minor plant nutrients.

MATERIALS AND METHODS

The propriety process of TVR results in almost complete removal of the volatile rubber compounds, leaving behind only the steel belting and CB4000 in the batch reactor. Table 1 provides an analysis of the major elements contained in the CB4000. The concentration of deleterious heavy metals/contaminants was very low with Pb averaging 30 ppm and Cd averaging 1.40 ppm.

Table 1. CB4000 Total elemental analysis (selected major components).

Element	**% of total**
Carbon	78.92
Zinc	7.76
Silicon	4.22
Sulfur	4.20
Iron	0.68
Calcium	0.49
Nitrogen	0.16
Phosphorus	0.13
Cobalt	0.08

CB4000 impact on bioavailable soil nutrients was performed using Plant Root Simulator (PRS®) probes according to the WERA standardized saturated paste method (Bremer, 2013). We added CB4000 at a rate of 1.3% by weight to three different soil types (Table 2). These were thoroughly mixed and 10:1 and 20:1 "dilution" of this stock soil was made with fresh soils of each type. This resulted in CB4000 in the concentration ranges of 1.3%, 0.13% and 0.065% that corresponded to Zn application rates of 1000 lb/ac, 100 lb/ac and 50 lb/ac, respectively.

Table 2. Properties of the soils amended with CB4000 in the preliminary PRS® bioavailability study and Stage 2 Corn pot experiment.

Soil Label	**Description**	**Location**	**Soil Series**	**Texture**	**SOM (%)**	**pH**	**EC**
PRS001	Low slope	Enchant, AB	Cranford	Loam	3.3	6.65	0.24
PRS002	Hilltop	Enchant, AB	Helmsdale	Loam	1.3	8.41	0.18
PRS003	Level, compost-amended	Bow Island, AB	Chin	Loam	1.7	7.38	0.32
Soil A (corn pot study)	Upper slope/level	Leroy, SK	Oxbow	Loam	3.0	7.80	0.50

A further stage 2 corn pot experiment was set up to test the phytoavailability of Zn from the CB4000 product added at typical fertilizer rates (0.5ppm and 2.0ppm) to a PRS® Zn deficient soil (0.3 ug/10cm2/day). The generalized pot culture protocol listed below:

- 1.8 kg of soil per pot with 3 replicates Control and CB4000 treatments.
- CB4000 Zn product coated on granular fertilizer (0.34 g urea, 0.39 g MAP, and 0.48 g potassium sulfate) and mixed into the middle third of each treated pot.
- Sweet corn (Honey and Cream Bicolour, Heritage Garden Products, Brandon, MB) was planted at 4 seeds/pot on 20/06/2019, thinned to one plant/pot after three weeks
- Randomized pot placement
- Watered to weight (field capacity) as required (once every one or two days)
- Duration: 7 weeks (50 to 70 cm in height)
- Measurements: water use during final two weeks of growth, plant height, shoot and root dry weights, shoot nutrient concentration, and uptake
- Plant tissue was dried and ground, with a subsample sent for acid digest and ICP analysis.

RESULTS AND DISCUSSION

The preliminary study revealed significantly increased PRS® bioavailability of Zn on all soil types when CB4000 was applied at the highest rate (Figure 1). Upon combined analysis of all soils, the 0.065% and 0.13% rates of CB4000 showed a significant but less clear trend toward increasing PRS® Zn. The Hilltop soil (Helmsdale) was significantly lower in Zn supply than the other two soil types due to the high pH and free carbonates fixing Zn. These ‘white Hilltop” soils, with thin A horizons and admixed high lime Cca horizons, are common in the glacial till of the Northern Great Plains. Effectively improving the Zn supply rate to a sufficient level (0.5 ug/10cm2/3day, Greer et al. 2002) will require substantially more CB4000.

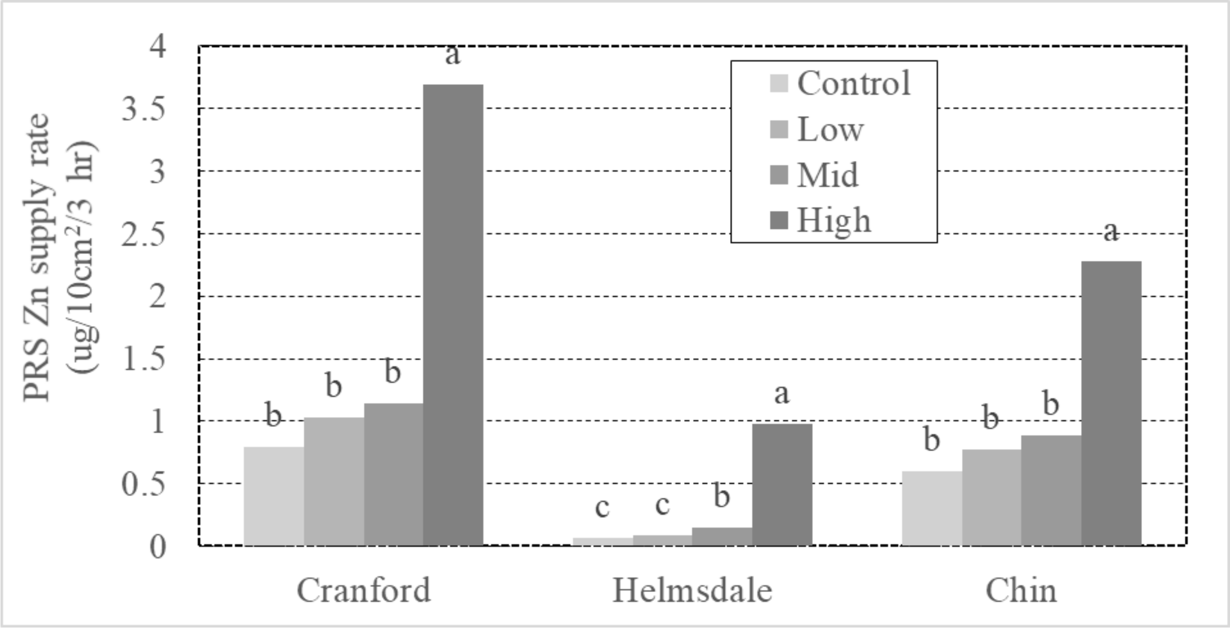

Figure 1. Mean PRS® Bioavailable Zn supply rates from standard soils (Cranford, Helmsdale, and Chin) having CB 4000 amended at 0 (control), 0.065% (Low), 0.13% (Mid) and 1.3% (High) rates (letters indicate LSD P=0.05).

STAGE 2 CORN POT STUDY:

A stage 2 corn pot study was set up following the PRS® bioavailability screening confirming that the CB4000 Zn was in an ionic/exchangeable form. It is important to note the ease and simplicity of the 3 hour saturated paste PRS® probe measurement as an initial step in testing repurposed nutrient products. By confirming that the repurposed products are in a form that the plant can take up, we eliminated one of the biggest questions before entering the costly and often confounding step, the pot study.

CB4000 exists as a fine black powder that readily coated the blended NPKS fertilizer prills, making distribution and amendment to the pots relatively simple. Given the distribution and proximity to other nutrients, we assumed the root access would be very similar to other co-precipitated or impregnated Zn fertilizer products. Therefore, more typical field rates of 0.5 ppm and 2 ppm of actual Zn (6.4 and 25.7 lbs/ac CB4000, respectively) were applied to the corn pots.

Following seven weeks of plant growth, the corn plant height and dry weight showed a significant response to the CB4000. Shoot dry matter was ground and analyzed in a total plant nutrient digest to allow shoot Zn yield (Zn uptake) to be calculated. The trend in shoot Zn concentration and shoot Zn yield agree with the conclusion of a Zn response. However, the variance in the tissue analysis was rather high (relative standard deviation=25%) and reduced the statistical robustness of our conclusion.

Table 3 Average corn height, shoot dry weight, and Zn content as affected by CB4000 application. (letters indicate LSD P=0.05; *significantly different from control at P<0.13).

Treatment	Plant height (cm)	Shoot dry wt. (g/pot)	Shoot Zn conc. (ppm)	Shoot Zn yield (μg/pot)
Control (no Zn)	59.0b	6.3ab	7.2a	55
CB4000 (0.5 ppm)	61.0ab	6.0b	9.5a	74*
CB4000 (2 ppm)	63.5a	7.1a	10.2a	96*

CONCLUSIONS

This study found that the proprietary TVR method of reclaiming giant mining tires results in a fine Carbon Black powder (CB4000) that has nutrients, specifically Zn, that can be repurposed to fertilizer. A circular economy of nutrients has always been part of the agricultural system as manures, composts, and other biological products. However, with 3B tires sold per year containing more than 2.2M tons of Zn, repurposing this nutrient to agricultural soil is a much-preferred scenario compared to effectively stranding it within rubber crumb/aggregate products, reformed rubber ramps, curbs, and mats (Shercom Industries Inc. 2020). Further new evidence has reported raw tire rubber will experience leaching/chemical transformations that deleteriously impact the environment (Tian et al., 2020). Given the efficiency of oil and gas extraction with the proprietary TVR process, the remaining CB4000 appears to have very few volatile organic components left in the product. As such land application as a beneficial plant nutrient appears to be a very promising win-win.

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FACTORS INFLUENCING EFFICACY OF ELEMENTAL SULFUR FERTILIZERS

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ABSTRACT

Elemental S is produced in large quantities in both the US and Canada as a byproduct of fossil fuel production. This form of S must be oxidized to sulfate by soil microorganisms before crops can utilize it and thus may not reliably meet crop requirements in the year of application. Rapid oxidation may be attainable with fine particle size (large surface area), effective dispersion, and favorable environmental conditions. Based on published results from four field experiments, elemental S can be an effective source of S if appropriately formulated and applied.

INTRODUCTION

The demand for S fertilizers has increased due to reduced S deposition and increased use of S-demanding crops such as canola. Most fertilizers applied to alleviate S deficiencies have S in the form of sulfate that can be directly taken up by plant roots, e.g., ammonium sulfate (21-0-0-24).

Although approximately 15 million tons of elemental S recovered annually from petroleum refineries, natural-gas-processing plants, and coking plants in North America, only a small fraction of this S is utilized directly as fertilizer for crops because this form must be oxidized by soil microorganisms before it is available to plants. The major factors influencing the efficacy of elemental S fertilizers and several examples of effective use are reviewed here. If effective, elemental S fertilizers have potential advantages of high S content and low manufacturing cost.

Factors influencing efficacy of elemental S fertilizers

Many different microorganisms capable of oxidizing elemental S are present in agricultural soils (Germida and Janzen, 1993). Most oxidation in agricultural soils is catalyzed by a mixed population of heterotrophs rather than autotrophic oxidizers such as *Thiobacillus oxidans*. The overall process is: $S^0 + O_2 + H_2O \Rightarrow H_2SO_4$ (i.e., acidifying). A lag before maximum oxidation rates may occur due to time required for microbes to colonize the surface of introduced elemental S.

As oxidation is a surface process, the rate of oxidation depends on the area, not quantity, of elemental S applied (Degryse et al., 2016; Fox et al., 1964). As particle diameter increases from 2 um to 2 mm, the time required for 50% oxidation increases from 1 day to more than 3 years under lab conditions (Table 1). Thus, it can be clearly seen that particles should be less than ≤ ≈20 µm to significantly contribute to crop S requirements in the year of application.

Table 1. Impact of particle size on surface area and oxidation rate.

	Per g of elemental S		
Diameter (mm)	**# Particles**	**Surface area (cm^2)**	**Days to oxidize 50%[†]**
0.002	10^{11}	14,000	1
0.02	10^{8}	1,400	10
0.2	10^{5}	140	100
2	10^{2}	14	1000

[†]Based on Janzen and Bettany 1987a and Janzen 1990.

Elemental S oxidation is suppressed when particles are in close proximity to each other. This suppression may be due to water limitation caused by hydrophobicity and/or the accumulation of acidic or toxic oxidation products. Janzen (1990) found that oxidation was negligible when the soil to S ratio was less than 100:1 and increased rapidly as this ratio increased to 1000:1. For this reason, banded application of elemental S fertilizer is less effective than broadcast application.

Elemental S is often co-granulated with bentonite or other fertilizers to improve handling. Oxidation is suppressed compared to a uniform mixing of fine particles, but can be considerably enhanced by reducing the proportion of elemental S and granule size in the final product. Compared to uniformly-mixed particles, oxidation was 30-fold slower for bentonite products (90% elemental S), but only 4-fold slower for products co-granulated with monoammonium phosphate (MAP) (5 to 7.5% elemental S) (Degryse et al., 2016).

The rate of elemental S oxidation also depends on environmental conditions. The process is more sensitive to temperature than most soil biological processes: oxidation was reduced by 50% at 73 °F (23 °C) and 90% at 59 °F (15 °C), compared to oxidation at 86 °F (30 °C) (Janzen and Bettany, 1987). The process is less sensitive to soil moisture, but as with many biological processes, the process is optimum at field capacity and reduced by dry or anaerobic conditions.

The efficacy of elemental S to meet crop requirements also depends on factors influencing the degree of S deficiency. Annual crops with a high and early S requirement (e.g., canola) will be more sensitive to delayed S supply than crops with a lower and later S requirement (e.g., corn). Crops grown on soils that are extremely deficient in S will be more sensitive to delayed S supply than crops grown on soils that are only moderately deficient in S.

Examples

Three elemental S fertilizers were compared in central Alberta: a finely-divided aqueous suspension (Micro-S) and two bentonite products (Karamanos and Janzen, 1991). The products were applied at 0, 27, 54 and 108 lb S/ac. In the year of application, extractable soil SO4-S, canola S uptake and canola seed yield were substantially increased by application of Micro-S, at an efficacy equivalent to about 50% of ammonium sulfate. Benefits of bentonite products in the year of application were small to non-existent, as were residual benefits of all products in two subsequent years.

A co-granulated elemental S product (particles <10 µm, Sulvaris Inc. Calgary, AB) was compared to potassium sulfate on a S-deficient site in Saskatchewan (Malhi et al., 2014). Both products were broadcast (fall and spring) and banded at 18 lb S/ac/yr in the same plots over a period of three years. The efficacy to increase S uptake of the co-granulated product relative to potassium sulfate was 49% when broadcast and 21% when banded. Similarly, the relative efficacy to increase seed yield of hybrid canola was 84% when broadcast and 61% when banded. The relative efficacy was similar in all years. Subsequent testing in nine trials in the mid-west showed equal efficacy for corn yield and tissue S concentration for granular and liquid products manufactured with the same technology (MST®), relative to ammonium sulfate (M. Howell, personal communication).

Crop use efficiency of elemental S and sulfate from the same co-granulated product (MES®; The Mosaic Company, Tampa, FL) was determined by enriching each form independently with ^{34}S (Degryse et al. 2020). Crop recovery in aboveground biomass was determined over a two year period in Canada, Argentina and Brazil (Table 2). Crop recoveries of elemental S were considerably lower than of SO_4-S in both Canada and Argentina, which was attributed primarily to low temperatures limiting oxidation of elemental S (median diameter of 40 µm). In contrast, crop recoveries of elemental S and SO_4-S were similar but low in Brazil, which was attributed to warm and wet conditions that supported rapid oxidation and subsequent losses by leaching. Crop recovery of elemental S was higher than SO_4-S in the second year, but remained lower overall in Canada and Argentina.

Table 2. The percentage of elemental S and SO_4-S recovered in aboveground plant material (derived from Degryse et al. 2020).

	1st year			2nd year		
Trial location	**Crop**	**SO_4-S**	**ES†**	**Crop**	**SO_4-S**	**ES**
Canada	Canola	59	6	Wheat	7	13
Argentina	Corn	78	12	Soybean	8	13
Brazil	Soybean/Corn	7	8	Soybean/Corn	3	8

†ES, elemental S, median diameter of 40 µm.

The efficacy of a micronized elemental S fertilizer (Sulgro 70, manufactured by Sultech, Calgary, AB) sprayed on the soil surface without incorporation was compared to sprayed ammonium sulfate in eight field trials in southern and central Alberta over a two-year period (Bremer et al., 2021). The supply of S to PRS® probes (ion-exchange membranes) in soil was consistently increased by application of Sulgro 70 relative to the unamended control, but less than that obtained with ammonium sulfate. On average, the increase in soil S supply of Sulgro 70 was 75% of that of ammonium sulfate between 4 and 8 weeks after seeding for trials that received a minimum of 5 inches of rainfall. Based on increases in biomass S concentration in three trials where the unfertilized control had low S concentration (<3 g S kg 1), the relative efficacy of Sulgro 70 was 34%. Canola seed yield was not increased by application of ammonium sulfate nor Sulgro 70 in any of the trials.

CONCLUSIONS

These examples demonstrate that micronized elemental S that is well dispersed in soil under favorable moisture and temperature conditions can be rapidly oxidized and an effective source of S in the year of application. Small particle size and effective dispersal is critical for the supply of S to crops that have a high demand for S early in the growing season. These crops may require adjustment in timing or rates of elemental S application or co-application of sulfate S.

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PHOSPHORUS AND POTASSIUM: HOW LOW CAN YOU GO IN ALFALFA

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ABSTRACT

Tissues testing whole alfalfa plants at harvest may more accurately direct nutrient decisions. Developing critical nutrient levels in-season improves recommendations and applications, saving producers time, expense and effort since many growers take samples for hay quality. 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 following is summation of the three years of results harvested at mid-bud stage for all cuttings on the same field. Increasing P rate from 0 to 240 lb P_2O_5 acre^{-1} increased yield by 0.9, 1.5 and 1.6 tons acre^{-1} in 2018, 2019 and 2020, respectively (Figure 1.) Yield increase of treatments in the first cutting peaked at 120 lb P_2O_5 acre^{-1} in 2018 and 2019 but in 2020 the 240 lb P_2O_5 acre^{-1} was the highest yielding treatment. Optimum economic P_2O_5 rates were 140, 150, 150 lb P_2O_5 acre^{-1} for \$150 ton^{-1} hay in 2018, 2019, and 2020 respectively. For \$200 ton hay, regression showed the 160 lb P_2O_5 acre^{-1} maximized gross income after fertilizer costs for all three years. Averaged over years, the whole plant tissue level at the economic optimum was 0.355 and 0.36% at mid-bud stage for 150 and \$200 ton^{-1} of hay, respectively. No potassium first cutting or total cutting yield response was found in the first year (2018) but in years two and three (2019 & 2020) alfalfa hay yield response to K was significant (1.14 and 1.26 tons lb K_2O acre$^{-1)}$. About 80% of total seasonal yield increased occurred in the first and second cuttings. Optimum K rate that optimized economic return after fertilizer costs varied considerably from year to year. When hay prices are \$150 ton^{-1} optimum K rates were 80 and 220 lb K_2O acre^{-1} for 2019 and 2020, respectively. Increasing the hay price to \$200 ton^{-1} the optimum rates were 320 and 240 lb K_2O acre^{-1} for 2019 and 2020, respectively. Optimum P content was consistent over both years at 0.36%, however, K content varied widely between years and in low testing soils whole plant tissue testing appears to be problematic.

INTRODUCTION

With high P and K fertilizer costs it is important to apply required nutrients accurately. Current soil sampling guidelines are calibrated from one-foot soil tests, yet alfalfa plants can remove potassium and other nutrients from much deeper depths creating disproportional inaccuracy between crop response and soil test results. Tissue testing provides the opportunity to direct nutrient decision making based on accurate critical levels for in-season recommendations that could include possible applications between cuttings or through fertigation. California scientists developed alfalfa tissue testing protocols, but producers are reluctant to adopt because the test demands the middle third of alfalfa of the plant at one-tenth bloom for P & K (Meyer et al., 2007). One-tenth bloom is well past dairy quality hay for most PNW producers, making this impractical. Alfalfa tissue testing has been proposed in New Mexico, which recommended a wide range from 2.0 to 3.5% K in the upper third of the plant at early bloom (Flynn et al., 1999). The current PNW alfalfa fertilizer guide states a critical K level of 2.0 to 2.5% for the whole plant at first bloom, but needs further refinement (Koenig et al., 1999). This research and others reveal P & K concentrations decline with crop maturity indicating the importance of the timing of tissue testing.

Fertilizer is the largest single expense in an irrigated alfalfa budget for the western U.S. Even at modest rates, fertilizer can easily reach over $216 per acre with P & K being the largest component. We have proposed using a harvest time mid to late bud stage (typical harvest timing for first cutting in PNW) and the use of whole plant samples, which could be taken at the same time and using the same method currently being used for quality analysis. We have emphasized first cutting because it is most desired by the dairy industry and most likely to be nutrient limiting due to growth in cold soils.

This research was funded all three years by National Alfalfa and Forage Alliance (NAFA) and was conducted near Prosser, Washington, on a low phosphorus soil at 5.4 ppm (Olsen et al., 1954) for the phosphorus study and 79 ppm potassium soil (ammonium acetate method). Our Objectives included: 1) Develop economic critical phosphorus and potassium tissue contents for bud stage alfalfa using tissue testing for maximum profit, yield.

MATERIALS AND METHODS

The P experiment occurred in a low P soil test field (< 10 ppm P), and the K experiment on a low K soil test field (< 100 ppm K). Studies were in a randomized complete block design with four replications at establishment of a spring alfalfa stand and harvested three times in 2018. Nutrients were applied on the surface for the second year of the experiment on April 11, 2019. Alfalfa was harvested 5 times in 2019. The experiments' treatments and descriptions are listed below.

“Phosphorus Rate Study” – What do P_2O_5 rates from MAP applied at 0, 30, 60, 120, 240 lb P_2O_5/acre have on the on refining tissue testing recommendations for P.

“Potassium Rate” – Response of alfalfa to six differing rates of Potassium Sulfate (0, 40, 80, 160, 240, 320 lb K_2O/acre) to develop/refine tissue testing recommendations for K.

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

RESULTS AND DISCUSSION - PHOSPHORUS STUDY

The field selected for this work had been in switchgrass for over 5 years with no fertility put back in the field and resulted in soil test of 8 ppm P (Olsen) and 101 ppm K (Ammonium Acetate). Visually the 0, 30, and 60 lb P_2O_5/acre plots had stunted growth going into the 2nd and

3rd spring of the 3-year study. No leaflet symptoms were present. Increasing P rate from 0 to 240 lb P_2O_5 acre^{-1} increased yield by 0.9, 1.5 and 1.6 tons acre^{-1} in 2018, 2019 and 2020, respectively (Figure 1.). In 2020, yield response to P was mostly in the first and second cuttings and averaged over rates made up 79% of the total increase in yield. Yield increases of treatments in the first cutting peaked at 120 lb P_2O_5 acre^{-1} in 2018 and 2019 but in 2020 the 240 lb P_2O_5 acre^{-1} was the highest yielding treatment. Since MAP was used in this study some nitrogen would be applied, however research has found that late season harvests are most likely to have a N response (Raun et al. 1999) and only 19% of the total yield increase in this experiment was from cuttings 3, 4 and 5.

By-harvest dry matter yield increases due to applied N were only found in late-season harvests, consistent with late-season decreased N2-fixing capacity in alfalfa documented by others.

Gross income after fertilizer expenses were calculated using regression to determine optimum fertilizer rates for the study using two prices of hay \$150 and \$200 ton^{-1} of hay and a P_2O_5 price of 0.538 lb^{-1}. Optimum economic P_2O_5 rates were 140, 150, 150 lb P_2O_5 acre^{-1} for \$150 ton^{-1} hay in 2018, 2019, and 2020 respectively. For \$200 per ton hay, regression showed that 160 lb P_2O_5 acre^{-1} maximized gross income after fertilizer costs for all three years. Averaged over years, the whole plant tissue level at the economic optimum was 0.355 and 0.36% at mid-bud stage for 150 and \$200 ton^{-1} of hay, respectively.

When tissue testing the stage of maturity and what part of the plant is being tested both must be considered when selecting a critical level. Our experimental results indicate the optimum level of P in the plant is higher than previously published (Meyer et al., 2008, Koenig et al., 2009). Our results indicate that even which cutting tested can affect the P tissue testing results (Figure 2). Koenig et al., 2009 recommends 0.2 - 0.25% P at first flower using the whole plant and Meyer et al., 2008 recommends 0.26 - 0.28% P for whole plant tissue at bud stage or early bud stage, respectively. In 2019, on our very low P soil with no P reached 0.26% at the second cutting (Figure 2). Interestingly, the soil level test levels continued to drop at all P rates (Table 1) except for the 120 and 240 P_2O_5 lb a^{-1} rates in 2018 which only had 3 cuttings in the first year as it was a spring planting. Crops seasons 2019 and 2020 each had five cuttings.

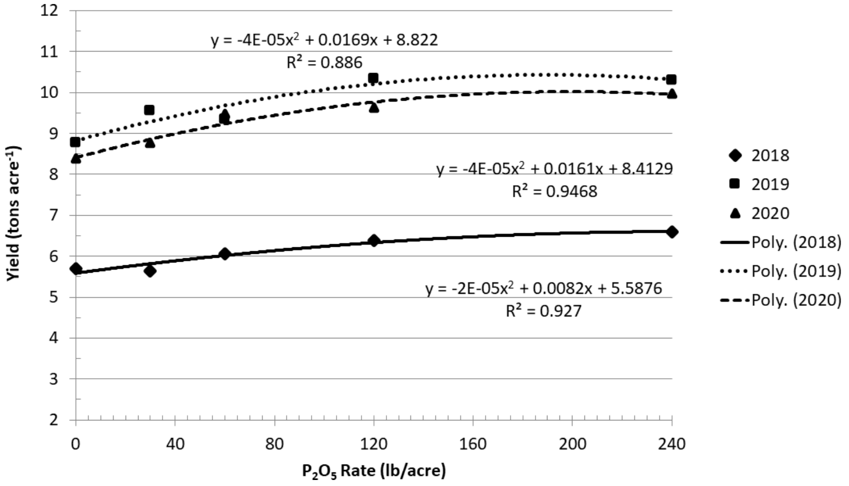

Figure 1. Influence of phosphorus fertilizer rate on total yield in 2018-2020 at Prosser, WA.

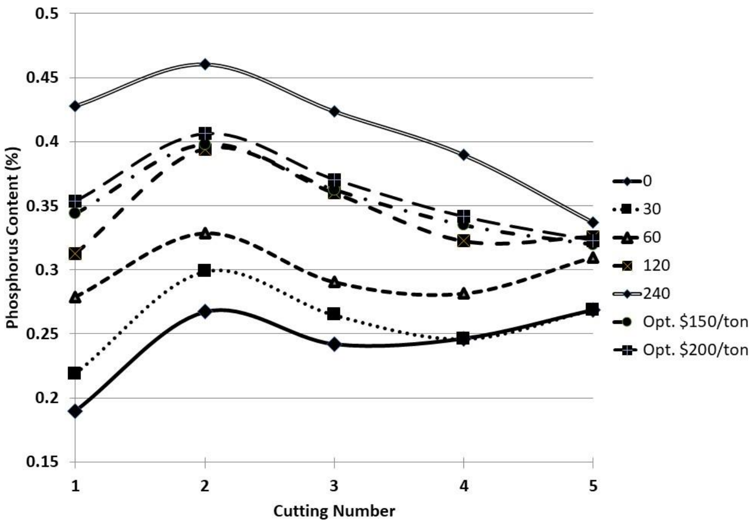

Figure 2. Influence of rate of P2O5 fertilizer and cutting on phosphorus content (%) in 2019. Economic optimum phosphorus content by cutting is given when hay is \$150 or \$200 ton^{-1}.

Table 1. Soil test values, application rates and removal rates of P2O5 for crop years 2018 to 2020 at Prosser, WA. Soil test in 2017 was taken just prior to the experiment.

P_2O_5 Rate Applied	**Total Applied in 3 Years**	**Total # of Removed in 3 Years**	**Fall Soil Test P 2017**	**Fall Soil Test P 2018**	**Fall Soil Test P 2019**	**Fall Soil Test P 2020**
(P_2O_5 lb a^{-1})	(P_2O_5 lb a^{-1})	(P_2O_5 lb a^{-1})	(ppm)	(ppm)	(ppm)	(ppm)
0	0	228	8.4	4.5	4.3	5.5
30	90	265	8.6	6.0	5.8	4.8
60	180	293	7.9	5.5	4.0	3.3
120	360	382	7.6	7.8	6.3	6.0
240	720	455	9.1	9.7	8.3	7.5

Potassium Rate Experiment:

The first year of the potassium study (2018) no response to potassium fertilizer was found in the first cutting or total yield for the year. The study was planted in 2018 so only 3 cuttings were harvested. Like the phosphorus study, the K level in 2018 soil was low at 101 ppm yet only a 0.18 ton acre^{-1} increase occurred by increasing K rate from 0 to 320 lb K_2O acre^{-1} (Figure 2). The beginning soil test for sulfur was 13, 13, 17 ppm so any additional sulfur from potassium sulfate should have had minor to no increases in yield in the experiment and not continue up to 108 lb acre^{-1} sulfur per acre which is in the 320 lb acre^{-1} rate of potassium sulfate. In years two and three (2019 & 2020) the response to K was significant at 1.14 and 1.26 tons lb K_2O acre^{-1}. Except for the 40 lb K_2O acre^{-1} rate, most of the yield increase (80%) occurred in the first and second cuttings. Virtually no yield increase occurred in the 3rd cutting compared to the control at any of the rates. Optimum K rate that optimized economic return after fertilizer costs varied considerably from year to year. In 2018, the lack of yield response put the economic optimum as no application. However, in the following spring the control plots had significant visual potassium deficiency symptoms. When hay prices are \$150 ton^{-1} optimum rates were 80 and 220 lb K_2O acre^{-1} for 2019 and 2020, respectively. However, when hay prices are \$200 ton^{-1} the gross income after K fertilizer costs was similar across a wide range of K rates and was \$1,847, \$1,813, \$1,944, \$1,941, \$1,905, \$1,950 for 0, 40, 80, 160, 240, 320, lb K_2O acre^{-1} rates, respectively. These results give a wide range of K rates for producers to choose but 320 lb acre^{-1} rate was the maximum in 2019. In 2020, the optimum K rate was 240 lb K_2O acre^{-1}, but again a wide range of rates could be chosen with 160 and 320 lb K_2O acre^{-1} rate being within \$15 and \$4 acre^{-1} gross return after K application, respectively. Soil test K in hay fields have been decreasing and this experiment was no different, even at the highest K rate, dropping from 93 ppm K at the beginning of the experiment to 78 ppm K after 3 years of alfalfa (Table 2.). At the 320 lb K_2O acre^{-1} rate after converting K in plant tissue to lb K_2O acre^{-1}, 1,298 was removed in hay and only 960 applied leaving a 338 lb K_2O acre^{-1} deficit. It seems impossible in this situation to determine an optimum %K content across years and cuttings, probably due to dilution of K with increases in yield and relatively high content in the plant. In 2019 and 2020 many of the K application rates had a lower K content than the control and K content differences between cuttings (Figure 2, Figure 3.). The year affect is significant (Figure 5.) Why 2020 did not take up as much is in 2019 a good question, but it was likely do to the dropping soil test results of averaging across treatments 80 ppm K in the soil at the beginning of 2020 and 60 ppm at the end of 2020 (Table 2). Current recommendations are 1.2 – 1.5% K being adequate (Meyer et al., 2008) for baled mid-bud hay, and 2 – 2.5% for whole tops at first flower (Koenig et al., 2009). Under this low K testing field tissue testing may not be the best choice for even determining sufficiency. Although K content did not increase much the amount taken up by the crop did increase by 104, 158, and 46 lb K acre^{-1} for 2018, 2019 and 2020 years, respectively. Why 2020 did not take up as much is in 2019 a good question, but it was likely do to the 80 ppm K in the soil that K was tied up in the soil.

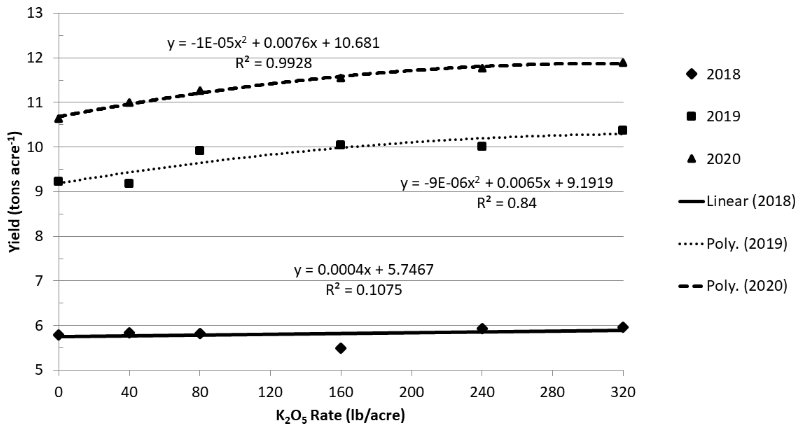

Figure 2. Influence of potassium fertilizer rate on total yield in 2018-2020 at Prosser, WA.

Table 2. Soil test values, application rates and removal rates of K_2O for crop years 2018 to 2020 at Prosser, WA. Soil test in spring of 2018 was taken just prior to the experiment.

K_2O Rate Applied	**Spring Soil Test K 2018**	**Spring Soil Test K 2019**	**Spring Soil Test K 2020**	**Fall Soil Test K 2020**	**2018 K_2O Removed**	**2019 K_2O Removed**	**2020 K_2O Removed**
lb K_2O a^{-1}	------------------------ppm------------------------				-------------lb K_2O acre^{-1}-----------		
0	106.8	90.5	79.0	67.3	196.1	458.3	334.9
40	104.3	85.8	69.0	54.5	212.1	431.5	316.1
80	87.0	82.3	82.8	53.3	213.5	450.8	302.6
160	106.0	88.0	83.0	64.0	239.3	525.6	334.8
240	106.3	85.0	83.5	54.3	308.4	567.2	369.0
320	92.8	84.8	78.3	62.0	300.2	616.1	381.2

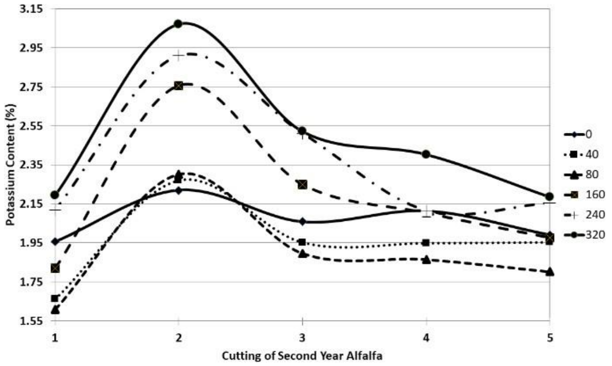

Figure 3. Potassium content of alfalfa as influenced by cutting and rate of K_2O acre^{-1} in 2019 at Prosser, WA.

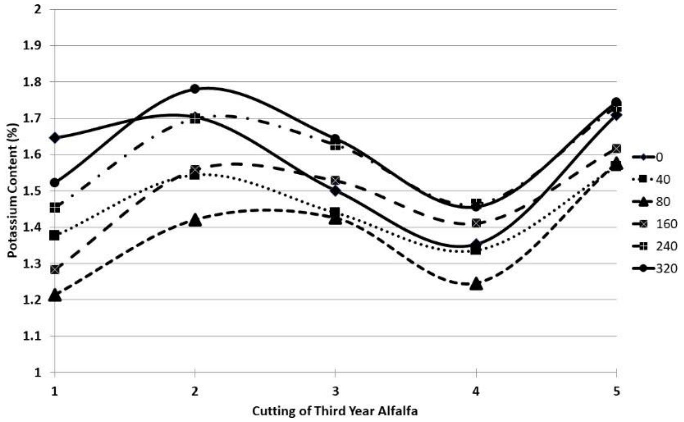

Figure 4. Potassium content of alfalfa as influenced by cutting and rate of K_2O acre^{-1} in 2020 at Prosser, WA.

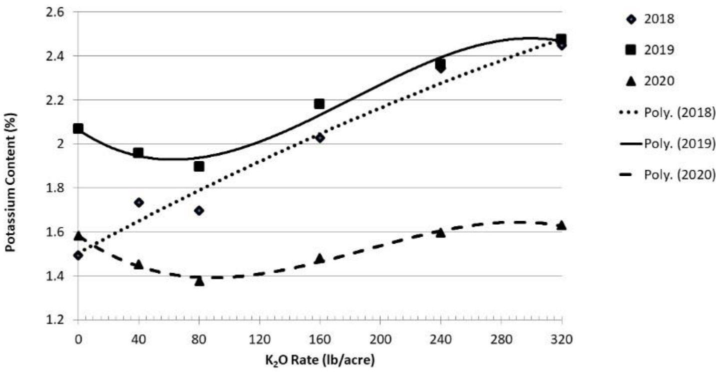

Figure 5. Potassium content of alfalfa as influenced by year and potassium rate applied to alfalfa near Prosser, WA from 2018-2020.

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TWENTY YEARS OF COTTON NITROGEN MANAGEMENT AND CYCLING TRIALS IN THE SOUTHWEST: WHAT HAVE WE LEARNED?

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ABSTRACT

Over 20 site-years of nitrogen fertilizer management and cycling trials have been conducted in Lubbock Texas and Maricopa Arizona from 1998 to 2019. Furrow, overhead sprinkler (OSI), subsurface drip irrigation (SDI) were used. Soil profile nitrate (0-36 inches in Texas and 0-72 inches in Arizona) was sampled and tested for in all trials. Nitrogen-15 labeled fertilizer was used for two years in Texas and for two years in Arizona. Canopy reflectance was measured with active optical sensors in every trial throughout the season. A pre-plant soil NO_3 test (0-24 inches in Texas, 0-36 inches in Arizona)-based N recommendation algorithm was successfully developed. A complementary approach of guiding in-season N applications with a vegetation index relative to a well-fertilized soil test-based plot saved N without hurting yields in both sites. The old 1984 recommendations for petiole NO_3 deficiency levels were lowered by 1000 ppm in Arizona after analyzing eight recent site-years of data. New lessons were learned on the fate of fertilizer N in irrigated cotton in Texas and Arizona. Nitrate leaching can be significant in furrow irrigation but is negligible in OSI and SDI. Recovery efficiency by cotton was about 20, 40, and 90 % of applied/fertigated N fertilizer for furrow, OSI, and SDI respectively. Internal N use efficiency for all yield levels, irrigation modes, and both sites was a remarkably consistent 40 lb N per bale. Net N mineralization was estimated by N uptake in zero-N plots minus credits for soil NO_3. Mineralization varied greatly, but was lowest with SDI where the wetting zone is small, and greatest with OSI where it was often as high as 50 lb N/ac. Testing irrigation water for NO_3 concentrations is an important N credit. Winter cover cropping with a small grain and strip- or zero-till cotton was tested extensively and is encouraged. This information all feeds into the pre-plant soil NO_3 test-based N recommendation which also requires a yield goal. Nitrous oxide (greenhouse gas 300 x more potent than CO_2) emissions were about 1 % of added N in furrow and OSI, but the N_2O emission factor was near zero with SDI and fertigation.

BACKGROUND

Following water, N is the largest constraint to cotton production in the western USA (Morrow and Krieg, 1990). Improving the N recommendations for irrigated cotton in both regions is a very critical task. In Arizona means basin, flood, and furrow irrigation are still the pre-dominant irrigation methods. Nitrogen fertilizer recovery, however, is usually less than 50 % in furrow-irrigated cotton in the West (Navarro et al. 1997; Booker et al., 2007). Current N management research and recommendations in the Western US are lacking for irrigated cotton, especially for newer cotton cultivars, and under conservation tillage. In the Western US, bi-weekly petiole NO_3 sampling and analysis is still a common approach to monitor in-season cotton plant N status. Petiole sampling is laborious and turn-around is several days. Canopy reflectance, on the other hand is a rapid newer technology to assess in-season cotton N status (Chua et al., 2003; Bronson et al, 2003).

W TEXAS 1998-2010

The 0-24-inch pre-plant soil profile NO_3 test was studied and tested at length in W. Texas during this period with a 2.5 bale/ac yield goal. The simple N fertilizer recommendation algorithm entailed:

N fertilizer (lb N/ac) = Lint yield goal (bale/ac)*50 lb N/bale – 0-24-inch soil NO_3 (lb N/ac) – inches estimated irrigation (inches)*ppm NO_3-N irrigation water*0.23.

In 2007-2009 (Bronson et al. 2011), 1.5* soil test N rates were also employed. In nearly all N fertilizer management trials in W. Texas a canopy reflectance-based N management treatment was tested as well. In this approach N rates were initially set at 50 % of the soil test treatment. Weekly canopy reflectance measurements were made with active optical sensors at 1 m above the plants in the soil test plots (passive sensor used in Chua et al., 2003). If the vegetation index calculated from the reflectance data in the reflectance plot was significantly less than that of the soil test plot, then the N rate in the reflectance plot was increased to match that of the soil test plot. This is a “save N without hurting yield” approach. This approach was successful in Lubbock in 2000 and 2001 with surface drip and SDI (Chua et al, 2003), 2005 and 2005 with SDI (Yabaji et al. 2009), and from 2007-2009 (Bronson et al. 2011) under SDI.

ARIZONA 2010-2018

In Arizona the N recommendation algorithm was modified slightly to use a 0-36-inch pre-plant soil NO_3 test and a 4.0 bale/ac yield goal. This is because of greater water inputs (nearly all irrigation), a longer growing season and greater yields that characterize the low desert Arizona cotton production compared to the high elevation, deficit irrigation (declining Ogallala aquifer irrigation water source) West Texas. The soil test NO_3 approach was successful with furrow irrigation in 2012 and 2013, with OSI in 2014 and 2015 (We also included a 1.3*soil test N rate, Bronson et al., 2017), and with SDI from 2016-2019 (Bronson et al., 2019). There was a small lint yield (94 lb/ac) reduction with the reduced N rates of reflectance management in 2015 and a seed yield (but not lint) in 2018.

Eight site-years of petiole NO_3 data taken from first square to peak bloom was evaluated from Maricopa and Safford, under OSI and SDI in Maricopa and furrow irrigation in Safford (Bronson et al., (2021). Results indicate that the deficiency levels based on Pennington and Tucker (1984) can be reduced 1000 ppm without hurting yields. Surprisingly petiole NO_3 in SDI cotton was very low most of the season (Bronson et al. 2020). It is possible that since water and N use efficiency is so high in SDI, the NO_3 reductase enzyme may be operating at a very rapid level, so that petiole NO_3 rarely builds up.

SITES IN BOTH STATES

Figure 1 A shows the lint yield response to N fertilizer rate on the 800 plots across both sites. Nitrogen response, N rates and lint yields were greater in the long-growing Arizona than W. Texas. In Arizona it appeared that the soil test N recommendations were over-predictions of the optimal N application rates. This is probably because the algorithm neglected to account for the contribution of net N mineralization from each plot. Recovery efficiency or the percentage of added N recovered by the cotton plants at first open boll generally increased from furrow to overhead sprinkler to subsurface drip irrigation. Recovery efficiency in Arizona was greater than in W. Texas. Leaching of NO_3 was probably the main N loss pathway with furrow irrigation. Recovery efficiency was > 90 % with subsurface drip irrigation in Arizona and emissions of the potent greenhouse gas N_2O were very low. Emission factors, or percent of added N emitted as N_2O were greatest in sprinkler irrigation in Arizona at about 1 % (Bronson et al. 2018) and similar to other crops like corn (Halvorson et al., 2014).

Recovery efficiency in Lubbock and Maricopa in ^{15}N studies showed similar recovery to the difference methods in SDI in Maricopa where there were 24 fertigation events (Bronson et al., 2019). In Lubbock, with three N applications, recovery efficiency by difference tended to be greater than with ^{15}N-labeled urea (Chua et al, 2003), giving more opportunity for immobilization of N in the organic matter.

Figure 1 B shows total N uptake vs. lint yield for both sites. A linear-plateau regression of has an R^2 of 0.60. The joint point of the linear-plateau regression is at 135 lb N ac^{-1} total N uptake. The 95 % confidence limits for the joint point was 130 and 140 lb N ac^{-1}. The plateau lint yield is 1623 lb ac^{-1} (Fig. 1 B). Dividing 1623 by 135 gives an optimal internal N used efficiency of 12.0 lb lint lb N $uptake^{-1}$. Using the 95 % confidence limits of the joint point we calculate an optimal internal N use efficiency range of 11.6 – 12.5 lb lint lb N $uptake^{-1}$. This very close to the 12.5 kg lint kg N $uptake^{-1}$ reported by Rochester for cotton in Australia (2011). Considering that a bale of cotton is 480 lb, the linear-plateau model estimated that the optimal N internal N use efficiency is 40 ± 1 lb N in the plant /bale for both regions. Internal N use efficiencies of 50 lb N/bale or more clearly represent luxury N uptake. This updated information can feed into the soil test NO_3-based N recommendations for cotton. Given that recovery efficiencies of added N fertilizer in cotton is < 100 %, we suggest retaining the 50 lb N/bale agronomic efficiency (product of recovery and internal N use efficiency) in the N recommendations detailed above.

KNOWLEDGE GAPS GOING FORWARD

Reliable methods to predict N mineralization are a most important research gap. Work is also need in Arizona (currently underway in Texas) on improving soil health, infiltration and soil organic matter with conservation tillage-cum-winter small grain cover cropping. Nearly all the described N management research in both states was with conservation tillage-cum-cover cropping, but it was not long-term and it did not compare conventional tillage. The canopy reflectance research described here used tractor-mounted sensors and so there is a need for drone-based remote sensing for cotton N management in both W. Texas and in Arizona. More research is needed for SDI cotton on petiole NO_3.

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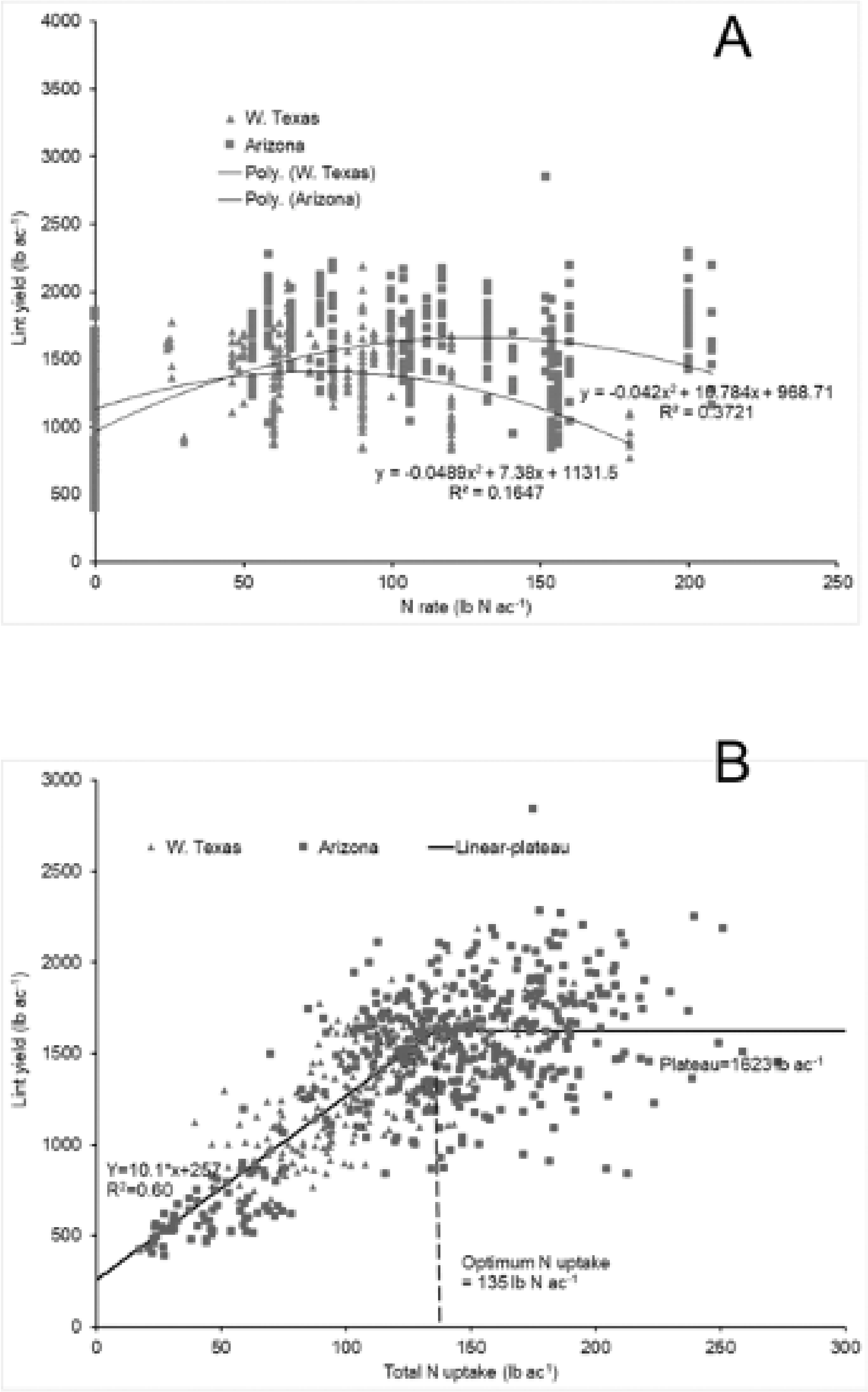
Figure 1. 2000-2018, W. Texas and Arizona cotton N studies. A. Lint yields vs. N fertilizer rate, B. Lint yields vs. total N uptake.



RESIDUE DECOMPOSITION OF SURFACE AND INCORPORATED BARLEY, CORN, AND WHEAT AT VARYING FERTILIZER-N RATES

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Cereal crops are commonly grown in southern Idaho and most parts of the western United States. These cereal crops are routinely harvested for their grain with the remaining plant material (chaff, stems, leaves, etc.) left in the field to decompose prior to planting of following spring crops. Understanding the effects of post-harvest residue management on barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), and wheat (*Triticum aestivum* L.) residue is important for optimizing agronomic and economic performance and minimizing negative environmental impacts in cropping systems. Research studies were conducted from Fall of 2018 to Fall of 2020 at the University of Idaho, Aberdeen Research and Extension Center, Aberdeen, ID. Research was focused on cultivar or crop type (Voyager (malt barley), Transit (food barley), Mycogen 2v489a (field corn) Alturas (soft white wheat), and WestBred (WB) 9668 (hard red wheat), residue management (surface and incorporated residue), and fertilizer-N rates (0, 50 and 100 lb N/ac). Cereal residues were applied in the Fall of 2018 and 2019 at a rate of 9000 kg/ha in non-reactive mesh bags in a randomized complete block design. Residue bags were collected, washed and dried, and re-weighed in Spring 2019 and 2020. Samples were then analyzed for total carbon (C) on an elemental analyzer. Results from the study indicated that incorporated cereal residue generally resulted in increased breakdown compared to surface applied cereal residue, corn residue broke down faster than barley and/or wheat residue, and fertilizer-N application had no effect on cereal residue decomposition amounts and carbon losses from the Fall to the Spring. The results of the current study indicate effective (incorporation) and non-effective (N fertilizer additions) methods to increase the rate of breakdown of cereal residue in irrigated production in the region from the time of harvest to planting in the Spring.

INTRODUCTION

Cereal crops (barley, corn, and wheat) rotated each season after harvest leave behind residue in the field which can tie up nitrogen (N) for the subsequent crop. Management of residue for cereal crops in Idaho currently recommends 15 lb N/ac for every ton of straw up to 50 lb N/ac as per the University of Idaho Extension recommendation despite known variations in the C:N ratio among crop residues. The objective of the study was to utilize residual cereal crop biomass to assess variation of in-field residue decomposition as affected by N fertilizer rates and residue placement (surface vs. incorporated) between fall and springtime.

METHODS

This study was conducted during 2018 to 2019 and 2019 to 2020 from October to March. The field study was located at the University of Idaho Research Extension Center, Aberdeen, ID on a sandy-loam soil. Soil samples were taken from the field at the initiation of the study in 2018 and 2019 to record initial nutrients as shown in (Table 1). Samples were from the 0- to 6-, 6- to 12-, and 12- to 24-in depths for soil pH, soil organic matter (SOM), and inorganic N (Miller et al., 2013). Residue was grown, collected, and dried for Voyager (malt barley (MB)), Transit (food barley (FB)), Mycogen 2v489a (field corn (FC)), Alturas (soft white wheat (SWW)), and WB 9668 (hard red wheat (HRW)) for use in the study (Table 2). Tissue composition of the barley, corn, and wheat was determined prior to field application (Table 4.2). Residues were put into non-reactive nylon mesh bags to represent 8000 lb/ac of residue being left on the field. The study design included residue placement (incorporated vs. surface), 3 different rates of ammonium sulfate $(NH_4)_2SO_4$ fertilizer (0, 50, and 100 lb N/ac), and 1 extraction period (spring) for a total of 120 plots. The study was a factorial of cultivar/crop, fertilizer rate, and residue placement arranged in a RCB.

Table 1. Initial soil fertility status of field study conducted during the 2018-2019 fall-spring season at the Aberdeen Research and Extension Center, Aberdeen, ID.

Depth (in)	Soil pH	OM (%)	NH_4-N	NO_3-N
2018			---------------mg/kg-----------	
0-6	8.3	1.1	BDL	3.6
6-12	8.3	0.9	BDL	3.2
12-24	8.6	1.1	BDL	3.2
2019				
0-6	7.9	1.1	BDL	3.6
6-12	8.5	0.9	BDL	3.2
12-24	8.4	1.1	BDL	3.2

† Below detection limit (BDL) values were <1.25 mg/kg

Application and Extraction of Residue Samples in the Field

Incorporated trials were buried at approximately 6 in within the soil representing a disc tillage in the field. Surface trials were held in place by using metal landscape pins to avoid being blown away or moved. Collection of samples were taken in the 1st week of spring between March 18th and March 21st for both years. Samples were extracted from the field washed and hang dried for 24 hours and oven dried at 140 °F to a constant weight. Dried samples were then weighed, and the weight from the initiation of the study was subtracted from the final collected weight to record any loss of residue. Following sample weight determination, samples were ground using a Wiley mill grinder (Thomas Scientific, Swedesboro, NJ, USA). Tissue was then analyzed using high temperature via a VarioMax CN analyzer (Elementar Americas, Inc. Mt Laurel, NJ) to determine the amount of C and N in the samples.

Statistical Analyses

Statistical analyses were performed using the Proc MIXED procedure of SAS (SAS Institute, 2011) where cultivar, residue placement, and fertilizer N rate were fixed effects and year and block were treated as random effects.

RESULTS AND DISCUSSION

Initial C:N ratios used within the study were 70:1 for barley, 67:1 for corn, and 96:1 for wheat on average (Table 2). Cultivar X Application Method was the highest-level interaction for both weight and carbon loss where N rate interactions and its main effect were not significant. Measurements of percent weight loss in general were greater from incorporated treatments, however Mycogen (surface) was comparable to both Alturas and WB9668 (incorporated) (Fig. 4.3). Mycogen (incorporated) measured the greatest weight loss at 37% which was followed by Voyager at 30%. Mycogen (incorporated) and Voyager (incorporated) differed in weight loss and were greater in residue weight loss compared to all other incorporated treatments (Fig. 1). Comparable measurements of incorporated treatments were seen between incorporated Alturas, Transit, and WB9668. In contrast, Mycogen surface differed to all other surface residue treatments but comparable weight loss of surface residue treatments was measured between surface applied Alturas, Transit, Voyager, and WB9668.

Table 2. **Initial mean chemical composition of barley, corn, and wheat used in 2018 and 2019.**

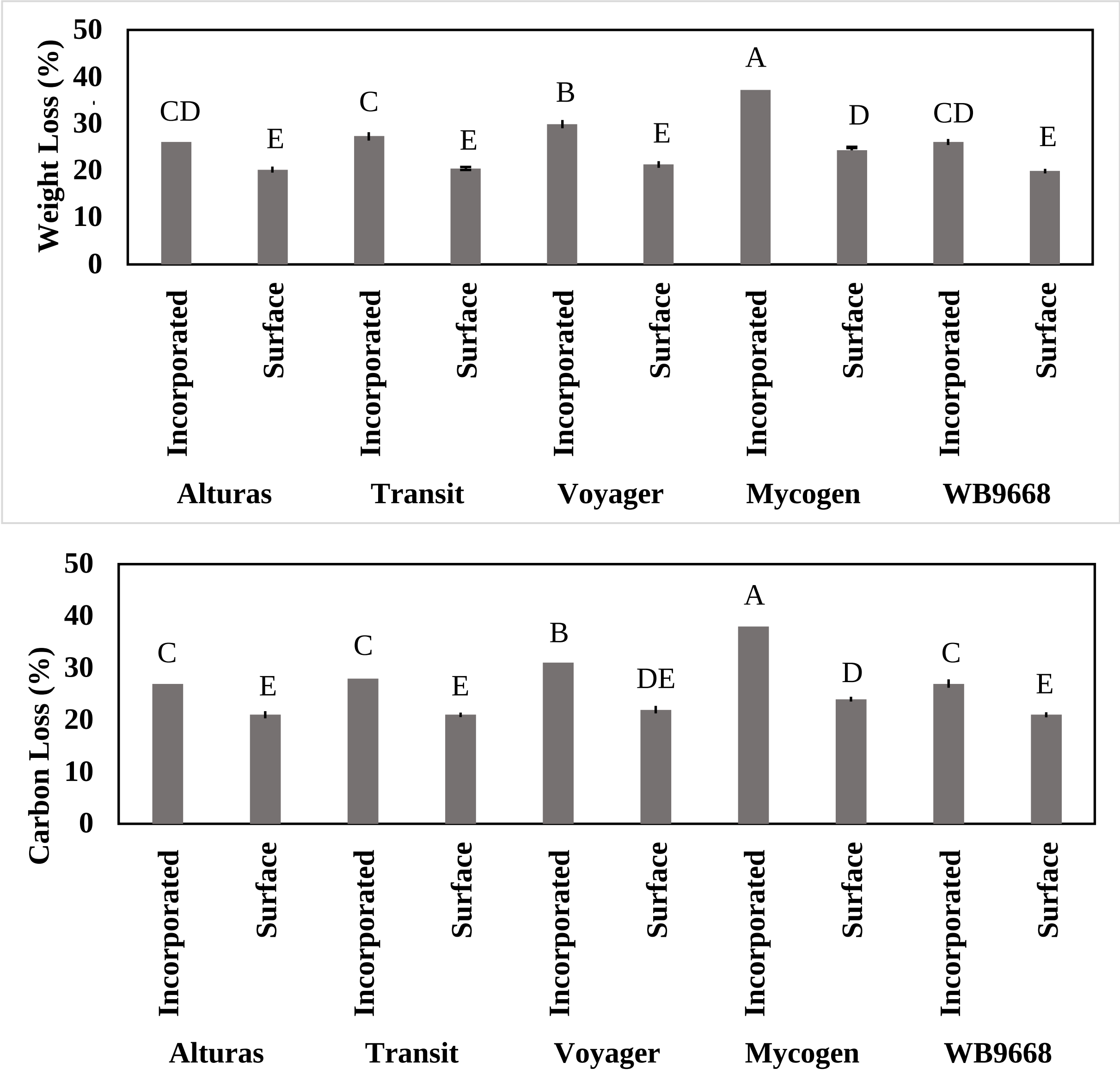
Crop	Cultivar	C/N
Barley	Transit	69
Barley	Voyager	71
Corn	Mycogen	67
Wheat	WB9668	90
Wheat	Alturas	103

Carbon Loss

Carbon loss only differed based on cultivar by application and interactions between N rates were not significant. All incorporated residue treatments showed greater carbon loss than all surface applied treatments within the field study (Fig. 4). Effects from incorporated Voyager and Mycogen measured the highest carbon loss compared to all others where incorporated treatments with Mycogen showed the greatest carbon loss at 38 percent. Comparable measurements of carbon loss were seen between incorporated residue of Alturas, Transit, and WB9668. In contrast, the greatest carbon loss measured for surface applied treatments was Mycogen at 24 percent followed by Voyager at 22 percent carbon loss. All surface treatments of the field study measured comparable carbon losses, but in this case Mycogen surface differed from all other surface applied residue. Variation in the surface v. incorporated environment and the C:N ratios of the crops as well as changes in microbial communities responsible for decomposition likely impacted the rates of breakdown.

The findings from this study showed greater carbon and weight loss in all incorporated treatments compared to surface applied residue and the general pattern of corn > barley > wheat in terms of residue decomposition. Effects from N applications were not significant. To increase carbon decomposition between fall and spring, it would be recommended to incorporate residue into the soil. Nitrogen applications to increase carbon or weight loss would not be recommended due to the non-significant effects shown within the study.

Figure 1. Residue weight loss and carbon loss of barley, corn, and wheat that was incorporated or left on the surface averaged across three N application rates for research conducted at the Aberdeen Research and Extension Center, Aberdeen, ID from 2018 to 2020.



[†] Different letters for each parameter indicate significant differences between cultivars and application methods.

THE FERTILIZER RECOMMENDATION SUPPORT TOOL (FRST) INITIATIVE: NATIONAL SURVEY ON SOIL FERTILITY RECOMMENDATIONS AND CORRELATION/CALIBRATION DATABASE

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ABSTRACT

Soil fertility testing is an integral tool used in nutrient management planning, providing information needed to determine where fertilizers are required and how much to apply. Historically, most soil test correlation and calibration efforts have been led by land-grant universities and recommendations have been developed on a state-by-state or lab-by-lab basis, resulting in limited interstate or regional coordination. Further, not all states have maintained up-to-date correlation and calibration studies, the foundation of fertility assessments and recommendations. The Fertilizer Recommendation Support Tool (FRST) project aims to advance the accuracy of soil-test- and science-based fertilizer recommendations. This presentation will cover two important components of the FRST initiative: a national survey of land-grant university soil fertility recommendations and the FRST database with P and K correlation and calibration studies. The purpose of the survey, conducted in early 2020, was to gain a better understanding of the current status of soil testing across the U.S. to direct collaborative efforts among states and regions, and to identify opportunities to harmonize recommendation guidelines. The support tool will use the FRST database, which contains current and historical data, with trial years ranging from the 1940's to the 2010's. The FRST database is currently populated with over 1,200 P and K response trials for a variety of cropping systems across the U.S. and will continue to grow.

INTRODUCTION

Fertilizer nutrient recommendations for crops have been developed on a state-by-state basis in the U.S. since the mid 1900's, and continue to be developed and maintained by land grant universities whose scope of inference is defined by state borders. Because soil testing was developed based on political boundaries rather than physiographic regions, soil properties, climatic zones, or cropping systems, inconsistencies exist among states in soil collection and research practices, laboratory methods, terminology, and thus fertilizer recommendations. In addition, much of the foundational research conducted was completed over 30 years ago, with agronomic practices and crop varieties no longer used today. The last national survey to summarize soil fertility recommendations and soil testing was conducted in 1994 by Voss (1998), who reported that only 30% of states based their recommendations on research conducted after 1980, and 25% of states reported not knowing the age of the research undperpinning their recommendations.

In 2018, the FRST effort was initiated with the goal of advancing the accuracy of soil-test-based fertilizer recommendations by establishing a foundational database and an associated decision support tool from which recommendations can be scientifically developed and defended as best management practices (Lyons et al., 2020). FRST is a collaborative and inclusive effort, and is made up of over 80 collaborators from more than 40 institutions. To achieve this, the FRST team: i) created a survey on current practices and recommendations in soil fertility; ii) is defining a minimum dataset requirement for future correlation and calibration trials; iii) is building a database to curate correlation and calibration data; and iv) will develop a user-friendly, searchable decision support tool. Inspired by Australia's Better Fertilizer Decisions for Cropping Systems (BFDC) initiative (Speirs et al., 2013), the decision tool will provide soil test calibration graphs with statistical confidence intervals for the area of interest, and the database will provide data to nutrient management scientists and modelers for in-depth analysis of soil test correlation and calibration.

The objectives of the state fertilizer recommendation survey are to gain a better understanding of the current status of soil testing across the U.S. to direct collaborative efforts among states and regions, and to identify where opportunities exist to harmonize recommendation guidelines. The objectives of the FRST database are to collect, curate, and preserve legacy correlation and calibration trial data as well as current and future data to be used by the decision tool and the soil fertility research community. Here, we discuss selected results from the survey and provide an overview of the database.

METHODS

Survey

A national survey was developed that covers land-grant university and state Department of Agriculture soil-test methods and nutrient recommendations, fertilization philosophies, and the provenance of the correlation and calibration data used to support recommendations. The survey included over 80 questions about fertilizer-P and -K recommendations, laboratory methods, soil health considerations, and sampling protocols. The web-based survey instrument was built using Qualtrics (Provo, UT), and was distributed to nutrient management experts at land grant institutions and state departments of agriculture across the U.S in February 2020.

Database

The FRST database was created in 2019 and includes correlation and calibration data collected from peer-reviewed journal articles, theses and dissertations, extension bulletins, conference proceedings, and unpublished datasets provided by FRST collaborators. The minimum criteria for legacy data includes the trial year, trial location (state), soil test P or K values before fertilization, soil test method and sample depth, replicated fertilizer P or K treatment rates, and crop yield response values. The legacy data criteria are much more inclusive and less strict than the minimum dataset requirements being developed for future research. The database was initially built using Microsoft Excel, and is evolving to a more sophisticated and interactive online database hosted by the USDA-ARS Agricultural Collaborative Research Outcomes System (AgCROS) and cataloged in the USDA National Agricultural Library. Moreover, we will build the database, which currently contains only U.S. P and K data, to have future expandability to include other nutrients, cropping systems, and geographical regions.

RESULTS AND DISCUSSION

Survey

By June 2020, over 60 individuals representing 48 states plus Puerto Rico completed the survey — the only two states with no responses were Alaska and Nevada. Respondents included research and Extension faculty as well as soil testing laboratory directors and staff.

A primary goal of this work was to gain a better understanding of resources and capacity available to investigate soil test correlation and calibration among states. The average response to questions about the number of faculty full-time-equivalents (FTE) currently involved in soil test correlation and calibration research and in updating (or validating) recommendations was 1.2 FTEs state^{-1}. This is a significant decline from a high of about 3.5 FTEs state^{-1} in the 1950's and 1960's and is consistent with the steady decline in average FTEs state^{-1} reported by Voss through the 1990s (1998) (Fig. 1).

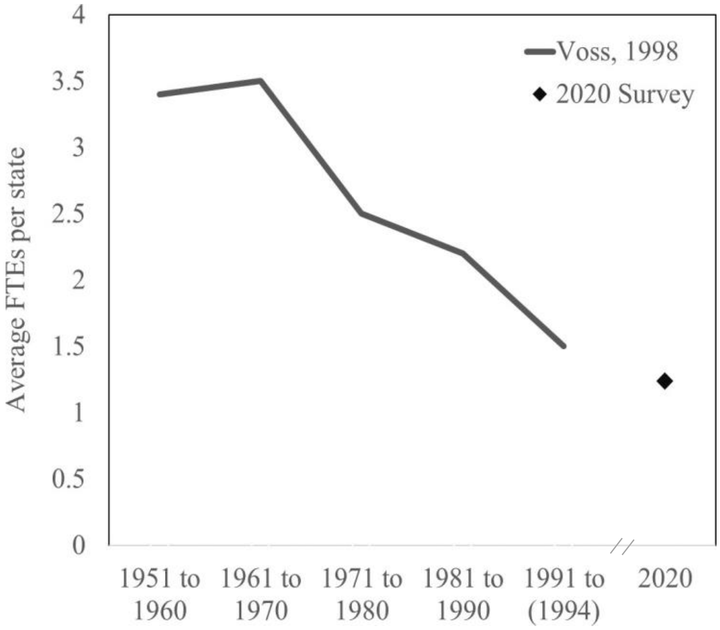

Figure 1. Average number of faculty FTEs per state involved in soil test correlation and calibration research. Observations from 1951 through 1994 were reported by Voss (1998).

Respondents were also asked to provide information about the origins of the state's soil test P and K correlation used to interpret results and make recommendations for major crops. These results are summarized in Fig. 2 for grain corn. Only 12% of states responding indicated that their soil test P correlation for corn has been updated or validated in the last decade, and only 14% had updated or validated their soil test K correlation. Almost 80% of states responding are currently using soil test P correlations that are either over 20 years old, or their origins are unknown. Similar reports were made for the age and origins of soil test K correlations. Especially concerning is that about one-third of states reported that the provenance of their soil test P and K correlation was unknown.

The survey also requested information about recommended soil test methods and interpretation of results. Recommended methods generally aligned with regional differences in climate and soil properties. For example, Table 1 summarizes recommended soil test P methods. The Morgan methods are used by New York and most of the New England states. Mehlich 1 is used by a few Southern states while the Mehlich 3 is the predominant method used by states in the mid-Atlantic and Southern regions. The Bray-1 is recommended by several states in the North Central region and Olsen is the predominant method recommended in the Western region.

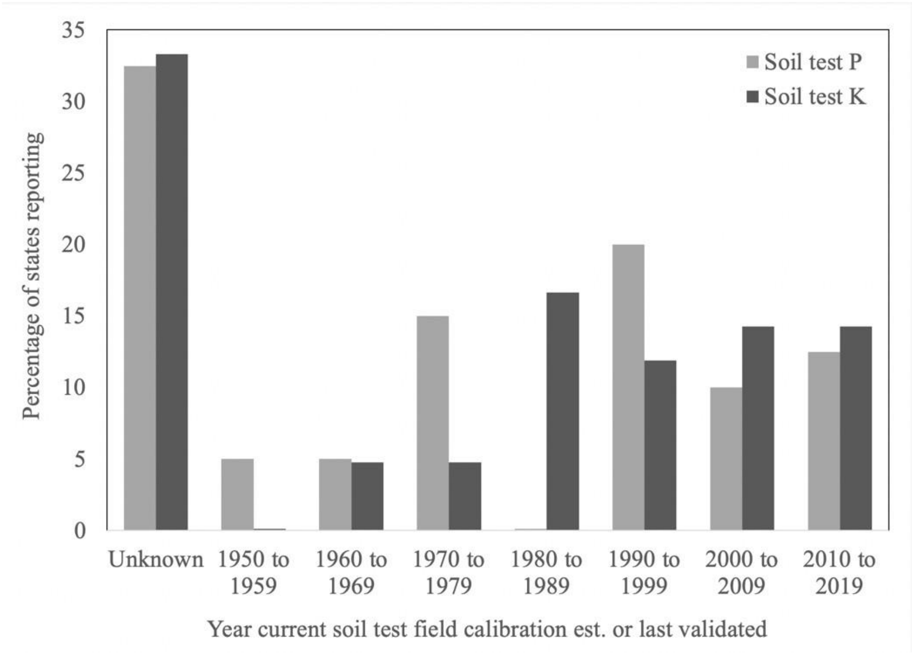

Figure 2. The year the soil test P and K field correlation for grain corn was established or last validated. Results expressed as a percentage of forty states responding.

It is widely recognized that soil test interpretation varies among states, both within and among regions, even when the same soil test methods are used. For example, the critical Olsen P level (the soil test level that includes the point of no yield benefit from fertilization), or range, for field corn used by several Western states is summarized in Table 2. The lowest critical range was reported for California, 6 to 12 mg P kg^{-1}, and the highest was reported by New Mexico, 25 to 30 mg P kg^{-1}. Similar variability was observed within other regions for other soil test P (and K) methods (data not shown). Differences in climate, edaphic factors (e.g., buffering capacity), and cropping systems among and within regions are expected to influence the correlation between soil test level and response to fertilizer nutrients. However, these variables are not generally associated with political boundaries.

Soil Test P Method	States
North Central Region	
Bray 1	IL, MI, MO, WI
Bray 1, Olsen	MN, NE, SD
Mehlich 3	IN, IA, KS, OH
Olsen	ID, ND
Northeast Region	
Mehlich 3	DE, MD, NH, NJ, PA, WV
Modified Morgan	CT, ME, MA, RI, VT
Morgan	NY
Southern Region	
Lancaster	MS
Lancaster, Mehlich 1	AL
Mehlich 1	GA, SC, TN, VA
Mehlich 3	AR, FL, KY, LA, NC, OK, TX
Western Region	
Bray 1, Olsen	OR, WA
Olsen	AZ, CA, CO, MT, NV, NM, UT, WY
Truog	HI

Table 1. Soil test P methods used in each state. Several states specified methods based on regions within the state (or selected soil conditions). In those cases, both methods are listed. Some states have correlation and calibration for multiple methods. In those cases, only the preferred or primary method is listed. Both Iowa and Kansas recommend determining P in the Mehlich 3 extraction using a colorimetric procedure.

Table 2. Critical Olsen P concentration or range and minimum soil test P concentration where no fertilizer P is recommended for field corn used by several Western states to make nutrient recommendations.

State	Critical soil test concentration or range†	Minimum soil test concentration where no fertilizer P is recommended
	----------Olsen P, $mg\ kg^{-1}$----------	
California	6 to 12	
Colorado	7 to 14	
Wyoming	15 to 22	23
North Dakota	15	25
Oregon	15	15
Utah	15	15
Montana	16	24
South Dakota	16	16
Idaho	20	25
New Mexico	25 to 30	31

†Critical soil test range defined as the soil test level that includes the point of no yield benefit from fertilization.

Soil test critical values or ranges used to determine land grant university nutrient recommendations have primarily been defined using unique datasets, many of which are several decades old, and are exclusive to sites within state boundaries. This approach limits the scope of inference, and results in arbitrary boundaries associated with state lines. This is one of the core issues that FRST will address through access to a wider range of newer, more complete datasets. The FRST decision support tool will allow the database to be queried and selected data analyzed to determine soil-test critical nutrient concentration to be determined for specific regions (independent of political boundaries), crops and soil-test methods.

Database

The FRST database currently has over 1200 trials that represent 34 states, 11 crops, and a variety of soil test P and K methods (Table 3). While many states and cropping systems are already represented, there are over 100 articles, dissertations, and bulletins currently on file to be entered. The more than 80 FRST collaborators who are currently on the project have been essential in obtaining relevant data for the database, as they have provided theses, dissertations, station bulletins, fact sheets and other historical documentation.

Due to the nature of field trials and the inconsistencies in correlation and calibration research across the country and over time, building the FRST database comes with challenges. Because we are accepting data in any format (journal articles, extension documents, etc.), there is often a drastic difference in the level of detail provided. Particularly for the older publications, research reports often lack important information such as year, location, laboratory methods, or even units. And while we can contact corresponding authors of more recent publications to request further details, authors are harder or impossible to contact for older reports. Another challenge rests with the technical aspects of the database. As the FRST project grows and evolves, changes to the database are often necessary. Adding, removing, or changing database fields is a tedious process that risks integrity of previously stored data. Hand-entering data has been necessary in the current database format; however, we plan to develop an online data entry form where FRST team members, as well as researchers, can submit data to be appended to the FRST database.

Table 3. Summary of correlation and calibration data currently in the FRST database.

Trials	1227	Years	1949-2018
Crops	Corn, soybean, wheat, cotton, rice, cool-season grasses, sugarcane, alfalfa, sorghum, sweet potato, pea	States	AL, AR, CO, CT, DE, FL, GA, IA, KS, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, OH, PA, RI, SC, TN, TX, VA, VT, WA, WI, WV
P Methods	Mehlich-1 & -3, Bray-1 & -2, Olsen, Morgan, Modified Morgan, Lancaster, acetic acid, Resin, Pi, water, double acid, total P, Oxalate, ammonium acetate, Haney, Truog, sodium acetate	K Methods	Mehlich-1 & -3, ammonium acetate, nitric acid, saturation, rate of release, MS Soil Test, Olsen, Morgan, Modified Morgan, Resin, Tetraphenylboron

SUMMARY AND CONCLUSIONS

The FRST project aims to support scientifically based and data-driven fertilizer recommendations across the U.S. The FRST team administered a national survey that clarified current soil fertility management practices, laboratory analysis methods, and nutrient recommendations. In addition, we developed a soil test correlation and calibration database that will support an online, interactive decision support tool. Both the survey and legacy database have shown that more consistent and up-to-date research is needed for efficient and functional soil fertility recommendation systems in the U.S.

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SOIL TESTING: SATURATED PASTE INTERPRETATION

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ABSTRACT

Soils with neutral to alkaline pH of the Western United States often contain elevated levels of soluble salts and/or higher concentrations of sodium associated with native salts or irrigation water. Elevated concentrations of soluble salts limit crop growth and sodium may impact water management. Soil analysis based on the saturated paste extraction (SPE) method provides insight on soil texture, soluble salt content, cation/anion constituents, and information on soil hazards, such as salinity, and B toxicity which reduce plant growth and yield. Interpretation of lab analysis is essential to developing an effective management strategy. This presentation will provide an overview on soluble salts, electrical conductivity (EC_e), cation and anion constituents, sodicity, boron toxicity, and management interpretation. Laboratory example reports will be discussed for evaluating soluble salt constituent analyses and management.

INTRODUCTION

The soil saturated paste extraction (SPE) method is the preeminent method for the assessment of salinity in arid or semi-arid agricultural soils of the western U.S. Soils of this region are largely dependent on irrigation water supplied from surface water associated with rivers and lakes or pumped from underground aquifers. The irrigation water quality is specific to the geology of the source water and vary in both the total soluble salt content and the chemical constituents which impacts soil soluble salts. Calcium (C^{2+}), magnesium (Mg^{2+}), and sodium (Na^{1+}) comprise the dominant alkali cations in in the soil SPE, whereas chloride (Cl^{1-}), sulfate (SO_4^{2-}), nitrate (NO_3^{1-}), and bicarbonate (HCO_3^{1-}) comprise the dominant anions. The soil SPE may also contain dissolved carbonate (CO_3^{2-}) and boron (B) in lower concentrations dependent on pH and source geology. Additional trace elements may also be present but at concentrations of no relevance to agricultural production. This paper provides guidelines for the interpretation of soil SPE salinity and chemical constituents in the Western United States. These guidelines are based on the university extension guides and 215 soil samples collected across North America by the Agricultural Laboratory Proficiency (ALP) program.

DISCUSSION

With the application of irrigation water to soils, subsequent evapotranspiration leads to the accumulation of soluble salts in the soil root zone. High concentrations of salts of the alkali metals are detrimental to plant growth and productivity. The SPE method is frequently used by soil testing laboratories and agronomists to assess soil salinity, salt constituents, and their impact on soils. The method quantitatively determines the concentration of dissolved chemical ions in the soil solution that are not associated with soil minerals and organic matter. The SPE involves saturating soil with water whereby 100% of the total pore space is occupied by water, and no free water remains on the soil surface. Dissolved soil chemical ions are subsequently extracted and analyzed for elemental chemical constituents. The SPE is considered to be the best indicator of plant response to salinity compared with other ratio extractions (US Salinity Laboratory Staff

1954; Rhoades et al. 1989). The SPE provides relevant information on qualitative assessment of soil texture, soil pH, dissolved salts, salt chemical constituents, potential management information on salinity, sodicity, and/or B toxicity. Generally coarse textured soils (i.e. sands and sandy loams) have low saturation percentages, whereas fine textured soils (i.e. clay loams) containing greater clay content have greater total pore space and higher percentages (Table 1). At saturation, soil pH can be evaluated to assess relative alkalinity or acidity of a soil. Salinity is evaluated based on the electrical conductivity as well as the chemical composition of the soluble salts. From analysis of the salt constituents, the soil sodicity can be evaluated based on the SPE sodium absorption ratio (SAR) along with potential hazards such as supra-optimal B.

Table 1. Saturated paste moisture content and approximate soil texture range.

SPE (%)	Soil texture
< 20	Sand or loamy sand
20 – 35	Sandy loam
35 – 50	Loam or silt loam
50 – 65	Clay loam
65 – 135	Clay
> 80	Organic soils > 15% soil organic matter

US Salinity Laboratory Staff, 1954.

pH

pH of the SPE represents the relative acidity or alkalinity of soil. Soils with pH< 5.5 are strongly acid, whereas those with pH between 5.5-6.5 are mildly acid. Soils with pH between 6.5-7.5 are neutral, 7.5 – 8.5 are alkaline, and >8.5 are strongly alkaline. Soil pH impacts nutrient availability and may impact specific crop suitability.

Salinity

Soil salinity is evaluated based on electrical conductivity of the soluble salts dissolved in the SPE extract which is denoted as EC_e. Its units are expressed as either mmhos cm^{-1} or dSm^{-1}. EC_e increases proportionally to the amount of total dissolved salts. Soils low in salinity have $EC_e < 0.5$ dSm^{-1}, whereas soils with high amounts of total dissolved salts may have $EC_e > 3.0$ dSm^{-1}. Table 2 list general crop salinity ranges based on EC_e and specific crop sensitivities. Management of soils with high EC_e will require removal of salts though irrigation leaching and/or selection of tolerant crops. Soil soluble salt content is dynamic, and it changes with rainfall, irrigation water quality, and crop growth.

Calcium (Ca^{2+})

Calcium generally represents the dominant cation present in soil SPE extracts. Generally, soils low in EC_e (< 0.5 dSm^{-1}) have Ca concentrations < 3.5 meq L^{-1}, whereas soils with EC_e between 0.5 - 1.0 dSm^{-1} have Ca concentrations between 1.0 – 8.0 meq L^{-1}. Soils with EC_e > 2.0 generally contain Ca concentrations > 12 meq L^{-1}, with the exception of soils dominated by Mg or Na soluble salts. Soil SPE extracts with > 60% cations as Ca generally have higher water infiltration rates than those dominated by Mg or Na.

Table 2. Impact of saturated paste soil salinity (EC_e) on plant growth.

EC_e dS m^{-1}	Plant salinity effects, productivity reduced 25%.
0 - 2	Salinity effects negligible (field bean, carrot, onion, red clover strawberry)
2 - 4	Very sensitive crops affected (spinach, lettuce, citrus, grape, alfalfa)
4 - 8	Moderately salt tolerant crops affected (tomato, beet, wheat)
8 - 16	Only salt tolerant crops yield satisfactory (barley, wheatgrass cotton, asparagus)
> 16	Few salt tolerant crops yield satisfactory

Hanson, et al. 1993.

Magnesium (Mg^{2+})

Magnesium generally represents the 2nd most dominant cation present in soil SPE extracts. Generally, soils low in EC_e (< 0.5 dSm^{-1}) have Mg concentrations < 2.0 meq L^{-1}, whereas soils with EC_e between 0.5 - 1.0 dSm^{-1} have Mg concentrations between 0.3 - 4.6 meq L^{-1}. Soils with EC_e > 2.0 generally contain Mg concentrations > 3.0 meq L^{-1}, with the exception of soils dominated by Na soluble salts. Soils which have SPE Ca:Mg ratios < 2:1 may have lower water infiltration rates, and ratios < 1:1 with EC_e < 1.0 will essentially have no water infiltration below the soil surface.

Sodium (Na^{1+})

Generally, Na represents the 3rd most dominant cation present in soil SPE extracts. In general, soils low in EC_e (< 0.5 dSm^{-1}) have Na concentrations < 1.0 meq L^{-1}, whereas soils with EC_e between 1.0 – 2.0 dSm^{-1} have Na concentrations between 0.2 – 1.0 meq L^{-1}, with the exception of soils with < 55% of the total cations as Ca. Soils with > 40 % of the SPE total cations as Na are likely to defloculate and have a poor water infiltration.

Sodicity and SAR

Sodicity or sodium hazard of a soil is represented by the sodium absorption ratio (SAR). It represents the ratio between Na and the sum of Ca and Mg based on the valance of the individual cations in the soil SPE, as represented by the formula $SAR = [Na] / (([Ca]+[Mg])/2)^{1/2}$, with units expressed as millequivalents per liter (meq L^{-1}). Generally, soils with Na constituting < 20% of the total SPE cations have an SAR < 2.0, however, soils containing naturally occurring Na salts or irrigated with water containing elevated Na concentrations will likely have an SAR > 4.0. Soils with an SAR > 13 are classified as sodic. Although alkaline soils may be referred to as saline or sodic, a high soil pH does not infer either description.

The effects of salinity and sodium are defined by five classes: (1) non saline, $EC_e < 2.0$ dSm^{-1}; (2) saline slightly, $EC_e > 2.0 - 4.0$ dSm^{-1}; and SAR < 13; (3) saline, $EC_e > 4.0$ dSm^{-1} < and SAR < 13; (4) saline-sodic, $EC_e > 4.0$ dSm^{-1} and SAR > 13; and (5) sodic soil, $EC_e < 4.0$ dSm^{-1} and SAR > 13. When saline-sodic soils leached with low EC water, they become sodic. Management of saline soils require irrigation to leach soluble salts while sodic soils requires amendment with gypsum.

Potassium (K^{1+})

Soil SPE K is generally low for soils with < 1.0 meq L^{-1} and containing < 300 mg kg^{-1} exchangeable K. Soils containing higher concentrations of exchangeable K or receiving high application rates of K fertilizers may contain 1.0 - 3.0 meq L^{-1} K and have an $EC_e > 2.0$. Soils with K concentrations < 0.2 meq L^{-1} may have potential crop K deficiencies.

Chloride (Cl) $^{1-}$

Soil SPE Cl concentrations vary greatly dependent on: (1) proximity to an ocean source, (2) Cl content of the irrigation water source, (3) past use of manure amendments, and (4) the amount and Cl content of the applied fertilizers. Across soils Cl generally constitutes 1-40% of the total anions present in the SPE, but Cl concentrations > 5.0 meq L^{-1} are frequently noted on soils with pH > 7.4. Crop tolerance to Cl in the soil SPE is shown in Table 3 and is generally not an issue for sensitive crops on soils with SPE Cl < 10 meq L^{-1}.

Table 3. Tolerance of some plants to chloride (Cl) in the soil saturated paste extract.

Crop	Chloride (meq l^{-1})
Alfalfa	23
Barley	90
Beets	90
Citrus (root stock dependent)	10 - 25
Corn (2-8 leaf stage)	70
Cotton	50
Grapes (Thompson seedless)	25
Tomato	39
Wheat	25

Western Fertilizer Handbook, 1985.

Sulfate (SO_4^{2-})

Soil SPE SO_4 concentrations vary dependent on: (1) gypsum content of soil parent material, (2) SO_4 content of the irrigation water source (3) past use of manure amendments, (4) and/or previous applications of gypsum or sulfur containing fertilizers. Across soils, SO_4 generally constitutes 1-25% of the total anions present in the SPE. Alkaline soils > 25% of anions as SO_4 have $EC_e > 2.0$ dSm^{-1} and SPE Ca concentration > 10 meq L^{-1}. Generally, high soil SPE SO_4 concentrations impact soil salinity and crop growth.

Nitrate (NO_3^{1-})

Soil SPE NO_3 concentrations vary dependent on: (1) previous crop residue, (2) NO_3 content of the irrigation water source, (3) past use of manure amendments, and (4) the amount and type of applied fertilizers. Generally, soils with NO_3^- concentration < 3.0 meq L^{-1} have EC_e < 0.5 dSm^{-1}, with the exception of soils containing > 1.0 meq L^{-1} SO_4. Generally, for soils where NO_3 constitutes > 80% of the total soil SPE anions, Ca accounts for > 50% of the total cations. Soil SPE NO_3 concentration is highly dynamic, changing with rainfall/irrigation and crop NO_3 uptake.

Bicarbonate (HCO_3^{1-})

Soil SPE HCO_3 may constitute 1- 80% of the total anions present in the SPE, with highest concentrations on soils with pH > 5.8. For soils where NO_3 constitutes > 80% of the total SPE anions, HCO_3 generally accounts for < 5%. Generally, a majority of soils with HCO_3^- concentration > 3.0 meq L^{-1} have a pH value > 7.0. Soil HCO_3 concentrations may increase during crop growth associated with root respiration and NO_3 uptake. Soils with SPE HCO_3 concentrations > 10.0 meq L^{-1} have shown to impact vegetable crop root growth (Wallace and Rhoades, 1960). Soils with high SPE HCO_3 concentrations decrease Ca solubility, Ca uptake, and results in precipitation of ferric iron hydroxide ($Fe(OH)_3$) on soil minerals (Inskeep and Bloom, 1984).

Boron (B)

Soil SPE B, measured as mg L^{-1} in the extract solution, is generally < 0.5 mg L^{-1}. Elevated B concentrations are associated with: (1) soil parent materials high in B, (2) irrigation well water containing elevated B content (> 1.0 m L^{-1}), and/or (3) past use of applied B fertilizers. Generally, potential elevated SPE B is associated with soil $EC_e > 2.0$ dSm^{-1}. Crop tolerance to B in the soil SPE is shown in Table 4 and is generally not an issue for sensitive crops on soils with SPE B < 0.7 mg L^{-1}. Agronomic management of soils with high SPE B is a challenge, and generally limited to B tolerant crops.

SPE Interpretation

Saturated paste extract data of four soils diverse in chemical properties from the ALP Program are listed in Table 5. Two of the soils were classified as sandy loam (i.e., ID 0906 and

ID 1307) and the last two as loam (i.e. ID 1405 and ID 1508). Soil ID 0906 and ID1307 had similar soil pH but different soil SPE salinity. , Soil ID 1307 had substantially higher concentrations of Ca and Mg cations and SO_4 and NO_3 anions, and classified as saline. Soil ID 0906 had a SPE Ca:Mg ratio of 1.4 whereas ID 1405 had a ratio of 0.6, which is < 1:1, and likely to have a lower water infiltration with loss of soluble salts. Soil ID 1508 had a moderately high EC_e (saline), which would impact vegetable crops and an elevated SAR, which may require an amendment with gypsum. Of the four soils IDs 1508 had elevated Cl and B which would limit specific citrus tree root stocks and B sensitive crops. Soil ID 1307 had elevated SPE NO_3, which constitutes 86% of the total anion content. Subsequently plant NO_3 uptake would result in a potential lowering of the EC_e. For soil ID 1508, three anions, Cl, NO_3, and SO_4 constituted 95% of the total anions and irrigation with low EC water would reduce salinity, resulting in leaching of SPE Ca and Mg, and potentially result in a SAR > 13, and a sodic soil.

Table 4. Tolerance of some plants to boron in the soil SPE paste extract.

B mg L^{-1}	Plant sensitivity
< 0.7	Safe for sensitive plants (peach, pear, plum)
0.7 – 1.5	Moderate tolerance (cotton, wheat, bell pepper)
1.5 – 4.0	Toxic to all but tolerant plants (alfalfa, lettuce, sugar beet)
> 4.0	Generally toxic to all plants

Hanson et al. 1993.

Table 5. Comparison of soil SPE constituents of four ALP soils, median values reported.

SPE Parameter	Soil ID 0906	Soil ID 1307	Soil ID 1405	Soil ID 1508
Sat Paste Moist. (%)	28.6	23.0	33.1	36.6
pH	5.7	5.9	6.8	7.7
EC_e (ds/m^{-1})	0.34	4.3	1.8	4.6
Ca (meq/L^{-1})	0.70	25.6	5.2	16.0
Mg (meq/L^{-1})	0.51	17.8	8.6	3.5
Na (meq/L^{-1})	0.15	0.61	4.1	27.9
SAR	0.62	0.14	1.5	9.0
HCO_3 (meq/L^{-1})	0.33	0.86	2.6	1.4
Cl (meq/L^{-1})	0.73	0.90	2.6	17.3
SO_4 (meq/L^{-1})	0.76	6.1	1.8	18.0
NO_3 (meq/Lm^{-1})	1.2	37.3	9.7	10.7
B mg L^{-1}	0.05	0.11	0.05	0.93

Overall, the SPE method provides qualitative information on soil texture, quantitative information on soil acidity/alkalinity, soil salinity, cation and anion constituents, and sodicity. It provides the basis for making sound agronomic management decisions for irrigated arid and semi-arid soils of the Western US.

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COMPARATIVE ANALYSIS OF SOIL TESTS FOR SOIL HEALTH AND NUTRIENT MANAGEMENT

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ABSTRACT

Options for soil tests to address soil health and nutrient management objectives have diversified. We compare different soil test methods to evaluate their similarities for providing recommendations. Traditional soil tests, ion exchange membranes and analyses using the Haney Soil Health Nutrient Tool and Soil Health Index were compared for soil sampled from long-term cropping system trials near Ritzville Washington and from the R.J. Cook Agronomy Farm near Pullman WA. Despite strong differences in surface soil organic matter between no-tillage (NT) and reduced tillage (RT), the Haney Soil Health Index was not appreciably different. Relationships between the H3A test and traditional soil test P were weak and tended to be influenced by tillage regime. Relationships between H3A and traditional soil test K were stronger but still tended to be influenced by tillage. Measures of labile soil carbon from incubation studies were strongly related to more easily measured analyses of permanganate oxidizable C (POXC) and water extractable organic carbon (WEOC). Both POXC and WEOC should be considered in addition to soil organic matter for soil health tests.

INTRODUCTION

Interest in soil testing to assess soil health and to explore alternative analyses on which to base fertilizer recommendations has been increasing. Examples include the Haney Soil Health Index, the Haney developed H3A extractant for macro- and micro-nutrients, various measures of more biologically active soil carbon, ion exchange membranes and the continued use of more traditional soil tests. Our objectives were to examine the utility of these various tests including a comparative analysis to examine relationships among new and more traditional soil tests.

METHODS

Soil samples (0-4 and 4-8 inches) were collected in the spring of 2017 at 60 geo-referenced points at the Cook Agronomy Farm (CAF) near Pullman, WA (Fig. 1). Thirty points were associated with a long-term continuous no-tillage (NT) site initiated in 1998 and the other 30 points were at an adjacent field that had been managed with similar crops but with reduced tillage (RT). The two sites comprise a paired watershed study for the USDA Long-Term Agroecosystem Research (LTAR) network. The samples were air dried and sent to commercial labs for a suite of traditional soil tests as well as the Haney Soil Health Index (which included a 24-hr CO_2 burst test, Solvita) and the Haney H3A test. In addition, soil samples representative of soil profiles (0-5 ft) were collected in 2015 at 25 geo-referenced points at the CAF NT site, incubated in the laboratory for 350 days to determine labile carbon pools (carbon with mean residence times of 5 and 60 days) and also analyzed for water extractable organic carbon (WEOC) and permanganate oxidizable carbon (POXC). A subset of samples was also incubated with ion exchange membranes (PRS probes) and subsequently extracted for macro- and micro-nutrients. In another long-term NT cropping systems experiment near Ritzville, WA, soil samples (depth increments to 1 foot) were collected in the spring of 2018 from diverse rotation experiments with wheat, peas and canola in rotation. Analyses included linear regression and spatial maps using inverse distance squared interpolation.

RESULTS AND DISCUSION

Soil organic matter (SOM) and pH ranged considerably across the two fields with SOM predominantly lower while pH was higher on RT compared to NT (Fig. 1). The Haney Soil Health Index was primarily driven by the CO_2 burst which was similar for NT and RT despite differences in SOM with CO_2 burst values considered high (>100) in the surface 4 inches, but decreased considerably in both NT and RT for the 4 to 8 inch depth-increment. Both of these measures were very sensitive to soil depth sampled. Other studies across the dryland cropping region of the inland Pacific Northwest have also shown that the Haney Soil Health Index is not very sensitive to differences in soil tillage management.

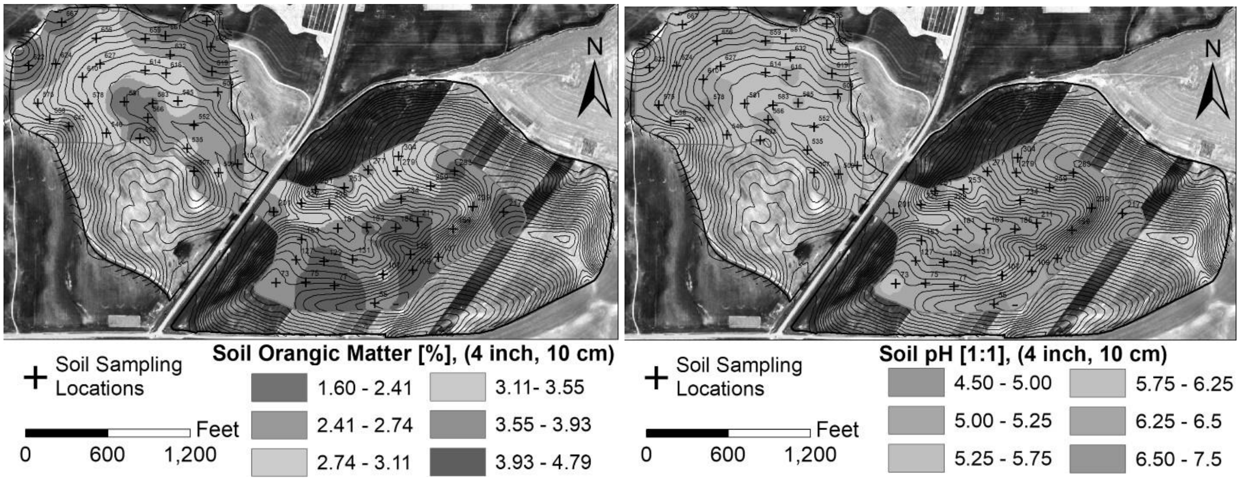

Figure 1. Geo-referenced locations for soil samples at the Cook Agronomy Farm and inverse distance squared interpolations of soil organic matter and pH (0-4 in).

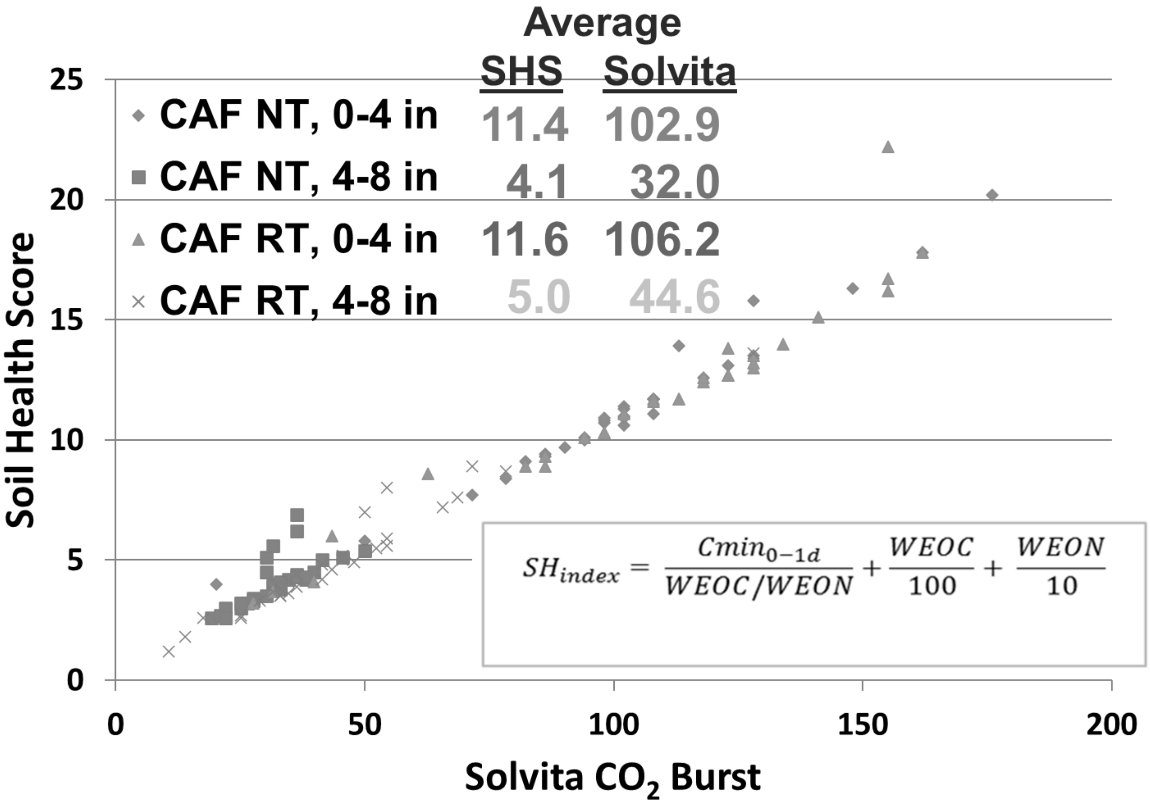

Figure 2. The Haney Soil Health Index (SH_{index}) and Solvita CO_2 burst ($Cmin_{0-1d}$) for 0-4 and 4-8 inch depth-increments in NT and RT for the Cook Agronomy Farm. WEOC is water extractable organic carbon; WEON is water extractable organic N.

Weak positive relationships occurred between Bray 1 P and H3A and also tended to be different for RT and NT (Fig. 3). In addition, the H3A test did not trend as the Bray, bicarbonate and ion exchange membrane (PRS) tests did across slope positions at the CAF (Fig. 3). Positive relationships were stronger between soil test K and H3A K, although the relationship was impacted by tillage regime (Fig. 4). As with P, the soil tests for bicarbonate K and ion exchange membrane (PRS) values were not well related with the H3A test across slope positions at the CAF (Fig. 4).

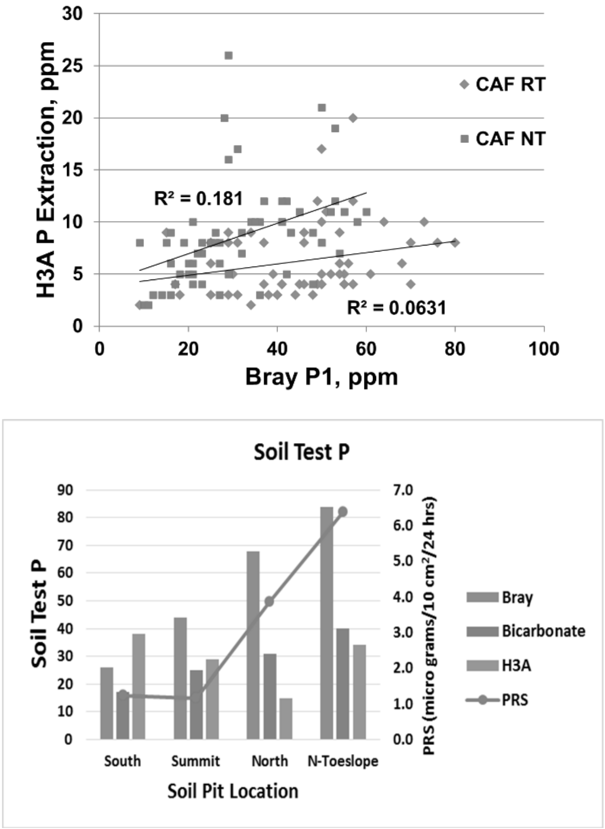

Figure 3. Comparison of H3A and Bray P1 for the CAF NT and RT. Also comparison of P soil tests (Bray, bicarbonate, H3A and PRS probe) at 4 landscape positions at the CAF.

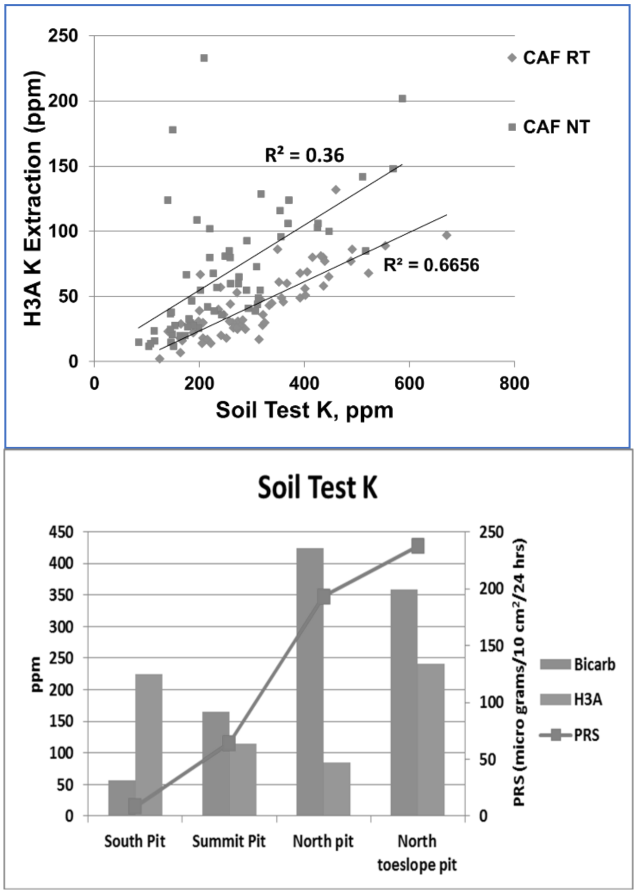

Figure 4. Comparison of H3A and soil test K for the CAF NT and RT. Also comparison of K soil tests (bicarbonate, H3A and PRS probe) at 4 landscape positions at the CAF.

Soil analyses from the long-term cropping system site near Ritzville, WA showed much stronger, positive, linear relationship between traditional soil test nitrate, ammonium, P and K and the H3A extractant. The field studies in this case did not have a tillage component, rather different crop rotation treatments (Fig. 5). In contrast, relationships between the tests were not as strong for S, Ca and Al (Fig. 5).

Soil management such as tillage tends to impact more labile constituents of soil organic matter (SOM). Labile constituents of SOM readily decompose serving as an energy source for the microbial community and stimulating its’ activity. Quantities of labile SOM can be estimated through laboratory incubation studies that can extend for many months to measure quantities of CO_2 respired over time. Results in Figs. 6 and 7 show the relationship between labile C pool estimates from long-term incubation studies of soil from the Cook Agronomy Farm and two other more rapid analyses: WEOC and POXC. The relationships in each case are positive and linear, indicating that the more readily analyzable WEOC and POXC can serve as good estimates of more labile SOM constituents.

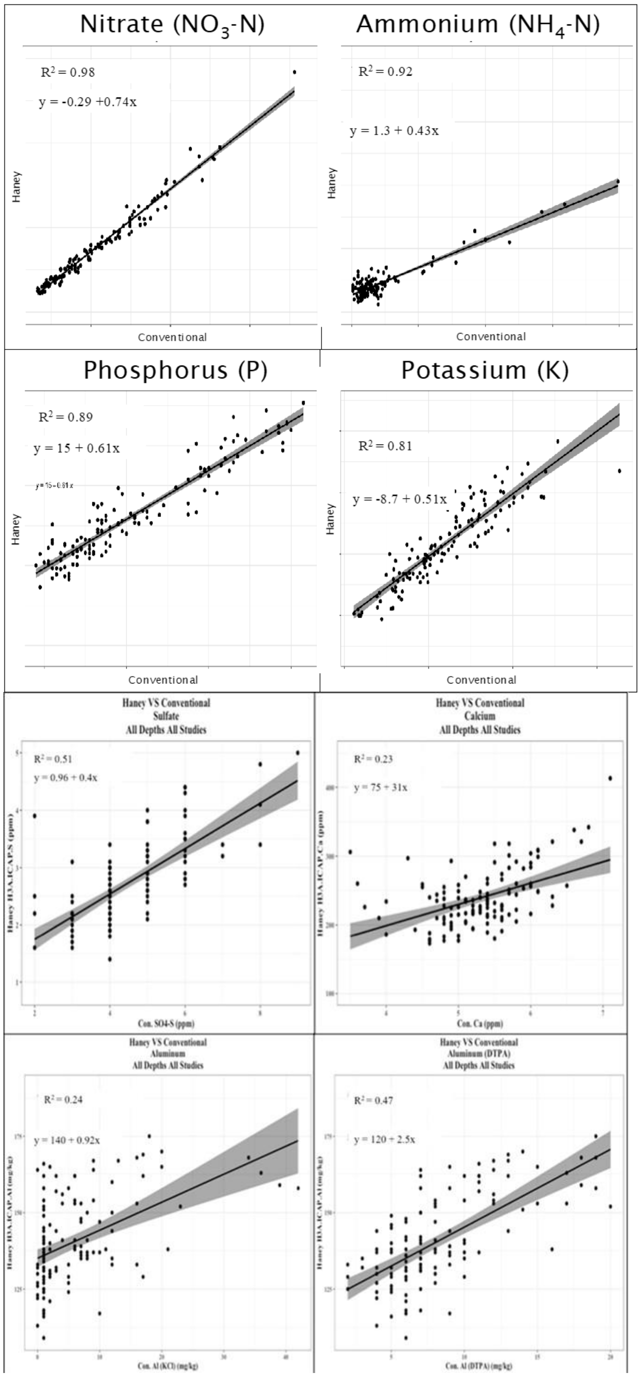

Figure 5. Relationships between conventional soil tests and the H3A test for nitrate, ammonium, P, K, S, Ca and Al at the long-term rotation study near Ritzville, WA.

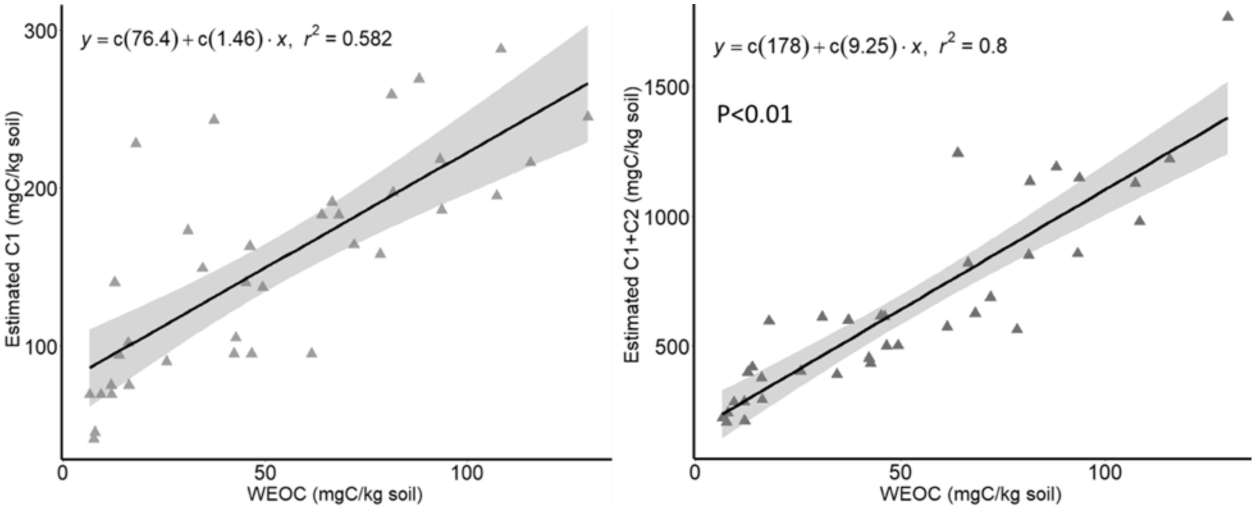

Figure 6. Relationship between water extractable organic carbon (WEOC) and labile soil carbon pools (C1 carbon has a mean residence time of 5 days while C2 carbon has a mean residence time of 60 days under controlled laboratory conditions).

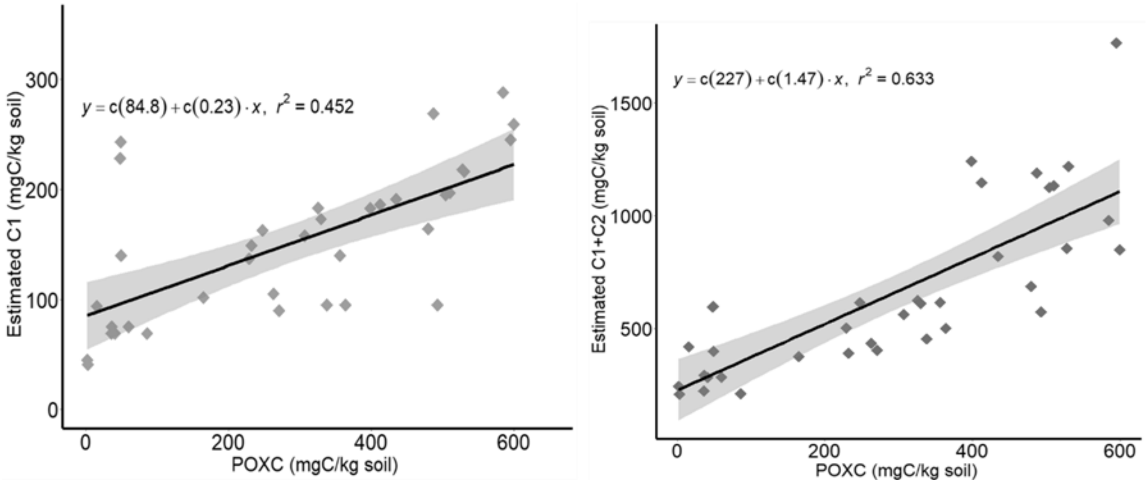

Figure 7. Relationship between permanganate oxidizable carbon (POXC) and labile soil carbon pools (C1 carbon has a mean residence time of 5 days while C2 carbon has a mean residence time of 60 days under controlled laboratory conditions).

IS COVER CROP SPECIES RICHNESS MORE IMPORTANT AT BUILDING SOIL HEALTH THAN SHOOT BIOMASS IN A SEMI-ARID REGION?

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ABSTRACT

Cover crop mixtures (CCMs) as partial fallow replacements have the potential to increase soil health, yet long-term studies on CCMs, especially in semi-arid environments are relatively rare. An eight-year study at two locations in semi-arid Montana sought to evaluate the effect of functional group (N fixer, tap roots, fibrous roots, Brassicaceae) and species richness (1, 2, 6, and 8 species) on a range of biological, physical and chemical soil parameters, when cover crops were alternated with wheat. Although several soil health parameters were sometimes higher with covers than fallow, there were few differences in soil health parameters among cover crop treatments. There were, however, significant positive relationships between total shoot biomass returned (covers, weeds, and wheat stubble) and both soil organic carbon (SOC) and potentially mineralizable nitrogen (top 4 inches) biomass at both sites. Specifically, each 1-ton shoot biomass/acre equated to an SOC difference in the top 4 inches of approximately 0.035%. This finding demonstrates why it's challenging to substantially affect SOC in a semi-arid environment by growing cover crops when cover crop-wheat systems only returned about 1-3 ton/acre more residue over the study life than fallow-wheat systems. The combined results demonstrate that selecting cover crop species that result in high amounts of total residue returned (cover crop residue plus cash crop stubble), is likely more important than cover crop species richness for improving soil health.

INTRODUCTION

Cover crops have become increasingly popular in the U.S. and Canada over the past twenty years, with soil quality often cited as a reason for growing them. In humid climates, high cover crop biomass production coupled with somewhat rare soil water limitations, often lead to improved soil quality and similar subsequent grain yields as controls (McDaniel et al. 2014; Olson et al. 2014; Yost et al. 2016). In the semi-arid northern Great Plains, lower residue returns and frequent severe water limitation, have often produced relatively modest or no soil quality benefits from pea cover crops (O'Dea et al. 2013), with generally lower profit than recropping or wheat-fallow (Miller et al. 2015a; Miller et al. 2015b). Much of this work has been done with single species pulse cover crops, namely pea or lentil. To determine if multi-species cover crop mixes (CCM) can increase soil quality compared to a sole pea cover crop, and whether certain "functional groups" improve specific soil quality properties more than others, we started a mixed species cover crop study in Montana in 2012.

METHODS

The study was begun near Amsterdam and Conrad, MT in 2012 on farm fields with no-till management histories (Table 1). Annual precipitation averaged approximately 14 inches at Amsterdam and 12 inches at Conrad. Study sites had four randomized complete blocks with 11 randomly assigned cover crop treatments that included a fallow and sole pea control (Table 2). Cover crop plots were 24 x 50 ft. During the wheat year, blocks were sown at a right angle to the cover crop seeding and nitrogen (N) fertilizer trisected into three rates; 1) none added, 2) 60 lb N/ac, and 3) 120 lb N/ac.

Table 1. Site data.

Site	Amsterdam	Conrad
Elevation (ft)	4740	3410
Texture	Silt loam	Clay loam
pH	8.2	6.5
SOC (%)	2.4	2.4
NO_3-N (mg kg^{-1})	6.0	8.5
Olsen P (mg kg^{-1})	13	28
Exch. K (mg kg^{-1})	359	498

The CCM treatments were designed to include four plant functional groups: **legumes**, included for their N fertility inputs; **fibrous rooted** plants, for their potential to add carbon (C) to the soils; **tap rooted** species, for their effects on soil structure and infiltration; and **brassicas**, due to their unique biochemistry and contribution to ground cover. We selected two species for each functional group. The CCM treatments include four single functional-group treatments, one full treatment mix of all eight species, and four treatments which include all but one functional group (minus fibrous root, minus legume, minus tap root, and minus brassica; Table 2). This addition-subtraction approach allows us to potentially identify the positive, negative, or neutral effects of each functional group. Functional groups have remained the same but some species were replaced because a) they were non-competitive under our management scheme - proso millet (*Panicum miliaceum* L.) and camelina

Table 2. Plant species included in 10 cover crop treatments and a chem fallow control.

Treatment	Abbrv	Plant Species
Fallow	SF	Incidental weeds
Pea	Pea	Forage pea
Full Mix	Full	Forage pea (*Pisum sativum* L. cv. Arvika) Black lentil (*Lens culinaris* Medik. cv. Indianhead) Oat (*Avena sativa* L.) Canaryseed (*Phalaris canariensis* L.) Turnip (*Brassica rapa* L.) Safflower (*Carthamus tinctorius* L.) Forage radish (*Raphanus sativus* L. var. *longipinnatus)* Winter canola (*Brassica napus* L.)
Brassicas	BR	Forage radish, Winter canola
Minus Brassicas	MBR	All but canola, radish and turnip
Fibrous Roots	FR	Oat, canaryseed
Minus Fibr Roots	MFR	All but oat and canaryseed
Nfixers	NF	Forage pea, black lentil
Minus Nfixers	MNF	All but pea and lentil
Taproot	TR	Turnip, safflower
Minus Taproots	MTR	All but turnip and safflower

(*Camelina sativa* L.); b) posed an unanticipated weed threat - Italian ryegrass (*Lolium multiflorum* Lam.); or c) could not be terminated with glyphosate - common vetch (*Vicia sativa* L.).

Soil Sampling and Analyses **-** A final comprehensive suite of biological, chemical, and physical soil assays was performed on samples taken prior to wheat seeding in spring 2019 to measure soil changes after four cycles of cover crops. This sample timing affords a ‘read’ of potential cover crop effects coincident with wheat at the start of its growing season. Soils were collected in two locations per subplot with a hydraulic probe from the medium N rate of all 11 cover crop treatments, and also for the low and high N rates for Fallow, Pea, and the Full mix. Only a smaller set of soil parameters was assessed in all treatments, allowing us to answer the question on whether species richness affected soil health.

The surface four inches were analyzed for potentially mineralizable nitrogen (PMN; 2-week anaerobic incubation) and total carbon and soil total nitrogen (STN) by combustion. Soil organic C was assumed to equal total C in soils with pH < 7.5 and inorganic C was measured on all others (Sherrod method) and subtracted from total C to obtain SOC.

Tissue sampling and stubble estimates – Cover crops and weeds were cut at the soil surface from a 0.84-m^2 area in each cover crop year, dried, and weighed. Wheat stubble was estimated using subplot combine wheat grain yield and typical harvest indices measured in similar Montana environments. Harvest indices were slightly adjusted based on N rate.

RESULTS AND DISCUSSION

Concentrations of PMN in Pea and Full were greater than in Fallow at Amsterdam in the medium N treatment, whereas there were no PMN differences among any treatments at Conrad (Fig 1). At both sites, there were no PMN differences between each 2-species functional group and the corresponding 6-species mix that did not contain that functional group, which was surprising especially for the N fixers (NF) v. Minus N fixers (MNF).

Pea and Full treatments resulted in higher SOC and STN than fallow, yet there were no differences in either parameter between the single species and 8-species mix (Table 3). While the difference in values might not appear great, they represent an approximate average 2,000 lb/ac difference in soil C, and 200 lb/ac difference in soil N, slightly less at Amsterdam, and slightly more at Conrad, in only the top 4 inches. Surprisingly, N fertility rates used in this study did not affect any soil parameter when analyzed across Fallow, Pea, and Full mix.

Concentrations of PMN in the upper 4 in. were 20 to 30% higher for the 6-species mixes than the 2-species mixes in the medium N treatment at both sites, although the absolute differences (~7 mg N/kg) equated to only about 10 lb N/ac. Concentrations of SOC and STN in the medium N treatments were not different between the 6-species and 2-species mixes at either site.

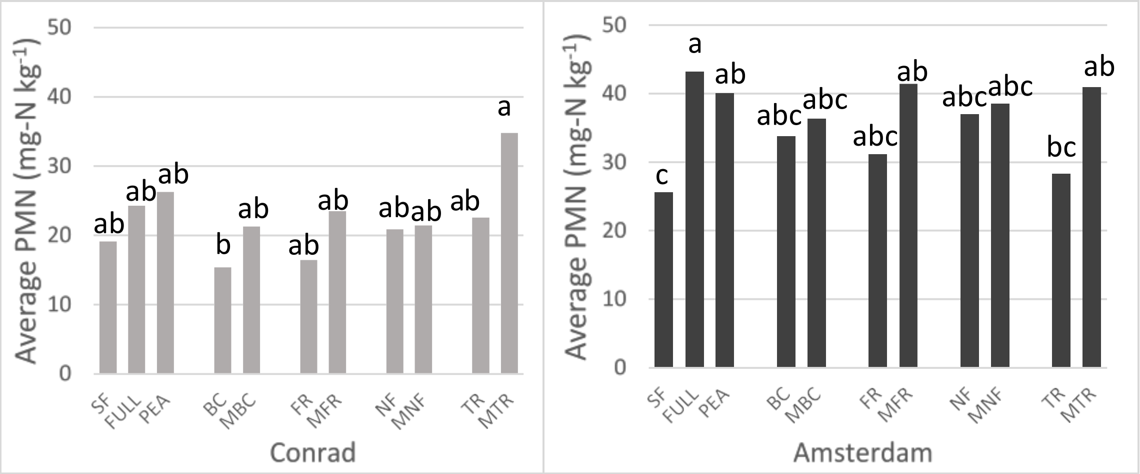

Figure 1. Potentially mineralizable nitrogen for 11 treatments at the medium nitrogen rate, following four rotations of cover crops at two field sites. See Table 2 for treatment descriptions. Letters show significant differences ($p < 0.1$).

There were positive relationships between total cover crop plus wheat stubble biomass (6-yr Amsterdam, 7-yr Conrad) and PMN at both sites (data not shown). In addition, total biomass was correlated with SOC somewhat weakly at Conrad (P=0.09) and strongly at Amsterdam (P=0.002), but with similar slopes (Fig 2). Specifically, each 1-ton shoot biomass/acre equated to an SOC difference in the top 4 inches of approximately 0.035%. The full range in biomass returned was less than 5 ton/ac at both sites (equating to an SOC difference of about 0.18%) and far less among the cover crop treatments (meaning without fallow). The large amount of biomass needed to affect SOC meaningfully demonstrates the challenge of increasing SOC in a semi-arid environment, even with cover crops.

Table 3. Soil organic carbon (SOC) and soil total nitrogen (STN) measured Apr 2019 in top 4 inches of soil at Amsterdam and Conrad, MT, after eight years and four cycles of cover cropping.

	Amsterdam		Conrad	
Cover	SOC	STN	SOC	STN
	---------- % ----------		---------- % ----------	
Full Mix	1.39 a	0.132 a	1.19 a	0.121 a
Pea	1.35 a	0.133 a	1.22 a	0.127 a
Fallow	1.25 b	0.119 b	1.05 b	0.108 b

Strong relationships between residue returned and SOC differences have previously been documented in somewhat wetter areas of the northern Great Plains (Shrestha et al. 2013; Engel et al. 2017). Due to the challenge in finding SOC differences among crop and fertility treatments, especially in short term studies, positive SOC v. biomass relationships suggest that biomass returned could be a surrogate for SOC. Even in our 7-year study, we found SOC was not different among our 11 cover crop treatments at Amsterdam at the medium N rate; however, there were several differences among total study biomass at this same site (Fig 3). Combined with the very strong relationship at Amsterdam between total biomass returned and SOC, it's likely that SOC differences existed, yet could not be detected due to high variability in SOC. The much larger area sampled for biomass (~ 3.3 m^2 over four cover crop years and ~10 m^2 per year for grain yield conversions to wheat stubble) than for soil (~ 0.0016 m^2) in each subplot, might partly explain why biomass differences were easier to detect than SOC differences.

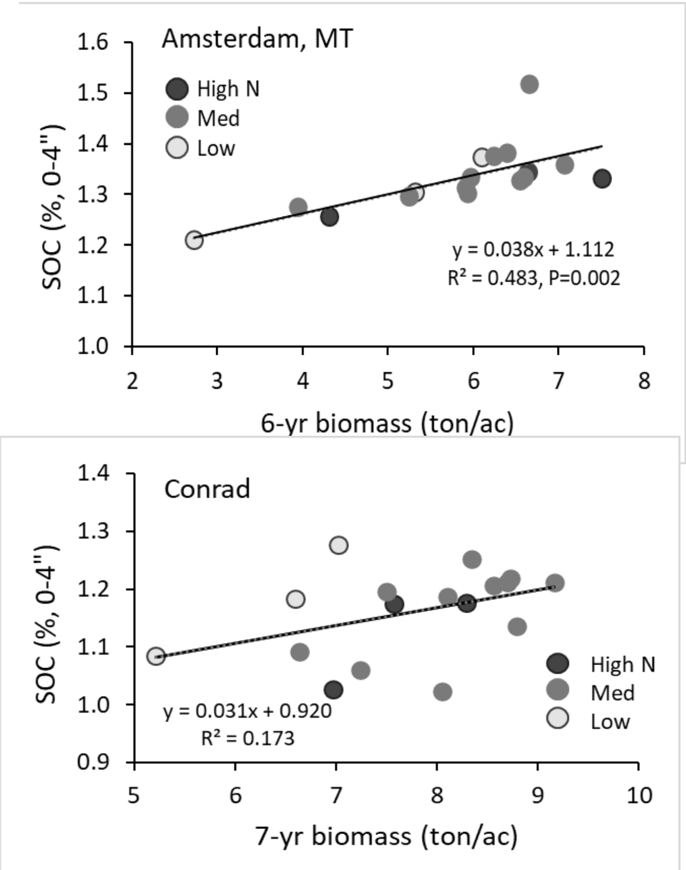

Fig. 2. Relationship between soil organic carbon (SOC) collected in April of final study year and total study biomass (covers plus wheat stubble) at Amsterdam and Conrad. Amsterdam wheat was hailed out in 2013, and hence had one less year of biomass. Soil was collected from low and high fertilizer N rate treatments for Fallow, Pea, and Full only, and in medium N treatments for all cover crop treatments.

Given that shoot biomass was correlated with some soil health parameters, notably SOC, we investigated whether species richness or perhaps legume presence was correlated with total biomass. At Amsterdam, 6-species mixes produced 4% more total biomass (cover plus wheat stubble) than the 2-species mixes (P=0.01) in the medium N treatment, whereas there was no difference between 6- and 2-species biomass at Conrad. In a semi-arid region, where low precipitation invariably limits crop yield, it's likely that species richness affects biomass less than in a more humid region.

Inclusion of legumes almost always resulted in higher total biomass returned. Notably, total biomass returned at both sites for the medium N rate was approximately 11 to 14% higher for the 2-species N fixer mix than for the other three 2-species mixes without N fixers, the Full mix produced 8 to 12% more biomass than the 6 species mix without N fixers (MNF), and Pea out-produced more treatments than any other cover.

SUMMARY

In conclusion, by growing cover crops more frequently than most producers grow them, we were able to detect soil health differences among cover crop treatments after four cycles. The largest soil health differences were generally between fallow and cover crops, rather than among cover crops. The amount of residue returned is more important at affecting soil properties, than the number of species in the mix, and the inclusion of legumes consistently increased biomass.

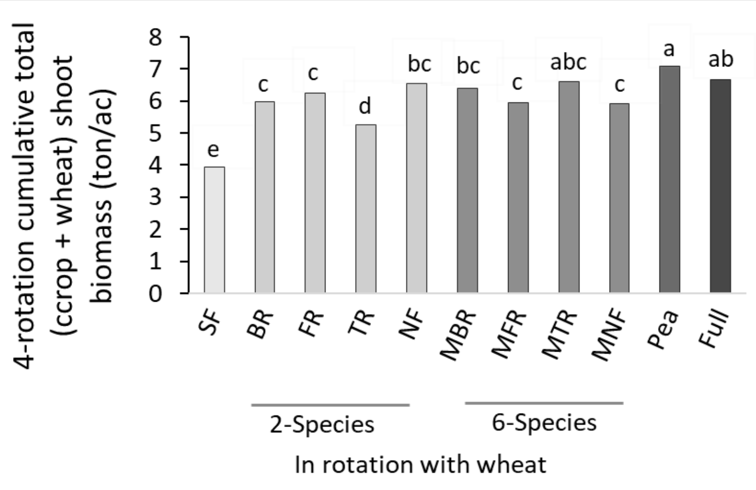

Fig. 3. Total 6-yr biomass (4 cover crop years + 2 stubble years) at Amsterdam. Different letters above bars indicate significantly different (P<0.10) biomass amounts. See Table 2 for descriptions of each treatment.

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COMPOST APPLICATION IN CALIFORNIA TOMATO CROPPING SYSTEM

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ABSTRACT

With the implementation of California Assembly Bill (AB) 341 the availability of composts such as green waste (GW) and co-composted green waste and food waste (FW) as a soil amendment is increasing. The use of those organic amendments in agricultural production systems has been recommended as an effective strategy to make full use of organic waste and improve soil health. However, little information is available to tomato growers to reassess N inputs from using GW and FW. This study was conducted to assess the impact of GW and FW on N availability in tomato cropping systems using chemical fertilizer N inputs and evaluate potential adjustments in N management guidelines for N fertilization rates. Crop yield, plant N uptake, soil N availability, and nitrate leaching potential under the practices of GW or FW in tomato systems were measured. In addition, laboratory studies of the same compost materials were conducted to understand N mineralization kinetics as affected by different temperatures in different soils to gain a more general understanding of the fate of N in compost inputs in a broader range of soils.

MATERIALS AND METHODS

Field site descriptions and agronomic management

The field experiments were conducted at the UC Davis Russell Ranch Sustainable Agriculture research site and grower fields in Central Valley. In the Russell Ranch site (RR), the soil is classified as Rincon silty clay loam, a fine monmorillonitic, thermic Typic Haploxeralf. This site has been in a tomato-corn rotation since 2013 with corn in even years and tomato in odd years. Subsurface drip irrigation with mineral fertilizers (i.e., fertigation) was implemented in 2014 and represents industry norms. In grower's sites (MR1 in year 1 and MR2 in year 2), the soils are classified as Brentwood silty clay loam, a fine monmorillonitic, thermic Typic Xerochrepts and Yolo silt loam, a fine-silty, mixed, non-acid, thermic Typic Xerorthent. The grower's sites have been in a cucumber-sunflower-tomato rotation during the past few years. The fields are equipped with subsurface drip irrigation.

Compost/Fertility management and experimental design

At the RR site, 16 experimental treatments were set up as a split-plot randomized complete block design with three blocks (replicates). The treatments include two compost types (GW or FW) X three compost rates (0, 4 tons/acre or 8 tons/acre) X two fertilizer N levels (0 or 100% of recommended N rate). In addition, different compost application rates combined with corresponding reduced N rates were also selected by replacing N from the fertilizer with compost sources: 85% of recommended N rate X compost (GW or FW at the rate of 0 or 4 ton/acre) and 70% of recommended N rate X compost (GW or FW at 0 or 8 ton/acre). Two consecutive seasons of treatments were conducted in this site. Composts were commercially purchased and hand spread evenly on the soil surface and disked in with standard equipment to a depth of 10-15cm in spring for year 1 and in fall for year 2. See Table 1 for compost characteristics. The FW compost was produced by co-composting 5% food waste and 95% urban yard waste. The GW was 100% urban yard waste.

In the grower's site, 5 experimental treatments were set up as randomized complete block design with three blocks (replicates). The treatments include two compost types (GW or FW) X three compost rates (0, 4 tons/acre or 8 tons/acre). Composts were applied by standard equipment (i.e., spreader) and disked in to a depth of 10-15cm in the fall for year 1 but were applied by hand and disked in in the fall for year 2.

Soil sampling and analysis

Soil samples were collected to a depth of 0-15 from four composite borings from each plot with a 1.83-cm diameter steel corer before and after fertigation events and approximately monthly during the remainder of the year. Inorganic N (nitrate (NO_3^-) and ammonium (NH_4^+)) was measured by extracting 10 g of well-mixed soil with 40 mL of 0.5 M potassium sulfate solution, and by analyzing the extracts colorimetrically for NH_4^+ and NO_3^- using a Shimadzu spectrophotometer (Model UV-Mini 1240).

Nitrate leaching potential determination

Resin bags were buried 30 cm deep over the winter rainy season to determine nitrate leaching potential from the highest application rate (8 tons/acre) of FW and GW composts and in control plots at the Grower's site and the same compost treatments in the 100% N plots at the Russell Ranch site. The resin bags were made by filling nylon stockings with 50 g NO_3^- specific ion exchange resin (AmberLite™ PWA 5, Dow Chemical Co., Waterfall City, Midrand). After the resin bags were removed from the ground in March 2020, the resin was extracted with 150 mL of 1M potassium chloride (KCl). The extracts were analyzed colorimetrically for NO_3^- following the same protocol and spectrophotometer use as mentioned above (Doane and Horwath, 2003).

Yield measurements

In both years, tomatoes were harvested in late August in both sites. Yields, biomass and N content of the harvested plant parts were measured. In both regular treatment plots and ^{15}N subplots, three adjacent tomato plants were randomly selected, and the aboveground biomass were separated into fruits and residues. Fruits were then sorted into green, red and rotten tomatoes and weighed.

Lab incubation and sampling

A laboratory aerobic incubation was conducted with two soils collected from the upper 15 cm in a conventional system (CMT) and a conservational system (OMT) at the Russell Ranch Sustainable Agricultural Facility and one soil collected from the upper 15 cm in California Central Valley. Soil samples were passed through a 2-mm sieve, mixed thoroughly to ensure uniformity and stored in a 4 °C cold room until the experiment began. FW and GW composts applied in this experiment were ground to pass through a 1-mm sieve before mixing with soil. The composts were added at the rate of 24 g dry weight kg^{-1} soil (oven dry basis).

Table 1 Basic properties of soils and composts in this study

Materials	pH	TN ($g\ kg^{-1}$)	TC ($g\ kg^{-1}$)	NO_3^--N ($mg\ kg^{-1}$)	NH_4^+-N ($mg\ kg^{-1}$)
RR soil	7.13	1.47	15.2	11.0	1.13
MR soil	6.72	1.52	9.33	9.05	6.42
Conventional treatment soil (CMT)	6.43	1.12	10.2	18.8	1.07
Conservational treatment soil (OMT)	6.50	1.85	15.8	61.0	0.98
Arbuckle soil (AS)	5.8	0.64	4.23	2.48	0.19
FW	7.65	18.6	229.7	121.9	1.89
GW	7.75	18.9	223.8	95.1	1.89

The experiment was a completely randomized block design and each treatment was replicated three times. The incubation experiment consisted of 36 treatments with a multifactorial combination of two composts (FW or GW), two N fertilizer levels (urea at 100 mg N kg^{-1} or control, non-urea), and three different soils (OMT, CMT or AS) under three temperature levels (10°C, 20°C, or 30°C). The incubation experiment lasted 28 days under three temperatures in environment-controlled rooms at the University of California, Davis. 20g dry weight equivalent of soil was placed in 120 ml specimen cups which were placed in 1L mason jars. In order to ensure gas exchange and maintain soil humidity, each mason jar was covered by a lid with a hole in the middle plugged by a sponge during the whole incubation process. To guarantee a homogenous distribution of fertilizer in soil, fertilization treatments received a dose of 100 mg N kg^{-1} oven dry soil in water solution and sprayed onto the soil in layers by a syringe to ensure the final moisture content of 60% of soil water holding capacity (WHC). Besides, soil was weighed every 2-3 days and adjusted with distilled water to keep the moisture to 60% WHC. On days 0, 3, 7, 14, 21 and 28, soil samples were collected for monitoring the dynamics of N_2O, NO_3^--N and NH_4^+-N. Soil net N mineralization rate was calculated as the difference in inorganic N between two time points and t temperature sensitivity coefficient (Liang et al.,2016), Q_{10}, was calculated using: $Q_{10} = (R_2/R_1)^{10/(T_2-T_1)}$

Where R_1 and R_2 are the mineralization rate of N at T_1 and T_2, respectively. T_1 and T_2 are incubation temperatures (°C).

RESULTS & DISCUSSION

Soil N availability as affected by compost application

Figure 1 shows the soil NO_3^- content at the time of tomato harvest (August) and eight months after harvest (April in the following year). The results showed that significantly higher NO_3^- occurred in soil after the fields had been fallowed for eight months following harvest. This is likely due from normal N mineralization and accumulation during the fallow season. However, in grower's site I, it was surprising to find that less NO_3^- occurred in the compost treatments compared with the control after the eight months of fallow. The similar results were also found in the 70%N treatment when food waste was applied. The detected NO_3^- in April reflects a balance of net N mineralization and N losses through gas emissions and leaching. Therefore, further data is needed to determine if less NO_3^- in the composts especially food waste treatments was caused by nitrate leaching or less N be mineralized.

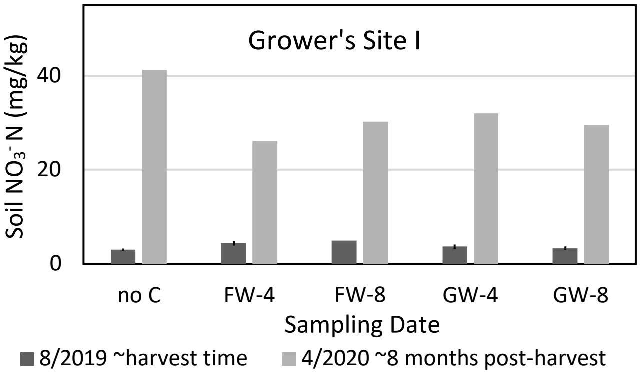


Figure 1: Soil N availability (mainly in the form of NO_3^-) at the time of harvest and eight months after harvest for both Russell Ranch and Grower sites.

Nitrate leaching potential in different compost treatments

The NO_3^- leaching potential of the control plots was compared to the highest application rates of compost (8 tons/acre) based on the NO_3^- concentrations extracted from the ion exchange resin bags that were buried over the winter rainy season. These data are shown in Figure 12. The results showed that the plots with no compost had the lowest rates of NO_3^- leached, while the plots that received GW compost had the highest NO_3^- leaching potential among all the plots. Interestingly, the leaching potential of FW compost applied in both sites was similar to the controls, suggesting that FW compost likely immobilized N, unlike GW compost treatments.

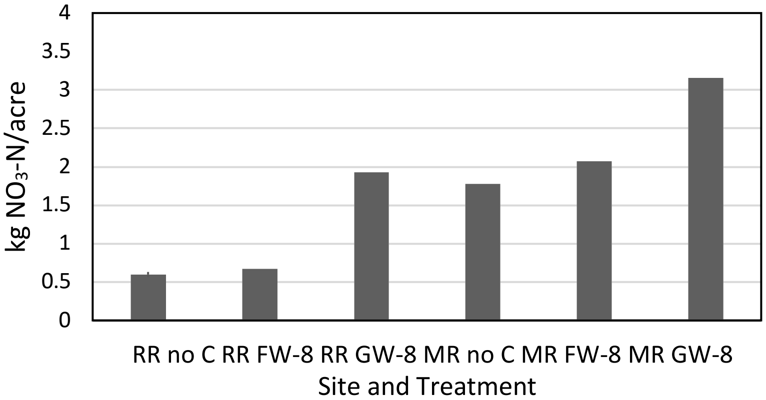
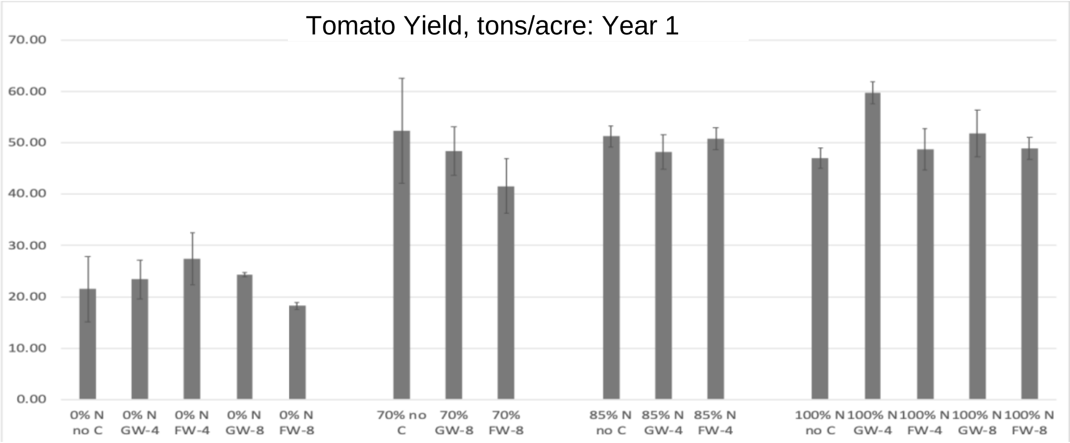


Figure 2: NO_3^- leached from the top 30 cm of soil in the control and highest rate of compost application plots at Russell Ranch and Grower's site II.

Crop yield in different compost treatments

There are varying results between the effect of compost types and compost rates on crop yield at RR site, but tomato yield did increase with increasing input rates of N fertilizer compared to no N addition (Figure 3). However, the yields in the treatments of 100%N were not higher than in the 85%N treatments, suggesting that fertilizer N inputs can likely be decreased by up to 15% of the recommended rate to maintain the same yield. Figure 4 shows tomato yield from MR site for the 2 compost types at 3 application rates. Similarly, the data vary between compost types and rates, although the yield from the treatment of 4 tons/acre of GW was significantly higher at the second grower's site than the first site. The higher yield in the treatment of 4 tons/acre of GW was also found in RR site when 100%N was applied.



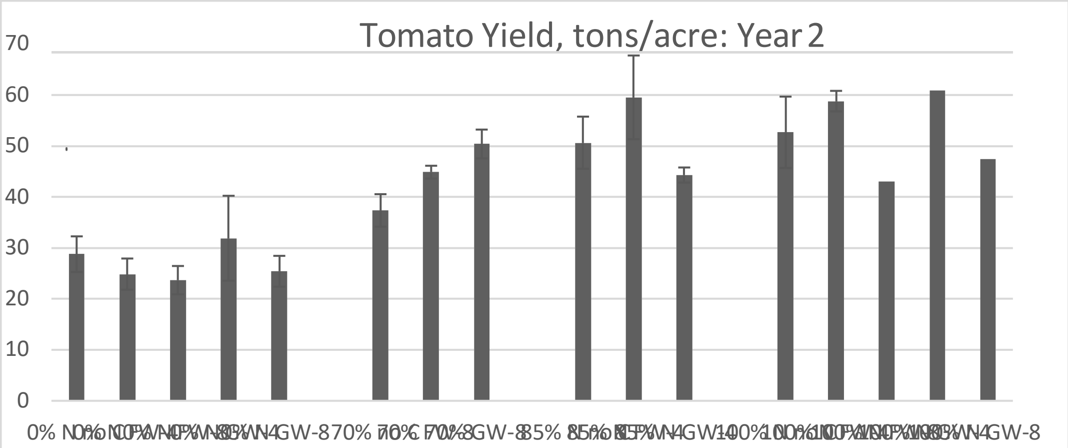


Figure 3: Tomato yield for two consecutive years at RR for the 2 compost types (FW and GW) at 3 application rates (no compost, 4 tons/acre, and 8 tons/acre), and 4 N levels (0%, 70%, 85%, and 100%) of the recommended amount. The error bars represent standard error.

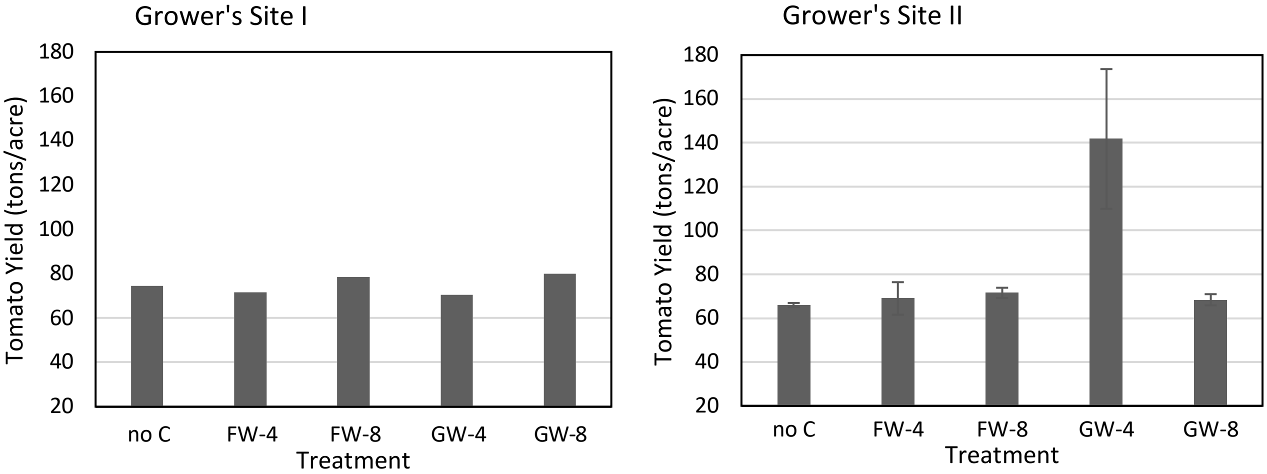


Figure 4: Tomato yield at the two MR sites for the 2 compost types (FW and GW) at 3 application rates (no compost, 4 tons/acre, and 8 tons/acre). The error bars represent standard error.

Net N mineralization rate and its temperature sensitivity

Table 2 shows the net N mineralization rates (NMR) during the 28 days incubation. As the temperature increased from 10℃ to 30 ℃, the NMR significantly increased in all three soils, except in AS soil incubated with FW alone, in which less N was mineralized in 30℃ than other temperature levels. Generally higher NMR was found in the urea treatments than the non-urea treatments. This is due to the hydrolysis of urea which released inorganic N (NH_4^+) during the incubation. Significantly higher NMR was found in the OMT soil than the other two soils. Unexpectedly, less N was net mineralized in the treatments of compost compared with the control (no compost) in the CMT and OMT soils. This is likely due to the addition of composts promoted soil N immobilization or the use of compost impaired microbial activities and therefore less N was mineralized. However, in the AS soil, the application of compost promoted net N mineralization. This is likely because the AS soil has very low fertility (low soil C and N, Table 4) and the addition of C enriched amendments promoted soil microbial activities that mineralized more N. Lower NMR was also found in the FW than in the GW treatments when compost was applied alone. This result was consistent with the field study which found less NO_3^- leaching potential and soil/compost derived plant N in the FW treatments compared with the GW application.

The response of N mineralization to temperature change was defined as Q_{10}, as shown in Table 6. Among the three soils, the Q_{10} values were slightly higher in the OMT than CMT and AS soils. The Q_{10} value varied greatly at different temperature ranges, with higher Q_{10} values found when the temperature increased from 20°C to 30°C than from 10°C to 20°C. This result indicated that N was mineralized faster in the higher temperature. The application of compost in the CMT and OMT soils had a trend to decrease Q_{10} values compared with the control (no compost). When the temperature increased from 20°C to 30°C, the response of N mineralization to temperature was more sensitive in the FW treatment than the GW treatment. However, the application of urea significantly decreased the temperature sensitivity of soil N mineralization compared to the control. Higher Q_{10} value was found in the GW+urea than in the FW+urea treatments.

Table 2 Soil N mineralization rate and Q_{10} under different temperature and compost treatments

Soils	Treatment	Net mineralization (mg -N kg^{-1} d^{-1})			Q_{10}	
		10°C	20°C	30°C	10-20°C	20-30°C
Conventional soil (CMT)	Control	-0.07	0.12	0.35	-1.78	2.99
	FW	-0.15	0.08	0.22	-0.5	2.79
	GW	-0.1	0.14	0.32	-1.42	2.38
	Urea	2.34	2.59	2.66	1.11	1.03
	FW+Urea	2.2	2.15	2.46	0.98	1.11
	GW+Urea	2.28	2.41	2.67	1.06	1.15
Organic soil (OMT)	Control	0.04	0.58	1.2	15.13	2.06
	FW	-0.28	0.35	1	-1.25	2.82
	GW	-0.23	0.48	1.14	-2.05	2.4
	Urea	2.07	2.55	3.18	1.23	1.24
	FW+Urea	2	2.56	2.99	1.28	1.17
	GW+Urea	2.01	2.31	2.85	1.15	1.23
Arbuckel soil (AS)	Control	-0.08	0.14	-0.2	-1.88	-1.43
	FW	-0.19	0.32	0.61	-1.72	1.88
	GW	1.06	1.16	1.4	1.1	1.2
	Urea	2.45	2.75	-0.8	1.12	-0.29
	FW+Urea	1.99	2.19	0.79	1.1	0.36
	GW+Urea	1.85	1.96	2.04	1.06	1.04

THE ELASTICITY OF BIOCHAR ACROSS THE FARM: NUTRIENT CAPTURE, COMPOST FEEDSTOCK, AND SOIL AMENDMENT

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ABSTRACT

When biomass is thermochemically altered in a low oxygen environment over a wide range of temperatures, the solid, carbon rich material that results is biochar. Biochar is an appealing material as a farm management tool because its potential use is varied, owing, in part, to its unique physicochemical properties. To better understand the potential on-farm use of biochar and its effect on nitrogen capture, we selected two regionally produced biochars (80 and 88 % C), and collaborated with a local compost producer to design two experiments: 1) each biochar was blended with manure bedding mix at a rate of 40.79 lb C, placed in 150.5 gallon stock tanks, allowed to rest for three weeks and analyzed for moisture, total C and N, NO_3-N, and NH_4-N, included in the experiment was an unblended manure bedding mix, which acted as the control, and 2) after the stock tank process was replicated three times, the total material for each treatment (biochar 1 and 2 and the manure/bedding mix control) was combined with additional manure/bedding mix (300 gallons) in a 450 gallon aerated composting vessel, composted for four weeks, and analyzed for moisture, total C and N, NO_3-N, and NH_4-N. Because composts are often used as soil amendments in vegetable production, we designed an additional field experiment that included six treatments (biochar 1, biochar 2, compost biochar 1, compost biochar 2, compost control, and control). Treatments were amended to meet an application rate of 8921.79 lb C acre^{-1} (dry) and then planted to broccoli. Following one growing season, broccoli plants and soil samples were collected and analyzed for yield biomass and bulk density, respectively. Nutrient and yield results suggest that biochar had very little effect on nutrient capture, though following amendment and incorporation, effects on soil physical properties, like bulk density, were observed.

INTRODUCTION

Woody waste material, which includes forestry residuals, hog fuel and construction debris, can be thermochemically altered in an oxygen deprived environment in a process known as pyrolysis. Under ideal conditions (temperatures above 482° F) and in modern systems, three products can result from biomass pyrolysis: an oil, a gas, and a solid. The gas and liquid products are often captured and utilized as fuel sources, among other uses, while the solid, commonly known as biochar, can be used utilized as a tool in environmental management (e.g., soil amendment or bioremediation). In part, what makes biochar so flexible in use, is its physicochemical properties: it has a high surface area and a varied porous structure, and, it is generally low in bulk density and made primarily of stable carbon (C). When biochar is used as an additive (e.g., soil amendment) these physicochemical properties impart certain generalizable functions. For example, biochar influences chemical properties like those involved in the sorption and desorption of organic and inorganic compounds, and it can alter physical properties like bulk density, permeability, and porosity.

Much research has focused on the use of biochar and its ability to adsorb organic and inorganic compounds. In organic mediums that include liquid, gaseous, and solid phases like those of manures, composts, and soils, biochar is frequently incorporated to retain elements like nitrogen (N). This approach, though not strictly limited to N, is frequently described as nutrient capture or retention, and the mechanisms responsible for this function are varied. Evidence from several discrete studies suggest that biochar can be used effectively to reduce nutrient loss in these same mediums (i.e., cow manure, composts, and soils). These effects, however, depend upon the properties of the biochar.

Therefore, the objective of this research is to evaluate the potential nutrient capture of two regionally produced biochars via on-farm use as an additive in manure/bedding mixes, a feedstock for a downstream compost product, and as an amendment in local vegetable production.

METHODS

Stock tank experiment

Biochar was purchased from two commercial manufacturers, Oregon Biochar Solutions (White City, OR) (Bior) and Olympic Biochar Solutions (Port Orchard, WA) (Bioly), and produced from pine and Douglas fir forestry residuals at 1600 °F and from Douglas fir, hemlock, alder and pine hog fuel and construction debris at 2004 °F, respectively. Additional biochar characteristics are listed in Table 1.

The manure/bedding mix was collected from animal pens, mixed on a concrete pad, and scooped into each of three 150-gallon stock tanks. Bioly and Bior were incorporated into each of two filled stock tanks at a rate of 40.79 lb C (dry), while the third filled stock tank, without biochar addition, was treated as the control. The three tanks were placed in a dry covered storage area and allowed to rest - exposed to ambient air temperatures - for three weeks. Then, three sub- samples from each of three stock tanks were collected, homogenized, and composited into an individual sample for each treatment. Samples were sealed in plastic bags and frozen, and later analyzed for moisture, total C and N, and inorganic N, on a dry and as-is basis. The remaining material was used as feedstock for the composting experiment and the entire process was repeated two additional times.

Table 1. Chemical and physical properties of the biochar products included in the study.

Biochar	% total C[†]	% total N	C/N	% ash	Surface area ($ft^2 lb^{-1}$)	Particle size range (in)
Olympic biochar	80.7	0.97	83.2	6.5	1.758×10^6	<0.019 - 0.315
Oregon biochar	88.0	0.78	112.8	3.7	2.226×10^6	0.039 - 0.157

[†] Total C and N, C/N, and ash are on a dry weight basis

Compost experiment

To evaluate the effects of biochar incorporation on the composting process, each of three stock tank materials (i.e., manure/bedding control, and two biochar blended manure/bedding mixes) was turned out onto a clean concrete pad, blended with 300 gallons of additional fresh manure/bedding material, and this new material (450 gallons in total) was homogenized and scooped into a 450-gallon, square plywood composting reactor. The composting vessels were capped with 75 lb of wood chips and outfitted with temperature probes positioned midway between the top and bottom of the reactor (data not shown). Reactors were placed in a dry covered area and the materials were composted for four weeks, sampled, and then analyzed for moisture, total C and N, and inorganic N on a dry and as-is basis. This process was repeated an additional two times, and each of the three materials from all three repetitions were combined into separate piles and stored until use in the field experiment.

Field experiment

Six treatments were arranged in a randomized complete block design, with four repetitions, across two, 100-foot, vegetable beds. The six treatments included: a control, Bior alone, Bioly alone, composted Bior (BiorC), composted Bioly (BiolyC) and a control compost (CC). Treatments were applied, by hand, to 32 ft^2 research plots to meet an application rate of 8921.79 lb C $acre^{-1}$ (dry); amendment rates are listed in table 2. Following application, amended plots were tilled to a depth of six inches, and evaluated for bulk density following one growing season.

Broccoli 'green magic' starts were grown from seed, in a greenhouse, for four weeks, and then transplanted into each of two beds, in two rows at 15 and 18 inch, in-row and between row spacing, respectively. Broccoli plants were fertilized with a 12-0-0 feather meal product at 104 lbs N $acre^{-1}$ and irrigated by drip irrigation. Once main shoots reached a marketable size, they were collected, counted, and weighed.

Table 2. Quantity of material applied to meet targeted carbon rate.

Treatment	Material applied (tons $acre^{-1}$)
Control compost	31.2
Oregon biochar	11.2
Olympic biochar	17.3
Composted Oregon biochar	29.3
Composted Olympic biochar	30.8

RESULTS AND DISCUSSION

Stock tank experiment

Overall, and in comparisons between treatments, no statistical differences were observed for any of the properties evaluated. Following biochar incorporation, we expected to see variation in inorganic N, but concentrations of NH_4-N and NO_3-N were below detectable levels (data not shown). This is likely due to the high levels of moisture in the material (Table 3), which may have impeded mineralization. Interestingly, we observed an increasing trend for total C and N treatment means (Bioor > Bioly > Control) which followed the concentration of added C (i.e., in the form of biochar).

Table 3. Treatment mean values for selected properties following stock tank incubation.

Treatment	% moisture	% total C††	% total N
Oregon biochar	74.46	52.9	1.23
Olympic biochar	75.16	44.5	1.20
Control	74.67	36.6	1.02

††Total C and N are on dry weight basis.

Compost experiment

The C and N content for the three composted materials was largely in line with expectations (Figure 1). C/N ratios for biochar amended materials (BiolyC and BiorC) were significantly greater than the control, reflecting the additional C in the form of biochar (Figure 1b), and total and organic N concentrations illustrated small, but significant differences between treatments (i.e., Control > BiorC > BiolyC) (Figure 1c,d). Given the low nutrient content of the biochars, the differences in total and organic N content likely reflect nutrient dilution, caused by the additional biochar material which was amended at different volumes (e.g., 15 and 9% (v/v), Bior and Bioly, respectively) to meet an equal amount of dry C. This is further supported, in part, by the levels of NH_4-N and NO_3-N which were below detectable limits and thus, had very little impact on total N concentrations.

Similar to the stock tank experiment, moisture levels were consistently high in all materials (75%) and no treatment significantly increased or decreased moisture content (data not shown).

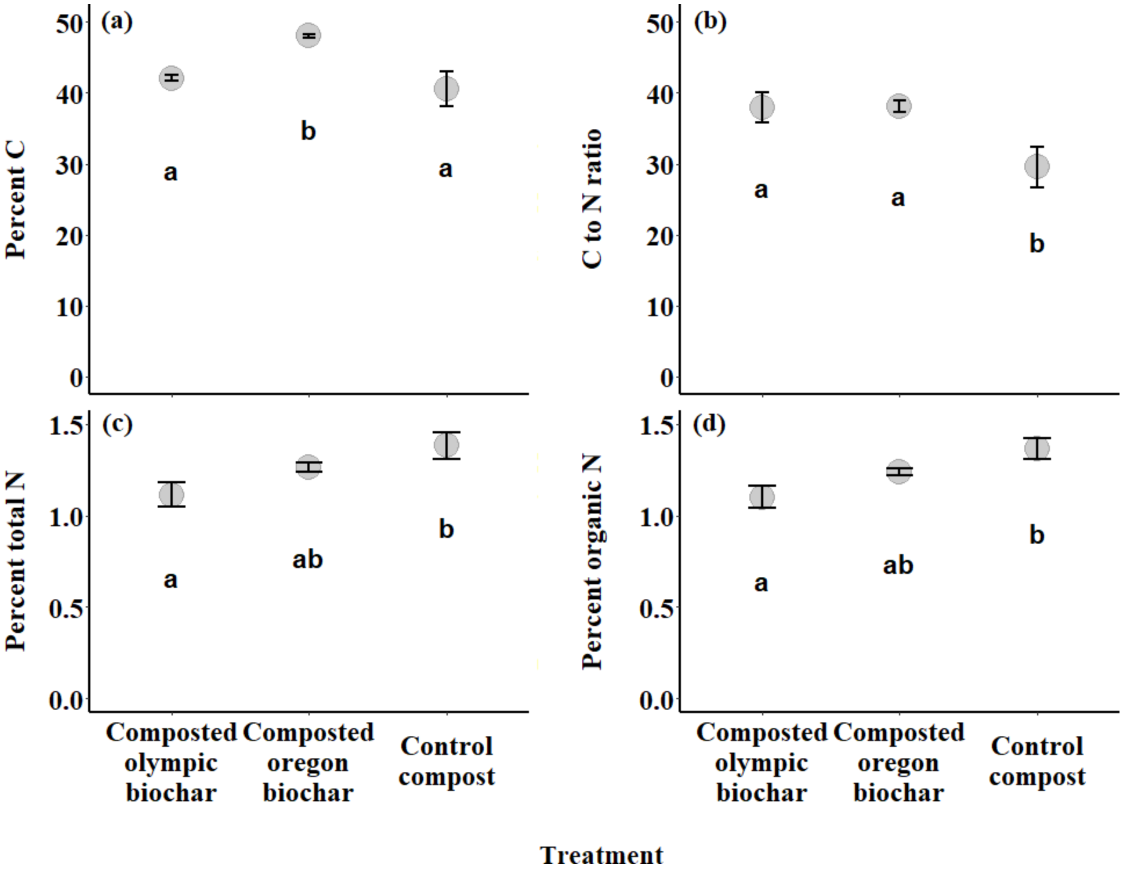

Figure 1. Treatment means for percent C (a), C to N ratio (b), percent total N (c), and percent organic N (d) following four weeks of composting. Letters in (a), (b), (c), and (d) indicate results of Tukey's HSD test ($p < .05$). Chemical properties are presented on a dry weight basis.

Field experiment

There were no clear trends in soil bulk density values following amendment. In comparisons with the control, only the Bior and BiolyC treatments significantly decreased soil bulk density (Figure 2). Other researchers have observed linear relationships between soil bulk density and amendment rate (i.e., soil bulk density decreases as amendment rate increases), but

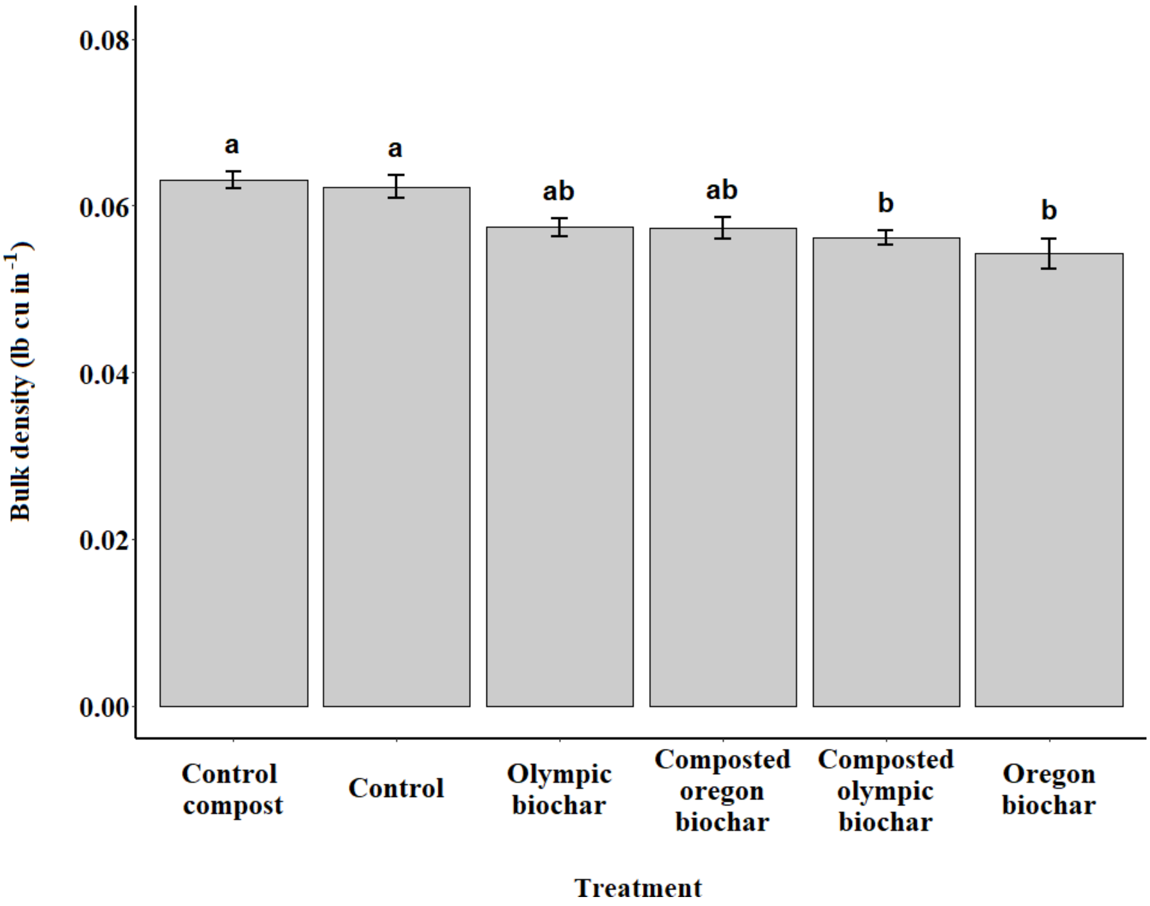

Figure 2. Soil bulk densities following treatment and one growing season. Letters above a bar indicate results of Tukey's HSD test ($p<0.05$).

in our study we observed nearly the opposite. The CC treatment, amended at the highest material rate, had no effect on soil bulk density when compared to the control, while the Bior treatment, amended at the lowest material rate, had the greatest effect on soil bulk density. The amount of labile C in each treatment may have something to do with this observation, but the inconsistent results, including bulk density values for BiolyC and BiorC treatments, make clear interpretation difficult.

Following amendment and one growing season mean broccoli yields ranged from 6672 to 9079 lb acre^{-1}. In comparisons with the control, however, no significant differences in yield were observed between treatments (Figure 3). This is likely a result of the high C/N ratios in the materials (Figure 1b). Even so, as the C/N of the material decreased (composted materials < biochars), yields increased (composted materials > biochars). This effect may have been more pronounced if we had not included a supplement N application which could have masked different N mineralization rates between treatments. Additional plant nutrients supplied by the compost and co-composted biochar amendments may have also contributed to the trend in broccoli yields.

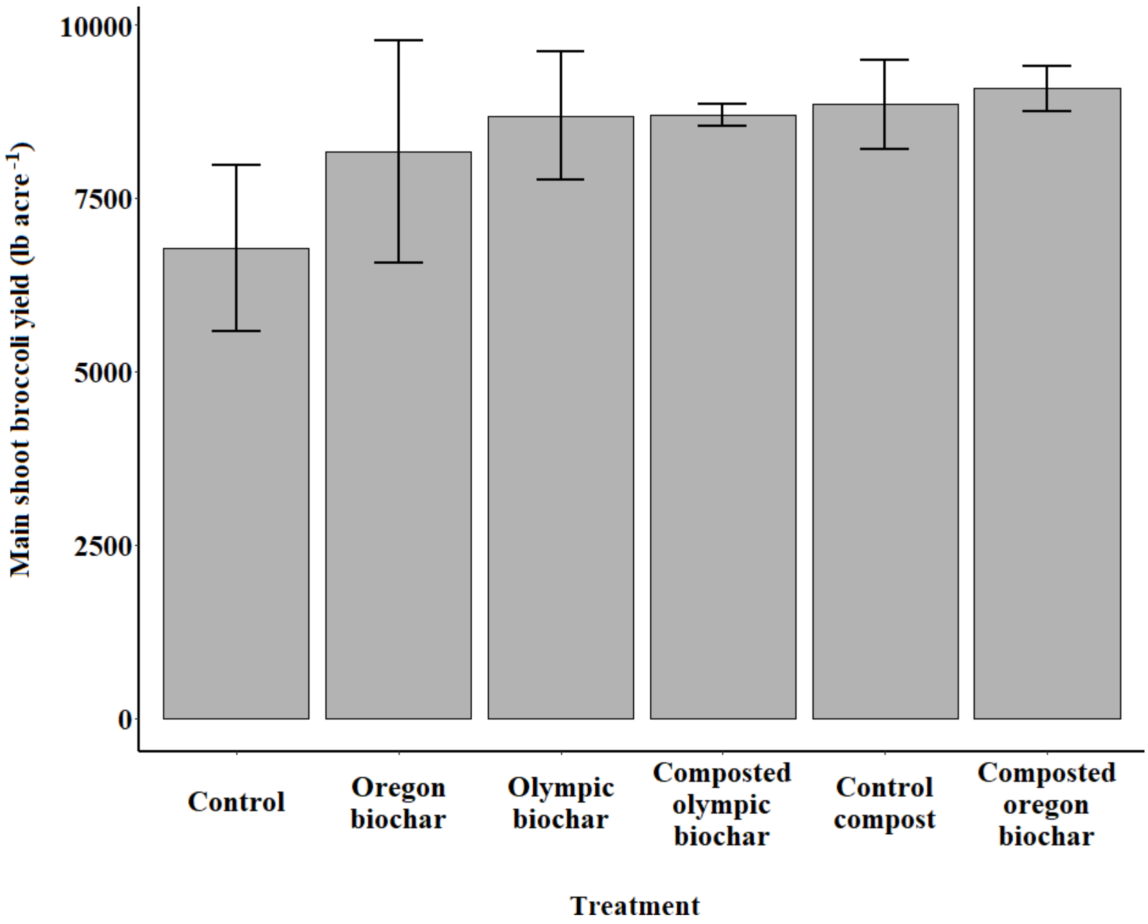

Figure 2. Broccoli main shoot yields for each treatment following amendment and one growing season.

At the rates utilized in this study, and when blended with manure/bedding mixes and composted, these two biochars had little effect on nutrient capture, and thus, no effect on broccoli yield. Amending soils with biochar and co-composted biochar materials, however, did reduce bulk density, but the physicochemical properties of the material likely had an impact on the magnitude of that effect. As many other researchers have observed, for biochar to be an effective environmental and farm tool, users must take into consideration, the physicochemical properties, application rate, and intended use of the biochar material.

DENITRIFYING WOODCHIP BIOREACTOR PERFORMANCE IN A CASCADIA CLIMATE REGIME

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ABSTRACT

Runoff and tile drainage from agricultural activity is known to be a significant contributor of nitrogen pollution to surface waters. Denitrifying woodchip bioreactors, also known as Permeable Reactive Barriers (PBR), have been studied as a possible edge-of-field technology for reducing nitrogen concentrations in agricultural runoff. These studies have been done mostly in the US Midwest and primarily for irrigated crop systems. Little work has been done in alternative climate regimes such as those found in the Cascadia Region of Oregon and Washington State where agricultural runoff is most likely to occur during the winter rain season. A field-scale denitrifying woodchip bioreactor was installed at Oregon State University (OSU), designed to treat drain-tile runoff from about 40 acres of forage fields for the OSU Dairy Farm. Samples were collected daily from 12/19/2019 to 5/27/2020 and tested for nitrate, nitrite and ammonia/ammonium concentrations. Samples were also collected approximately weekly, 3/30/20 – 5/27/20 and tested for fecal coliform concentrations via IDEXX Colilert Quanti-tray MPN tests. Preliminary results showed significant nitrate reductions even during colder winter months, with average percent reduction in concentrations of 48% (STD +/- 41.5%) from influent concentrations ranging from 87.7 to 2.0 mg NO_3/L. Results for ammonia/ammonium [mg NH_4^+-NH_3/L] were much more variable, with an average percent change of just 7.8% (STD +/- 31.4%), mostly related to changes in influent concentrations. This, however, was to be expected as the conditions in the PBR were inherently anaerobic and reducing, and were not conducive to ammonium oxidation. Fecal coliform results were inconclusive, with some sample sets showing good reductions while others showed count increases between the inlet and internal positions.

INTRODUCTION

Ever since the development of industrial fertilizer manufacture, the nitrogen cycle has been out of balance: nitrogen has been added to surface systems at rates far in excess of what would occur naturally. Agricultural activities can be a major contributor to excess nutrients in surface waters and reducing nutrient runoff from fields and livestock operations has been a concern for many years. Drain-tile systems are of particular concern as they can provide direct transit for leached nutrients to reach surface waters (David et al, 1997, 2010)

Denitrifying woodchip bioreactors, also known as “permeable reactive barriers” (PRB), have been under study as a possible “edge-of-field” treatment method since 1994 (Blowes et al, 1994). The functional concept behind PRB is that they provide a readily available carbon source for denitrifying organisms (bacteria, archaea, fungi) to colonize, which then respond by consuming nitrogen compounds present in the drainage outflow for their metabolic processes. The denitrification process is a series of biotic enzyme catalyzed reactions that convert nitrogen in the form of nitrate (NO_3^-) to N_2 gas as follows: $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O_{(gas)} \rightarrow N_{2(gas)}$. If the denitrification process is incomplete, byproducts such as nitric and nitrous oxide, both powerful green-house gases, can be released. For denitrification to occur, conditions must be anaerobic at minimum. However, if redox conditions are too reducing, pollution swapping can also occur with the formation of undesirable compounds such as CH_4 (methane), H_2S (hydrogen sulfide gas) and methyl-mercury. Since denitrifying organisms are biotic in nature, conditions such as contact time with the nutrients as controlled by hydraulic retention time (HRT), water temperature, pH and oxidation state can all play a role in the functional success of a denitrification system.

The majority of the research into denitrifying woodchip bioreactors has been conducted by groups in New Zealand and the mid-west U.S.A. Louis Schipper's 2010 paper (Schipper et al, 2010) reviewing developments in the technology up to that time has been a foundational paper for successive researchers, and Laura Christianson's work in Iowa, along with that of J.A. Chun (Iowa), Ehsan Ghane (Ohio) and others, has focused on treatment bed parameters for optimizing PRB design. Thus, the majority of the research to date into woodchip bioreactors has been conducted in regions with quite different climate regimes than that found in the U.S. Pacific Northwest. There is little information for how such units might perform in a "Cascadia" or "Mediterranean" climate regime where most runoff occurs in the colder winter months. There is also little information regarding how these units might perform with respect to pathogenic bacteria. In lab studies, Soupir, (Soupir et. al., 2018) and Rambags (Rambags et al., 2019) found consistent reductions in pathogenic bacteria; however, there is currently no known study using a field-scale denitrifying bioreactor unit.

In the summer and fall of 2019, a research PRB unit was installed at Oregon State University in order to process tile-drainage effluent at the OSU Dairy Farm, Oregon State University, Corvallis, OR. The tile system drains approximately 40 acres of forage fields that are rotationally grazed or harvested. Liquid manure is applied seasonally in Spring and early Fall. In the first season of operation (Dec. 2019 – May 2020), a pilot study was conducted to establish baseline performance characteristics and to address the following questions: 1) How does a field scale unit perform with respect to nitrogen constituents under Western Oregon climate conditions? and 2) Would these units be effective against fecal coliform bacteria?

METHODS

Project Site and Design: The PRB was designed largely per guidelines from Christianson, et. al. (Christianson 2011, 2012, 2013) to treat approximately 15% of the local estimated peak flows in 10-24 hour HRT. Unit dimensions were 12'W x 60'L x 3.3'D (3.64m x 18.2m x 1m), a 5:1 L:W aspect ratio, with a rectangular cross-section and level base (minimal slope). AgriDrain flow control boxes were installed at the inlet and outlet as well as a dosing well for injection of tracer and/or nutrient pulses. The treatment pit was lined with 4 ml plastic and filled with 1" mixed hardwood chips as available from a local landscape supply center. 10' lengths of 6" diameter perforated ADS drain pipe were used at each end for flow diffusion and collection, stabilized with 1 ½" round drain rock prior to adding the woodchips. In addition, PVC sampling wells were installed at 3 internal heights (0.25m, 0.5m and 0.75m from base) approximately every 10' of the longitudinal length of the unit along with flow baffles to discourage development of preferential flow paths. The treatment bed was capped with soil to bring the surface back to existing ground level; plans are to seed the cap to grass cover once the soil has settled. No bacterial inoculation was performed; microbial colonization was allowed to occur naturally by species present in the drainage flow. Once the soils were saturated with seasonal rains, this PRB experienced almost "steady-state" flow conditions at maximum treatment volume until the early cessation of the rainy season in April 2020.

Sampling and Testing: Near-daily water samples were drawn via ISCO 2900 automated water samplers from Dec 19, 2019 to May 27, 2020. The samples were collected 1x per week, taken directly to a lab at the university where they were filtered through 0.45µm MCE filters and frozen until they could be tested for concentrations of nitrate (NO_3^-), nitrite (NO_2^-) and ammonia/ammonium (NH_3/NH_4^+) via colorimetric Vanadium reduction and salicylate/sodium nitroprusside/sodium hypochlorite reaction (method details available upon request). In addition, "manual" samples were collected from internal monitoring wells approximately 1x per week from March 30 – May 27. 100 ml of these samples were immediately processed for fecal coliform testing per the IDEXX Colilert Quanti-tray method. The remainder was filtered, stored and tested for nitrogen constituents as for the daily samples.

RESULTS

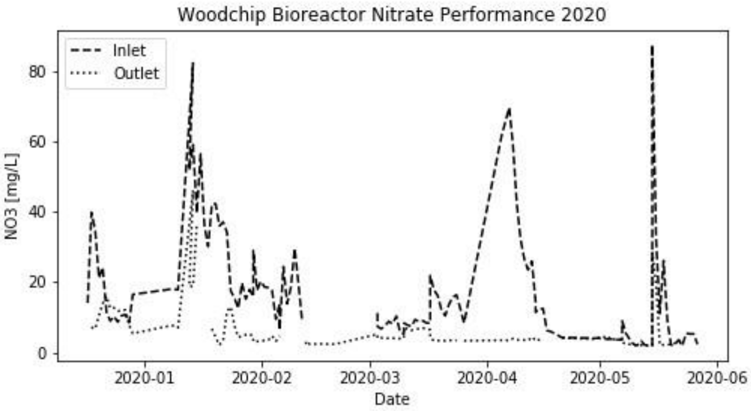

Figure 1. Inlet/Outlet Nitrate Performance, Winter/Spring 2020

Inlet/Outlet daily samples: As shown in **Figures 1, 2** and **3**, as well as **Tables 1-3**, nitrate concentrations saw consistent reductions between the inlet and outlet, over a variety of conditions. Concentration spikes were observed after high precipitation events and after liquid manure was spread on the forage fields in April/May. Inlet concentrations for the season ranged from a maximum of 87.7 to a minimum of 2 mg/L, and outlet concentrations ranged from 46.2 to 2 mg/L. The average percent reduction was 39.8%. This value differs from that presented in Abstract due to data-entry errors discovered during development of tables and plots. Results for nitrite showed a tendency to an increase from inlet to outlet, but on a very small scale. When larger inlet concentrations were experienced, the nitrite concentrations were also significantly reduced. Inlet/Outlet concentrations of ammonia/ammonium did not demonstrate any consistent changes overall.

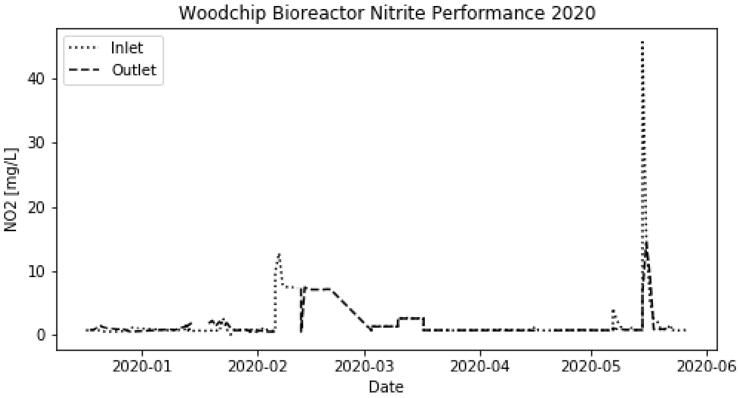

Figure 2. Inlet/Outlet Nitrite Performance, Winter/Spring 2020

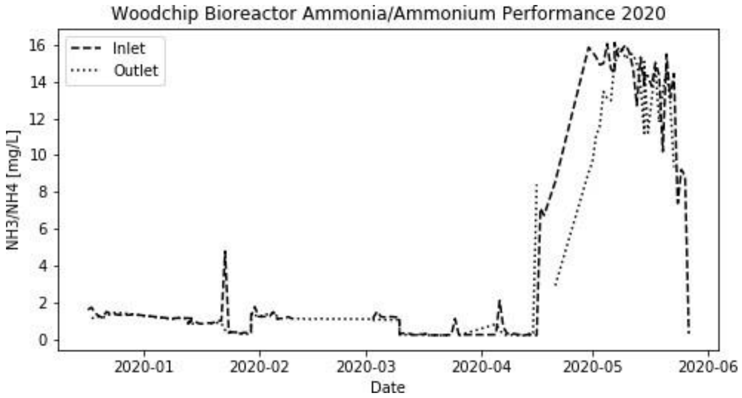

Figure 3. Inlet/Outlet Ammonia/Ammonium Performance, Winter/Spring 2020

Table 1. PBR Nitrate Inlet/Outlet Statistics

	NO_3 in [mg/L]	NO_3 out [mg/L]	Δ In-out [mg/L]	NO_3 %reduction
Mean	17.979	6.079	12.642	39.80
St.Dev	17.078	6.506	16.908	1.10
Min	2.004	1.938	-28.328	-86.51
Max	87.685	46.179	68.314	97.60

Table 2. PBR Nitrite Inlet/Outlet Statistics

	NO_2 in [mg/L]	NO_2 out [mg/L]	Δ In-out [mg/L]	NO_2 %reduction
Mean	1.988	1.748	0.397	-37.5
St.Dev	4.590	2.240	3.298	215.3
Min	0.493	0.472	-1.589	-1860.5
Max	45.736	14.331	31.405	94.6

Table 3. PBR NH_4 Inlet/Outlet Statistics

	NH_4 in [mg/L]	NH_4 out [mg/L]	Δ In-out [mg/L]	NH_4 %reduction
Mean	4.132	3.722	0.443	-26.30
St.Dev	5.706	5.311	1.364	317.20
Min	0.230	0.220	-4.388	-2901.80
Max	16.107	15.805	6.248	91.00

Internal Water Quality: As presented in **Figure 4**, samples taken from the longitudinal centerline showed a clear utilization of nitrate within the first 20’ of the treatment unit during the month of April. Internal water quality results for the May sampling dates showed less change over the profile, but outlet concentrations were still less than the 10 mg/L dictated by EPA regulatory requirements. Nitrite and ammonium showed a less clear relationship; nitrite tended to be reduced somewhat early in the treatment bed, but small increases were also sometimes observed further down the profile. Ammonium showed no clear relationship along the profile of the treatment bed.

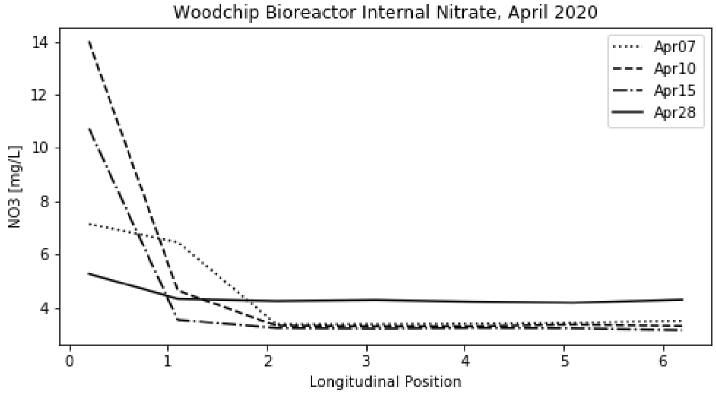

Figure 4. PBR Longitudinal Nitrate Concentrations, April 2020

E. ***Coli* and Total Fecal Coliform MPN counts:** Early spring (late March to mid-April) results for both Total Fecal Coliform (TFC) and *E.coli* MPN counts seemed promising, showing significant reductions in counts taken between the inlet and internal locations. However, results from later in the season showed a less clear pattern, with internal increases in MPN counts being observed on several occasions.

DISCUSSION

Results for this first year of operation of a denitrifying woodchip bioreactor in Western Oregon are quite promising. Significant reductions of nitrate were observed, even with winter water temperatures. Large reductions were observed during concentration spikes, although not always sufficient to bring outlet concentrations to below 10 mg/L during periods of highest inlet concentrations. This is in line with previous research reporting reductions of 23% to 98% (Schipper et al., 2010, Christianson et al, 2012). Relatively good performance is expected in early years due to the presence of readily available carbon from the “fresh” woodchips. It is expected that performance will decrease somewhat once that carbon source is fully utilized. Changes in nitrite concentrations are of interest as they may be potential indicators of the progress through the denitrification series. Nitrite is inherently a transitional molecule and doesn’t tend to be of long duration in a natural environment. An observed increase in the longitudinal profile of the treatment unit may indicate that the first step of denitrification is occurring, but perhaps not as much of the following steps and could indicate incomplete denitrification. Nitrite is becoming a “contaminant of concern” with even more strict guidelines proposed than that for nitrate. Any increase in nitrite must be further investigated. The lack of response for ammonia/ammonium is as expected as the treatment bed is inherently anaerobic and does not provide an environment conducive to ammonium oxidation. Initial fecal coliform results are inconclusive: some sample sets show good reductions while others may actually show MPN increases. Current hypotheses are that internal conditions of the PBR (temperature and pH/redox) are likely playing a role in changes to fecal coliform populations. With the weekly testing regime, it was not possible to closely relate changes in internal MPN to inlet counts. To test this question more fully, a sampling regime where several samples are collected within a single volume change of the reactor would likely be required.

CONCLUSION

A definite conclusion from this pilot study is that denitrifying woodchip bioreactors can work in a “Cascadia” climate regime, providing good reductions in nitrate concentrations even during the colder winter runoff season. Less conclusive are results regarding nitrite and fecal coliform reductions.

Questions for continuing research include:

- How does performance in the PRB change over time, particularly once the readily available carbon is fully utilized?
- How does the unit perform under varying hydraulic regimes? i.e., how do changes in outlet control box settings change HRT, internal conditions and resulting water quality results?
- Questions abound regarding fecal coliforms. A more rigorous test method that can capture changes within a treatment volume exchange should be considered.
- Is there pollution swapping? Potential aqueous (H_2S, methyl-mercury) and/or gaseous (NO, N_2O and CH_4) byproducts should be investigated.

- Does the colder temperature regime show significantly different results than other units operating in a warmer climate? Would it be possible to tease out in-situ temperature related microbial kinetics?

ACKNOWLEDGEMENTS

Funding and support for this project was provided by the Oregon Dairy Farmers Association, the Oregon Department of Agriculture and the Department of Biological and Ecological Engineering at Oregon State University. Special thanks go to Seth Spencer, Farm Manager, for providing on the ground assistance for the installation of this project.

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EVALUATING COVER CROPS FOR NITROGEN MANAGEMENT IN A WALNUT ORCHARD

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ABSTRACT

Cover crops provide numerous benefits in agricultural systems. From increasing soil water storage to reducing fertilizer inputs, quantify cover crops benefits is crucial in nutrient management, crop productivity, environmental sustainability, and adoption by growers. The goal of this study was to quantifying nitrogen (N) and carbon (C) inputs in a walnut (*Juglans regia* L. 'Chandler') orchard that implemented three cover crop mixtures. The study site was a 5-year-old walnut orchard located in Knight Landing, California. Cover crops treatments were planted in November 2019 and included clover mix, grass-clover mix, and commercial blend (Bell beans, peas, vetch, and oats). The control treatment consisted of resident vegetation. Soil cores (0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm depth) were collected before cover crop planting and after walnut harvest. Additionally, five in-season soil samplings were performed during the walnut growing period (0-15 cm, 15-30 cm depth). Soil samples were analyzed for ammonium (NH_4^+), nitrate (NO_3^-), and total C and N. Aboveground dry matter was measured before cover crop termination and analyzed for C and N content. The C and N inputs were compared among treatments. Dry matter production and C inputs differed among species. The average aboveground biomass was 3.37 Mg ha^{-1} in the clover, 3.31 Mg ha^{-1} in the grass-clover, 5.45 Mg ha^{-1} in the multiplex, and 3.33 Mg ha^{-1} in the resident vegetation. Cover crops significantly increased inorganic N ($NH_4^+ + NO_3^-$) availability in the top 30cm of soil profile during the walnut growing season compared to the control. Average inorganic N at the top 30 cm soil layer was 12.95 mg N kg^{-1} in the resident vegetation, 17 mg N kg^{-1} in the multiplex, 17.42 mg N kg^{-1} in the grass-clover, and 19.98 mg N kg^{-1} in the clover. The findings from this study are essential in developing N management guidelines for walnut orchards.

OBJECTIVE

1. Quantify C and N inputs from cover crops implemented in a young walnut orchard.

METHODS

Site Description

This study was conducted at the River Garden Farms, Knight Landing, California (38°55'23.88", 121°50'50.28", m.a.s.l. 8) in an established walnut orchard planted in 2015. The soils at the orchard are classified as Grandbend loam, Mollisols, OM 1.5% at the north side and Tyndall sandy loam, Inceptisols, 1.5% OM at the south side. The mean annual temperature is 16.62°C and the annual rainfall is 49.6 mm.

Cover Crop Treatments

Three cover crops mixes were planted on 18 November 2019 and included clover mix, grass-clover mix, and commercial blend commonly used in the region. A control with residential vegetation was included. The clover treatment incorporated a mixture of three Subterranean clovers (*T. subterraneum* L.) with different maturity times at a seeding rate of 28 kg ha^{-1}. The grass-clover treatment included a mixture of the previously describe Subterranean clovers and bromegrass at a seeding rate of 28 kg ha^{-1}. The commercial blend included bell bean, peas, vetch, and oats (Multiplex Max 90 kg ha^{-1}) in addition to a mix of brassicas at a very low seeding rate. Treatments were replicated four times. Mechanical termination through mowing varied among treatments due to different maturity times. Multiplex and resident vegetation treatments were terminated on 14 April 2020, and the grass and legume mixtures on 13 June 2020.

Carbon and Nitrogen Inputs

Aboveground biomass was clipped from four 1 x 1 m^2 quadrants in each cover crop treatment before cover crop termination. Cover crop and weeds biomass were separated and dried in the oven to obtain dry weights. Total carbon (C) and nitrogen (N) contents of plant tissues were measured using an elemental analyzer (Costech EAS 4010, Valencia, CA). The C and N inputs from implementing cover crops were calculated, multiplying biomass production by nutrient content.

Soil Measurements

Soil temperature and moisture were monitored weekly during the 2020 walnut growing season using soil sensors installed at 1ft depth in each cover crop treatment (n = 16) (TEROS 11, Meter Group Inc., Pullman, WA). Soil N status was measured after cover crop termination and five times during the walnut growing season. At cover crop termination, soil samples were collected using an ESP soil sampler at six depths (0-15, 15-30, 30-60, and 60-90 cm) in the tree line and cover crop planting area. For the in-season sampling, a composite soil sample was obtained from 0-15 and 15-30 cm depths using a soil auger. Soil samples were analyzed for pH, and inorganic N (ammonium and nitrate).

RESULTS AND DISCUSSION

Cover crop aboveground biomass varied from 3.31 to 5.4 Mg ha^{-1}, with the lowest production found in the grass-clover mix and the highest in the Multiplex blend (Table 1). The average biomass production in the clover mix was 3.37 Mg ha^{-1}. Because cover crops have been implemented only for 1-year (2019-2020), we were not expecting to find differences in weed suppression. However, preliminary data suggested weed biomass was the highest in the resident vegetation, followed by the Multiplex blend, the grass-clover mix, and the clover mix treatment. Clover showed potential in suppressing weeds, most likely due to its mat-forming growth pattern that increases groundcover.

Table 1. Aboveground cover crop biomass in dry weight (Mg ha^{-1}).

Treatment	Species	Biomass (Mg ha^{-1})
Clover mix	Clover	3.37 ± 1.56
	Weeds	0.64 ± 0.49
Grass-clover mix	Clover	1.04 ± 0.73
	Grass	2.27 ± 0.62
	Weeds	0.95 ± 0.59
Multiplex	Bell bean	0.15 ± 0.17
	Brassica	2.04 ± 1.5
	Oats	1.02 ± 1.01
	Peas	0.85 ± 0.68

	Vetch	1.4 ± 1.01
	Weeds	1.49 ± 0.96
Resident vegetation	Weeds	3.34 ± 0.72

During the walnut growing season, the clover mix and grass-clover mix treatments showed the highest soil moisture consistently during the walnut growing season (Figure 1). In contrast, the multiplex and control (resident vegetation) had the lowest moisture content associated with higher weed pressure measured in those treatments (Table 1). Soil temperature did not show apparent differences between cover crop treatments.

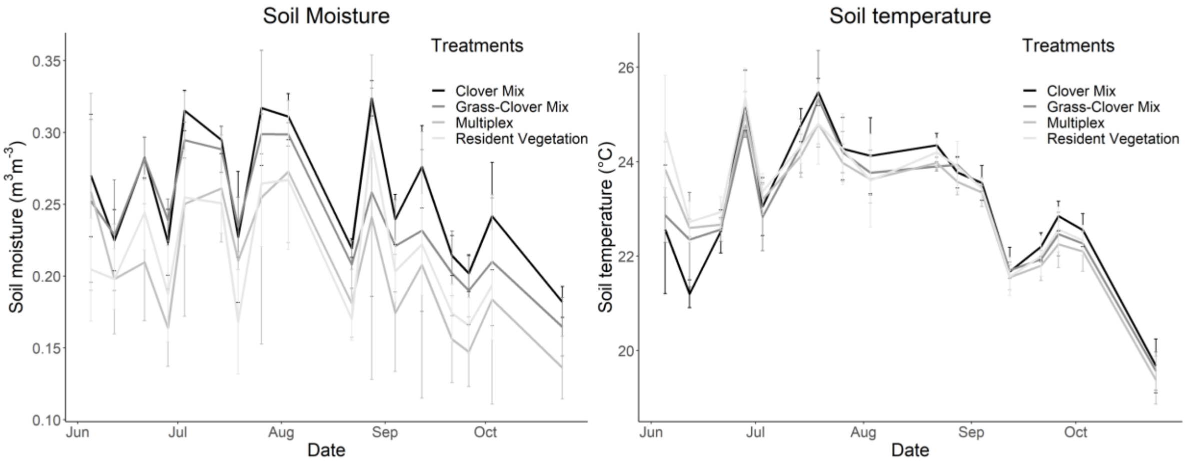

Figure 1. Soil moisture (left) and temperature (right) installed at 1ft depth during the 2020 walnut growing season.

Above and belowground biomass inputs from cover crops increased soil N mineralization compared to the control (resident vegetation) (Figures 2 and 3). At the topsoil 30 cm, clover increased N availability consistently during the walnut growing season with an average of 19.98 mg N kg^{-1}, followed by the grass-clover mix with 17.42 mg N kg^{-1}, and the Multiplex blend with 17 mg N kg^{-1}. Resident vegetation had the lowest soil inorganic N content, with an average of 12.95 mg N kg^{-1}. In summary, preliminary data after 1-year of implementing cover crops suggested that cover crops can increase C and N inputs in walnuts orchards. The highest soil N content was measured during late-July and early-August, with a decline later in the season. The seasonal increase in N availability under cover cropping found in this study occurred around the maximum N uptake in walnut trees. This information can also help growers improve N management in orchards as cover crops can release N in synchrony with crop N demand. Further research will compare current findings with leaf analysis performed in July and harvest yield.

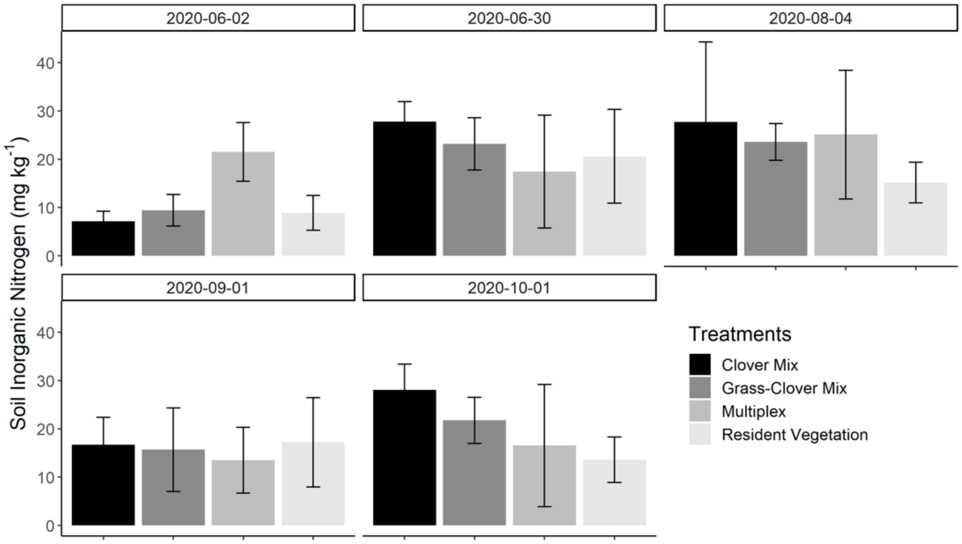

Figure 2. Soil inorganic N measured from 0 to 15 cm depth during the walnut growing season

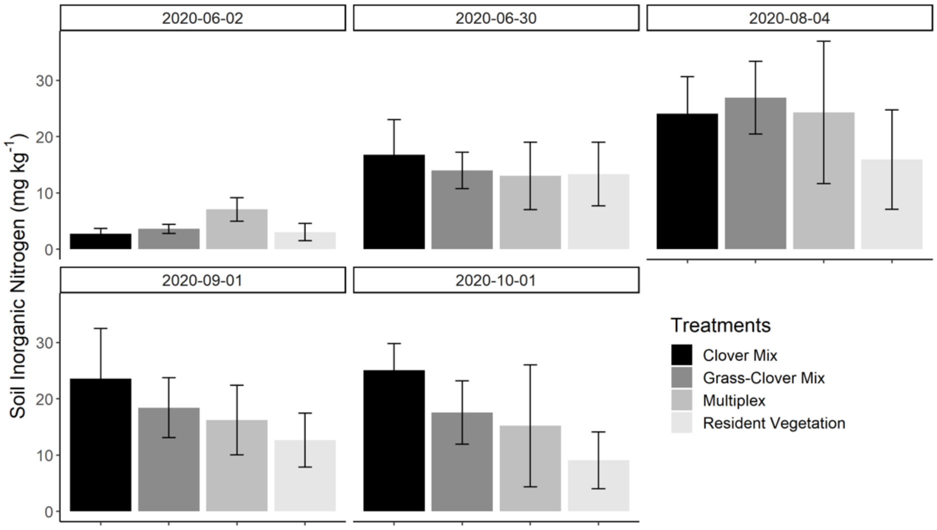

Figure 3. Soil inorganic N measured from 15 to 30 cm depth during the walnut growing season

REFINING NITROGEN MANAGEMENT FOR ORGANIC BROCCOLI PRODUCTION

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Specialty organic fertilizers used in organic vegetable production are expensive. So, from environmental and economic perspectives, growers want to maximize nitrogen (N) fertilizer use efficiency by the crop. This research was conducted to (1) determine sufficient N fertilizer rates for organic broccoli, (2) evaluate the efficacy of a specialty organic fertilizer (feather meal; 12-0-0), and (3) confirm the effectiveness of midseason soil nitrate analyses (0-30 cm) in determining appropriate sidedress fertilizer rates. Crop and soil response to feather meal application was compared to urea. Fertilizers were applied at rates of 0, 67, 134, and 202 kg N ha^{-1} (0, 60, 120, and 180 lb N $acre^{-1}$) via preplant broadcast or banded sidedress application (6 leaf stage). Two experiments were conducted in successive years in small plots within the same field (Newberg sandy loam; 2.3% SOM in 0-30 cm depth). Soil samples for midseason nitrate analysis were collected between rows at 0-30 and 30-60 cm depth at 39-43 d after seeding. Non-fertilizer N contributions were monitored. During the growing season, irrigation supplied 30-35 kg N ha^{-1}, and nitrate mineralized from SOM (buried bag method) supplied 70-110 kg N ha^{-1}. Broccoli was efficient in taking up N from the soil. With zero N fertilizer applied, aboveground biomass contained 155-185 kg N ha^{-1} at harvest. With fertilization, biomass contained 200-260 kg N ha^{-1} at harvest. Feather meal N mineralized rapidly to nitrate. At midseason, apparent nitrate-N recovery from soil (0-60 cm depth) accounted for 73% of the preplant feather meal N applied. At harvest, all fertilizer treatments were low in residual soil nitrate-N (< 20 kg ha^{-1} in 0-60 cm depth). Because of the high efficiency of crop N uptake from non-fertilizer sources, broccoli yield and N uptake were maximized with fertilizer rates of 67-134 kg N ha^{-1}. Broccoli head yield was maximized without sidedress N application when midseason soil nitrate-N concentrations were > 25-30 ppm (0-30 cm). Based on this research, we recommend applying a modest rate (40 to 70 kg N ha^{-1}) of feather meal or other fast-acting organic fertilizer when preplant NO_3-N is less than 20 ppm (0-30 cm depth). Sidedress N application can be omitted when soil NO_3-N exceeds 30 ppm nitrate-N (0-30 cm) at the 6 leaf stage.

INTRODUCTION

Matching N supply from organic fertilizers to the needs of a broccoli crop is a challenge. Nitrogen uptake by broccoli is limited (< 20 kg N ha^{-1}) during the first month after seeding. During this time, irrigation supplied by overhead sprinklers usually exceeds evapotranspiration and some nitrate leaching occurs from topsoil. From the 6 leaf stage to harvest, broccoli accumulates N rapidly (3 to 5 kg ha^{-1} d^{-1}), taking up 200-300 kg ha^{-1} at harvest, depending on plant population.

Under organic management, the amount of plant-available N mineralized from soil organic matter typically increases. Preplant N mineralization tests have proven ineffective in forecasting the rate of N fertilizer required to meet crop need. Therefore, current N management recommendations for conventional production are to apply a small amount of starter N fertilizer at planting and apply the rest of the N fertilizer based on a soil nitrate test collected just before the onset of rapid crop N uptake.

Feather meal is a specialty N fertilizer that is rapidly converted to nitrate in the soil. At typical summer soil temperatures in western Oregon (70 °F), approximately 60 % of feather meal N is mineralized to nitrate in 4 weeks, with an additional 15% of total N mineralized between 4 and 10 weeks (OSU EM 9235).

This research was conducted to (1) determine sufficient N fertilizer rates for broccoli, (2) evaluate the efficacy of a specialty organic fertilizer (feather meal; 12-0-0), and (3) confirm the effectiveness of midseason soil nitrate analyses (0-30 cm) in determining appropriate sidedress N fertilizer rates.

MATERIALS AND METHODS

Two experiments were conducted in successive years in separate locations within the same field (Newberg sandy loam; 2.3 % SOM in 0-30 cm depth) at the OSU Vegetable Research Farm near Corvallis, OR. Before our trials, the field was conventionally fertilized for 5+ yr. Subplots were 2.7 x 7.6 m (9 x 25 ft) in a randomized complete block design with 4 replications. *Cascadia*, an exerted head cultivar for mechanical harvest, was seeded and thinned to 52,000 plants ha^{-1} (21,000 acre^{-1}).

Fertilizer treatments compared N rate, timing and placement (Table 1). Feather meal was applied at rates of 0, 67, 134, and 202 kg N ha^{-1} via preplant broadcast or banded sidedress application (6 leaf stage), and compared to urea (134 kg N ha^{-1}). Fertilizers were broadcast preplant and immediately incorporated by tillage, or sidedressed at 42 days after planting (DAP) in 2018 and 45 DAP in 2019. Sidedress fertilizer treatments were applied by hand in a furrow 5-8 cm deep and 5-8 cm beside the row. Conventional management was used for weed and insect control.

Broccoli was seeded on 2 Jul 2018 and 3 Jun 2019. Heads were harvested 84-93 DAP in 2018 and 77-85 DAP in 2019. Heads were harvested by hand from 6 m (20 ft) of row.

Soil samples for nitrate analysis were collected between rows at 0-30 and 30-60 cm depth at the 6 leaf stage (39 DAP in 2018, and 43 DAP in 2019) and at final harvest. Three plants per plot were harvested to determine crop N uptake. Soil and plant analyses were performed by Brookside Laboratories, New Bremen, OH. Soil nitrate was determined by colorimetry. Plant N concentration was determined by combustion.

Non-fertilizer N contributions were monitored. During the growing season, sprinkler irrigation water was collected; it supplied 30-35 kg N ha^{-1} during the growing season. Moist soil (0-30 cm) was collected for an in-situ buried bag incubation before preplant fertilizer application. Incubation bags for N mineralization determination were installed in border rows within each replication the day after seeding as described by Sullivan and Moore (2017). We estimated "Unaccounted N" the balance between N supply and N recovery at harvest:

Unaccounted N = N supply - N recovered [Eq.1], where:

N supply = [fertilizer treatment N + soil N mineralization (buried bag; 0-30 cm) + NO_3-N applied in irrigation water + starter N applied with planter at seeding (22 kg ha^{-1})].

N recovered = Crop N uptake + postharvest nitrate-N (0-60 cm)

RESULTS AND DISCUSSION

Crop response to fertilization was more apparent in 2019 than in 2018. In 2019, less N was mineralized from soil organic matter than in 2018 (Figure 1). Crop response to fertilizer treatments is shown only for 2019 (Table 1; Figure 2). Maximum head yields in our trial were lower in 2019 (12 Mg ha^{-1}; Table 1) than in 2018 (20 Mg ha^{-1}; data not shown), even though maximum crop N uptake (200-260 kg ha^{-1}) was similar for both years. We attribute inconsistent yield response across years to interactions of variety x weather. Growers also reported inconsistent head yield for *Cascadia* in 2018-19.

Broccoli was efficient in extracting N from the soil. With only starter N applied at seeding (22 kg ha^{-1}), aboveground biomass at harvest contained 154 kg N ha^{-1} in 2019 (Table 1) and 185 kg N ha^{-1} in 2018 (data not shown). Maximum crop N uptake values measured in this trial are similar to those reported previously for broccoli grown in the Willamette Valley (PNW Extension 513). The amount of N mineralized from soil organic matter in this trial was similar to typical values (80-135 kg N ha^{-1}) measured across 25 conventional sweet corn fields in the Willamette Valley (Figure 5 in OSU EM 9165).

Calculations of apparent balance between total N supply (including non-fertilizer sources) and total N recovered (crop N uptake plus postharvest soil nitrate) demonstrated high efficiency of crop N uptake from non-fertilizer N sources. For the unfertilized control, unaccounted N (the balance between N supply and demand) was negative indicating more than 100% utilization of apparent N supply (Table 1). Unaccounted N was near zero for N fertilizer rates up to 67 kg ha^{-1} in 2018 and for N rates up to 134 kg ha^{-1} in 2019. Unaccounted N increased with feather meal N rate and was high (> 50 kg ha^{-1}) at feather meal N rates > 67 kg ha^{-1} in 2018, and at the highest N rate (202 kg ha-1) in 2019. High levels of unaccounted N are associated with an increased risk of nitrate leaching loss. Research conducted in the Salinas Valley of California also demonstrated high N removal efficiency for broccoli, associated with deep root system development.

Efficacy of feather meal as a fast-acting fertilizer for broccoli. Feather meal N mineralization was rapid following preplant application. Averaged across years, apparent midseason soil nitrate recovery averaged 54% of total N applied in 0-30 cm depth and 73% in 0-60 cm depth (slope of lines in Figure 3). In comparison, soil nitrate recovery from preplant urea treatments at midseason was close to 100% (data not shown). Findings in the present study for nitrate-N recovery from feather meal agree with Extension guidance (OSU EM 9235), which estimates 60% recovery of plant-available N at 4 weeks, and 75% recovery at 10 weeks following feather meal application.

Broccoli head yield with sidedress feather meal application was equivalent to preplant feather meal application in 2018, but yields with sidedress feather meal were lower than for preplant feather meal in 2019 (Figure 2). We attribute this difference in crop response between years to the amount of early season (0-40 DAP) soil nitrate present. When zero preplant N was applied in 2018, nitrate-N (0-30 cm) was 20-22 ppm from 0-40 DAP. In 2019, with zero preplant N, soil nitrate-N (0-30 cm) was 9-10 ppm from 0-40 DAP. Apparently, in 2019, sidedress feather meal application did not provide N early enough, and so crop growth was limited by N deficiency at the 6 leaf stage. Head yields with sidedress urea (faster nitrate release than feather meal) were similar to preplant feather meal or preplant urea at the same N rate (134 kg ha^{-1}; Table 1). In both years, the split feather meal treatment (67 kg N ha^{-1} at seeding plus 67 kg N ha^{-1} at sidedress) and the split urea treatment (67 + 67 kg N ha^{-1}) produced maximum head yields.

The failure of feather meal N to rapidly correct midseason plant N deficiency in 2019 is also seen in the distribution of head yields. With sidedress feather meal, head yield was delayed (fewer heads in the first harvest, more heads in the third harvest), compared to preplant urea or preplant feather meal. Head yields with the highest rate of feather meal were not different than the unfertilized control.

Midseason soil nitrate analyses as an indicator of N sufficiency. Broccoli head yield and biomass N uptake were maximized when soil nitrate (0-30 cm) was 30+ ppm at the 6-leaf growth stage (Figure 3). A considerable amount of nitrate was measured in the 30-60 cm depth. In-season leaching was expected, based on early-season irrigation water application. From 0 to 40 DAP, water supplied by irrigation plus precipitation exceeded cumulative ET by 15-16 cm (6 inches). From 0-40 DAP, irrigation supplied 21-24 cm, while cumulative ET was 6-8 cm during this time. For the rest of the growing season (40 DAP to harvest), the water application rate (17 cm) was approximately equal to cumulative ET (16 cm).

Averaged across all fertilizer treatments, midseason soil NO_3-N concentrations were 26 and 13 ppm in 0-30 and 30-60 cm depths, respectively. The amount of NO_3-N present in the 30-60 cm depth increased with preplant feather meal application rate, indicating that a portion of feather meal N mineralized and was leached to 30-60 cm depth during the first 40 d after seeding. The slopes of linear regression lines for feather meal N rate vs. nitrate-N recovery from soil suggest that about 20% of feather meal N was leached to the 30-60 cm depth (Figure 4).

SUMMARY AND RECOMMENDATIONS

1) Head yield was maximized with an N application rate of 67-134 kg ha^{-1}. The most consistent positive crop growth response was observed with split N application (67 kg ha^{-1} preplant, 67 kg ha^{-1} at midseason). Midseason N application can be omitted when the midseason soil nitrate test (0-30 cm) exceeds 30 ppm nitrate-N.

2) Feather meal N mineralized rapidly, almost as fast as urea. However, feather meal mineralized N too slowly to be effective as a midseason sidedress “rescue treatment” when soil nitrate was low (10 ppm NO_3-N). We advise applying preplant N (40 to 80 kg ha^{-1}) when a preplant nitrate test is low (< 20 ppm NO_3-N; 0-30 cm).

3) Broccoli did not respond to additional sidedress N fertilization when midseason soil nitrate-N exceeded 30 ppm. This finding agrees with current OSU Extension guidance for N management for Willamette Valley vegetable crops (OSU EM 9221).

4) Broccoli was extremely efficient in recovering N from the soil. Biomass N uptake at harvest was roughly equivalent to the sum of N supplied by fertilizer and non-fertilizer N sources (soil N mineralization, irrigation water) when appropriate fertilizer N rates were supplied (67 to 134 kg ha^{-1} in our trials). Because our trials were conducted on a field with low SOM (2.3%) and no history of manuring, we expect even lower N input requirements for commercial organic fields.

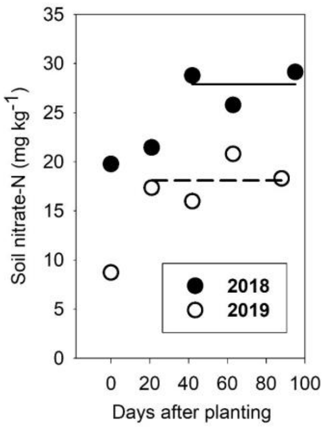
5) At harvest, broccoli plants contained 200-260 kg N ha^{-1}. Of this total N, about a third is removed in harvest, with the remainder returned in crop residues. Planting a cereal cover crop following a summer broccoli crop is strongly recommended to limit nitrate leaching loss over winter.

Table 1. Apparent balance between total N supply (including non-fertilizer sources) and total N recovered (crop N uptake plus postharvest soil nitrate). A positive number for unaccounted N indicates N supply was greater than N recovered[a].

Year	Trt ID[b]	Total N supply	Head yield (fresh wt)	Crop Biomass at harvest	Crop Biomass N conc.	Crop Biomass N uptake	Postharvest soil NO_3-N (0-60 cm)	Unaccounted N[b]
		kg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	%	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
2019	None	126	6.7	6.8	2.3	154	2	-30
2019	F 67/0	193	9.6	7.5	2.6	193	1	-1
2019	F 134/0	260	10.1	9.3	2.6	245	3	12
2019	F 202/0	328	10.8	8.1	2.9	238	6	84
2019	F 0/67	193	9.1	8.5	2.5	213	1	-20
2019	F 0/134	260	9.0	7.6	2.8	210	5	45
2019	F 0/202	328	7.7	6.9	2.8	193	2	134
2019	F 67/67	260	10.8	9.2	2.9	262	4	-6
2019	U 134/0	260	10.6	8.2	3.1	253	4	3
2019	U 0/134	260	10.3	7.1	3.0	213	3	44
2019	U 67/67	260	12.0	8.1	3.2	258	2	1
	PLSD 0.05		*2.5*		*0.4*	*56*		

[a] Unaccounted N = N supply - N recovered [Eq.1].

[b] Trt ID: F = feather meal, U = urea. Numbers indicate preplant/sidedress N applied (kg ha^{-1}). Example: F 67/67 is 67 kg N ha^{-1} preplant, with an additional 67 kg N ha^{-1} sidedressed at 6-leaf stage.



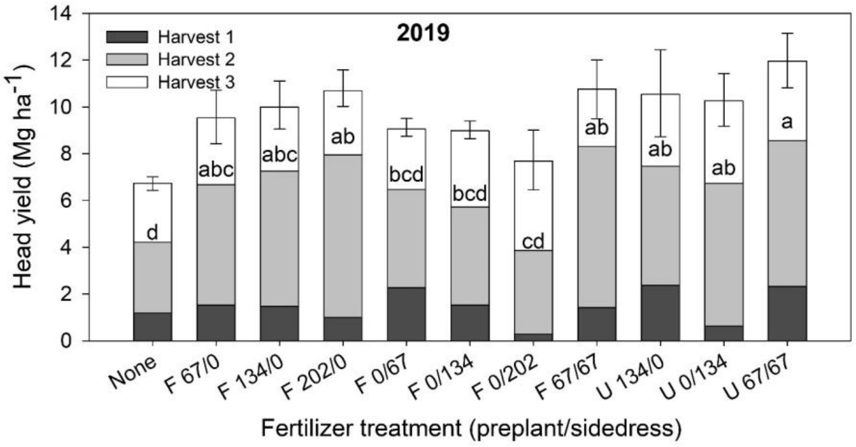


Figure 1 (left). Nitrate recovered from buried soil incubation bags placed in the field at planting time and destructively harvested during the growing season. Soil for the buried bag incubation was collected from 0-30 cm depth prior to preplant fertilizer application. Plateau nitrate-N concentrations were equivalent to 110 kg ha^{-1} in 2018 and 70 kg ha^{-1} in 2019.

Figure 2 (right). Cumulative fresh weight broccoli head yields from three successive harvests in 2019. Letters above bars denote mean separation (PLSD 0.05). Trt ID: F = feather meal, U = urea. Example: F 67/67 is 67 kg N ha^{-1} preplant, with an additional 67 kg N ha^{-1} sidedressed at 6-leaf stage.

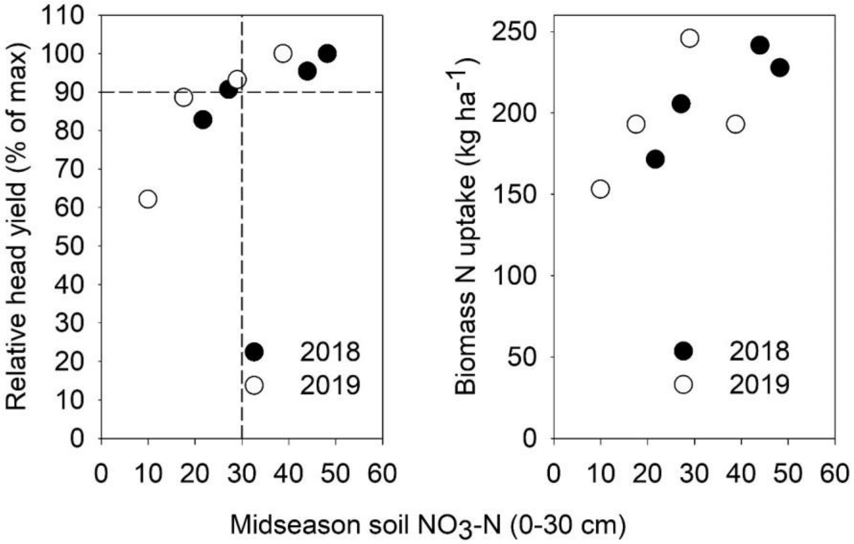


Figure 3. Midseason soil nitrate-N (0-30 cm) for preplant feather meal N treatments (0, 67, 134 and 202 kg ha^{-1}) vs. relative head yield (left), and biomass N uptake at harvest (right). Fertilizer treatments with more than 25-30 mg kg^{-1} nitrate-N in soil at midseason had head yields equivalent to 100% relative yield (P = 0.05; left), and biomass N uptake averaging 230 kg ha^{-1} (right).

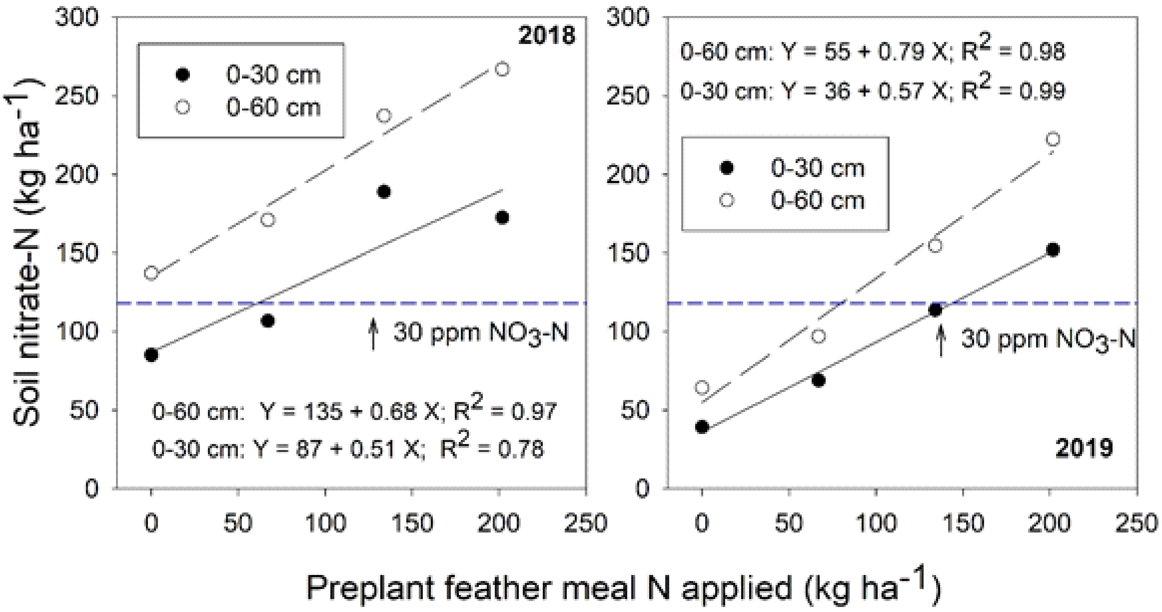


Figure 4. Soil nitrate in 0-30 and 0-60 cm depth at midseason following a preplant feather meal application. The target value for sufficient nitrate-N at midseason is 30 ppm (118 kg N ha^{-1}; OSU EM 9221) in a 0-30 cm depth soil sample (dashed horizontal line). Soil bulk density of 1.3 g cm^{-3} was used in converting ppm to kg ha^{-1}.

DOES POST-HARVEST NITROGEN APPLICATION AFFECT BLUEBERRY YIELD OR COLD-HARDINESS?

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ABSTRACT

In central Washington, nitrogen (N) management in blueberries typically consists of all N being applied prior to harvest. For early cultivars, such as Duke, this means all fertilizer is applied before the end of June, leaving a long period of growth with no supplemental N. To evaluate the potential for splitting N fertilizer applications into pre- and post-harvest timings, we conducted an experiment in a randomized complete block design with four replicates on a commercial, organically managed 'Duke' blueberry field for three years (2018 - 2020). Treatments were 100, 80, 70 or 60% of the N fertilizer (140 kg/ha) applied pre-harvest and the remaining 0, 20, 30, or 40% applied post-harvest. All treatments were made using WISErganic 3-2-2 (WISErg, Redmond, WA) liquid fertilizer in a simulated drip application on a weekly basis. Yield was determined by hand picking fruit from the center three plants in each 16-plant plot. Fruit from each plant was weighed and a subsample of at least 100 g of ripe fruit were collected and fruit quality assessed by measuring soluble solids, pH, titratable acidity, and fruit firmness. Soil and leaf tissue samples were collected to evaluate plant nutritional status in August of each year, after all fertilizer applications were complete. Since late season applications of N may reduce acclimation, each year cold-hardiness was monitored through late fall to early spring. Timing of the N applications did not affect yield, fruit quality, or leaf tissue N status but cold-hardiness decreased with increasing lateness of N applications. However, since plants remained cold-hardy to a temperature far below the average monthly temperature minimums for the region, later season application of N would not be a risk.

INTRODUCTION

Historically in northern highbush blueberry (*Vaccinium coryumbosum* L.) production in the Pacific Northwest, all nitrogen (N) fertilizer is applied prior to harvest (Hart et al., 2006). Post-harvest N fertilizer applications may stimulate excessive vegetative growth that can reduce floral bud set for the following season and increase the risk of winter injury by delaying acclimation (Caruso and Ramsdell, 1995; Hart et al., 2006). However, early season blueberry cultivars planted in a region with a long growing season may have two or more months of growth after harvest. While soils with high concentrations of organic matter may be able to release N post-harvest to benefit plant growth, soils with low organic matter content may not effectively release N, making post-harvest N fertilizer applications beneficial.

Bañados et al. (2012) observed that dry weight allocation and N derived from fertilizer continues to increase in leaves and shoots after harvest in highbush blueberry through Sept. in Oregon. These observations suggest that post-harvest fertilization with N in perennial crops like blueberries may contribute to the N storage pool in plant tissues that could be used later via reallocation according to plant needs in subsequent years. Abbott and Gough (1987) also observed that root growth in highbush blueberry occurs post-harvest, often in late July or early Aug. as soil temperature decreases. Bañados et al. (2012) also noticed total N concentrations and N derived from fertilizer increased in root tissues during this period, further supporting the idea that there may be benefits of post-harvest N applications in blueberry.

The objective of this study was to evaluate splitting N fertilizer across a combination of pre- and post-harvest applications in early season blueberry grown on low organic matter soils in central Washington. In addition to impact on yield and fruit quality, we evaluated how crop cold hardiness might be affected.

MATERIALS AND METHODS

An on-farm study was established in Prosser, Washington in Feb. 2018 on a commercially managed organic 'Duke' field (lat. 46º16'24.7" N, long. 119º44'56.5" W). The soil is classified as a Warden silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids) (USDA-NRCS, 2019) and the plants were in their eighth growing season, established on raised beds (approximately 0.3 m high) mulched with apple (*Malus ×domestica* Borkh.) and sweet cherry (*Prunus avium* L.) wood chips. Planting rows were in a north-south orientation with plants spaced 0.76 m apart within the row and 2.7 m between rows (4873 plants/ha).

Plots were established in a randomized complete block with four replications with each plot consisting of 16 plants in a single row, resulting in a plot size of 18 m X 0.76 m. Fertilizer applications began in at approximately 10% bloom, on 17 April 2018, 25 April 2019, and 9 April 2020. Using the organic fertilizer WISErganic (WISErg Corporation, Redmond, WA, 3N-0.9P-1.6K), a liquid fertilizer derived from digested plant materials, was applied to provide 130 $kg \cdot ha^{-1}$ N. The rate of fertilizer applied each week was adjusted to apply the following treatments: 1) Control (100% of N applied pre-harvest; standard grower practice); 2) 80/20 (80% of N applied pre-harvest, remaining 20% applied post-harvest); 3) 70/30 (70% of N applied pre-harvest, remaining 30% applied post-harvest); and 4) 60/40 (60% of N applied pre-harvest, and remaining 40% applied post-harvest). Each year the control treatment received a total of 10 fertilizer applications (all pre-harvest), the 80/20 treatment received 12 fertilizer applications (10 pre-harvest, 2 post-harvest), the 70/30 treatment received 14 fertilizer applications (10 pre-harvest, 4 post-harvest), and the 60/40 treatment received 16 fertilizer applications (10 pre-harvest, 6 post-harvest). Fertilizer applications were suspended the week before, during and one week post harvest.

Plants were fertilized in a simulated drip application by applying the product around the crown of the plants and near the root zone under the dripline. Plants were irrigated throughout the growing season and sufficient irrigation water was provided to ensure the fertilizer moved into the rootzone. Soil temperature was monitored using HOBO® loggers (Onset Computer, Bourne, MA) installed at 30 cm depth in the control treatment plots. Temperature data were recorded every 20 minutes. Also, air temperature data were taken from AgWeatherNet station installed at IAREC, Prosser, WA (Fig. 1)

Total yield (kg/plant) was determined by hand harvesting the center three plants per plot on 26 June 2018, 9 July 2019, and 2 July 2020, with fruit from each plant weighted separately. A random sample of 50 fully ripe berries were sampled from each plot for analysis of fruit quality. Average berry mass and firmness were evaluated within 48 hours of harvesting from 30 fully ripe berries per plot. Berries were weighed on a precision weighing scale (Mettler Toledo PB 303-S/Fact, Mettler Toledo, Columbus, OH, US). Firmness was measured using a FirmTech II (Bioworks Inc., Wamego, KS) with maximum and minimum compression forces of 200 g (1.96

N) and 15 g (0.15 N), respectively. Piston speed was configured to 6 mm·s^{-1}. All berries were then frozen at -23˚C until fruit quality analyses could be conducted. Soluble solids concentrations (°Brix) were determined using a digital refractometer (H19680, Hanna Instruments, Woonsocket, RI) from juice collected after manually crushing 50 berries per plot and straining through cheesecloth. Initial juice pH and titratable acidity were measured using a digital titrator with a pH probe (HI-84532, Hanna Instruments, Woonsocket, RI).

Cold-hardiness of floral buds was evaluated after all three growing seasons using a custom built “polar pod” machine. The polar pod machine consisted of individual chambers each wrapped with temperature controlling heating pads around them which regulate the temperature for each chamber to temperatures appropriate for the time of season. In Oct. 2018, polar pod temperatures were set at -13° C to -19° C. In Nov. and Dec. pods were kept at -17° C to - 23° C and - 19° C to - 28° C, respectively (Gwen Hoheisel, personal communication). Samples were removed at -1° C interval within each temperature range. Each pod contained three lateral shoots from each plot and each lateral contained three fully developed floral buds wrapped in aluminum foil. Lateral shoots were collected from each plots in the morning (~ 0600 hr) and pre-processed by removing the vegetative buds and additional wood. Buds were exposed to the low temperature treatment for 24h, then thawed for 24h at room temperature (23° C), and dissected to count the number of dead and alive flowers per bud (Mills et al., 2006).

Leaf tissue samples for tissue nutrient analyses were collected on 13 Aug. 2018, 27 Aug. 2019, and 25 Aug. 2020 from the inner ten plants per plot. Four fully expanded leaves, two from each side of the plant, were collected from mid-canopy height (n = 40 leaves per plot). Collected leaves were oven-dried at 60º C for 48 hours and ground to <40 mesh with a Wiley Mill (Thomas Scientific, Swedesboro, NJ). Total N in leaf tissues were analyzed using dry combustion (Sweeney, 1989) on a LECO C-N-S analyzer (LECO CHN628, LECO Corporation, St. Joseph, MI).

Data were first evaluated for normality and equal variance using Shapiro-Wilk and Levene’s test, respectively. Significant interactions between treatment, year, and treatment by year were analyzed for using analysis of variance (ANOVA) with a Tukey’s Honest Significant Difference (HSD) *posthoc* test for multiple comparisons using RStudio (R Core Team, Ver. 1.1.456; RStudio, Inc., Vienna, Austria).

RESULTS AND DISCUSSION

Crop yield and the fruit quality factors firmness and berry mass varied with year but there were no differences with the timing of N fertilizers (Table 1). The yield trends show a slight but not statistically significant trend for increased yield when 30 or 40 percent of the N was applied post-harvest. Additionally, leaf N concentration differed by year but not by timing of N fertilizer application (Table 1). This suggests that including some post-harvest N fertilizer applications could be an advantage to early season blueberries grown in this region, supporting both above and below ground growth (Bañados et al., 2012).

Late season N applications frequently raise the concern about late season growth being tender and predisposing plants to reduced cold hardiness. There was decreased cold hardiness in Oct., Nov, and Dec. 2018 when a greater proportion of the N was applied post-harvest (Fig. 1). However, after the 2019 and 2020 growing season, cold hardiness did not show a clear trend of being lower with later season applied N (Table 2). Perhaps equally important is how the cold hardiness compares to the temperatures found in this region during the cold months. In October

2018 (Fig. 2) and 2020 (Table 2), there was no significant drop in cold hardiness unless temperatures were below -17ºC. For November (2018 and 2019, Fig. 2 and Table 2) the outdoor air temperature had to reach -19ºC before there was at least 10% bud damage. Looking at long term (18 year) temperatures recorded for the area (Fig. 1), the lowest temperatures in October, November and December were 2, -2, and -6ºC, respectively. This suggests that post-harvest N application is not likely to adversely affect cold hardiness in this region.

The overall conclusion from this work is that there could be an advantage to applying a proportion of N fertilizer post-harvest in early season blueberry and concerns of reduced hardiness to temperatures relevant for the region were not realized. Our results suggest that up to 40% of the N may be applied post-harvest.

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Table 1: Blueberry yield and quality as well as leaf tissue nitrogen (N) concentration after treatment with different post-harvest nitrogen (N) fertilizer application times in Prosser, Washington, 2018-2020. Treatments included 60/40 with 60% of N applied pre-harvest and the remaining 40% applied post-harvest, 70/30 with 70% of N applied pre-harvest and the remaining 30% applied post-harvest, 80/20 with 80% of N applied pre-harvest and the remaining 20% applied post-harvest, and control with 100% of N applied pre-harvest (standard grower practice).

Parameter	Yield (kg/plant)	Berry mass (g/berry)	Firmness (g/mm deflection)	Leaf Total N[x] (%)
Year				
2018	6.62 b[z]	1.7 b	199 a	1.63 a[z]
2019	7.08 b	2.8 a	156 c	1.53 b
2020	8.44 a	1.9 b	176 b	1.50 b
Fertilizer				
60/40	7.89	2.1	178	1.55
70/30	7.53	2.1	172	1.57
80/20	6.89	2.2	179	1.55
Control	7.08	2.2	178	1.55
Significance [y]				
Year (Y)	0.0001	0.003	0.002	0.001
Treatment (T)	0.245	0.737	0.811	0.895
Y X T	0.703	0.005	0.851	0.807

Table 2: Percent floral bud injury of 'Duke' blueberry after treatment with different post-harvest nitrogen (N) fertilizer application times in Prosser, Washington. Treatments included 60/40 with 60% of N applied pre-harvest and the remaining 40% applied post-harvest, 70/30 with 70% of N applied pre-harvest and the remaining 30% applied post-harvest, 80/20 with 80% of N applied pre-harvest and the remaining 20% applied post-harvest, and control with 100% of N applied pre-harvest (standard grower practice). Data presents percent floral bud injury for buds exposed to progressively colder temperatures on 4 Nov. 2019, 18 Nov. 2019, 20 Feb. 2020, and 26 Oct. 2020.

		Floral bud injury (%)			
Date	**Temperature (°C)**	**60/40**	**70/30**	**80/20**	**Control**
4-Nov-19	-20	1.4	8.3	8.6	14.3
	-21	16.9	9.0	26.2	8.8
	-22	29.9	26.0	34.8	8.1
	-23	22.0	27.3	47.4	41.1
	-24	54.2	56.8	43.8	40.6
	-25	82.5	66.7	69.1	62.5
	-26	72.8	88.1	85.5	85.1
	-27	83.8	87.5	94.1	85.7
18-Nov-19	-21	12.0	2.2	16.4	8.1
	-22	34.8	24.6	13.4	9.2
	-23	25.9	22.7	28.6	35.9
	-24	50.7	70.0	46.5	59.7
	-25	52.7	75.3	63.2	80.0
	-26	87.9	86.7	79.1	71.2
	-27	79.2	90.8	80.3	97.0
20-Feb-20	-16	1.6	12.3	35.6	13.3
	-17	11.9	76.3	39.3	20.8
	-18	54.4	19.0	55.7	70.7
	-19	86.6	90.8	36.5	71.9
	-20	93.2	86.9	91.2	98.2

26-Oct.-20	-15	1.6	1.5	0.0	0.0
	-16	6.0	9.9	0.0	3.2
	-17	1.6	4.6	8.6	1.7
	-18	18.3	8.1	26.4	30.4
	-19	31.9	18.5	20.3	30.3
	-20	44.2	57.8	31.6	36.2

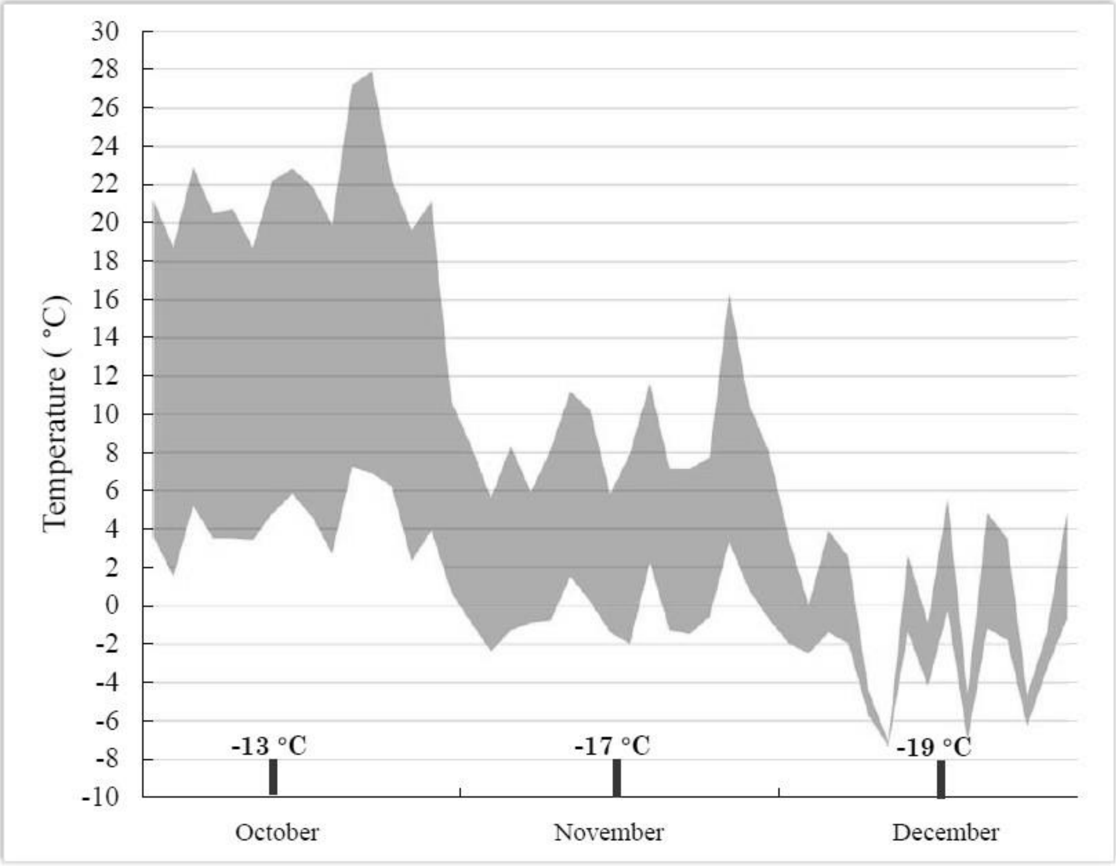

Figure 1. Yearly minimum and maximum temperature (°C) in Oct., Nov., and Dec. from 1990 to 2018 for Prosser, WA. Bars represent temperature where damage first occurred in October 2018.

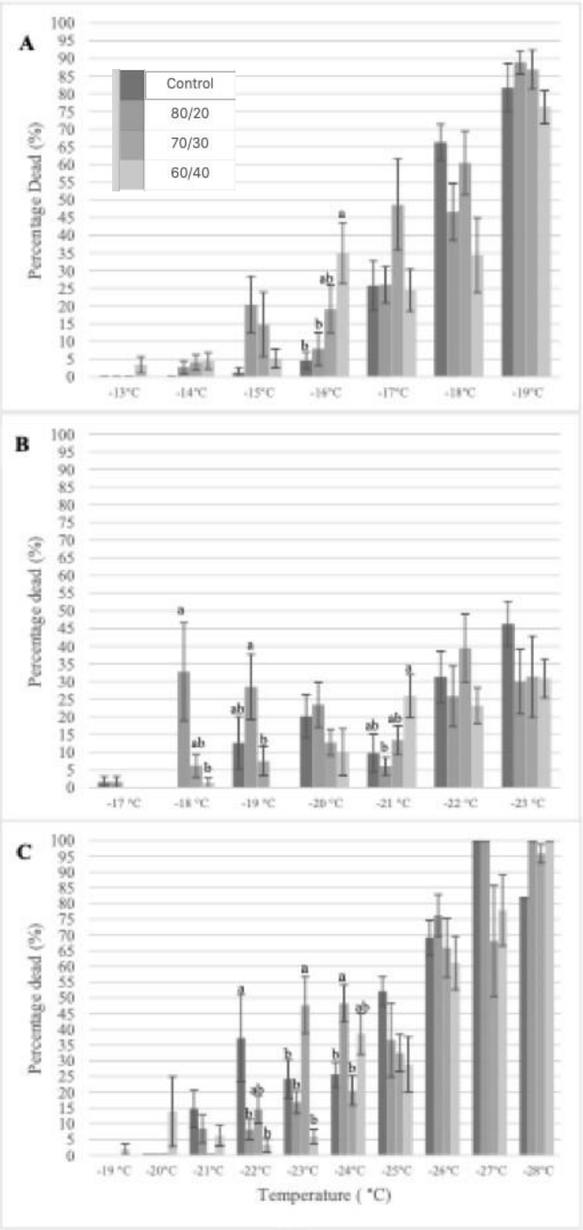

Figure 2. Average floral bud death in when exposed to progressively colder temperatures in ‘Duke ’ blueberry treated with nitrogen (N) fertilizer treatments that varied in the timing of application treatments in 2018. Treatment included Control with 100% of N applied pre-harvest (standard grower practice), 80/20 with 80% of N applied pre-harvest and the remaining 20% applied post-harvest, 70/30 with 70% of N applied pre-harvest and the remaining 30% applied post-harvest, and 60/40 with 60% of N applied pre-harvest and the remaining 40% applied post-harvest in eastern Washington. Error bars represents standard error between treatments. **A** = Oct.; **B** = Nov., **C** = December, all 2018.

ASSESSING NUTRIENT UPTAKE AND ACCUMULATION IN HOP PRODUCTION

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ABSTRACT

Hop growing practices and market demands have both evolved in the past 30 years. Oregon hop growers need updated information on the timing and quantity of nutrients in order to better time nutrient applications to achieve optimal yields and quality and reduce environmental losses. During the 2020 growing season, total biomass and nutrient concentration samples were taken at seven time points in three commercial hop yards of Cascade cultivar. Mean N, P, K, and S accumulation were 114, 16, 95, and 24 lb/ac/season, respectively. Cones accumulated proportionally more P, K, S, and Zn than vegetative biomass, and less Mg and Ca. Maximum nutrient uptake for most nutrients was observed around early July and reached over 2 lbs/ac/day for N uptake. N uptake rates declined relatively sharply as the season progressed, while for other nutrients the rate of uptake slowed, but not as dramatically. Data reported here is the first of a three year study that aims to generate uptake and accumulation data that can be expressed relative to a range of growth and development metrics (calendar date, growing degree accumulation and growth stage) to provide growers with robust data that can be translated between sites and years.

INTRODUCTION

Commercial hop production practices and cultivars have changed in the past 25 years and there is a need for updated nutrient management information under cotemporary practices. Current nutrient accumulation and uptake curves are only available for nitrogen (N). Current regional nutrient management guides from Oregon State University and Washington State University date back to the 1990's or earlier (Gingrich et al., 2000, Roberts, S. and Nelson, S.E., 1961). In the meantime, market forces and breeding efforts have led to a proliferation of new varieties, many of which are higher yielding than when this original nutrient work took place. At the same time, winters may be less severe and with altered precipitation patterns; together these factors have potentially shifted nutrient uptake profiles and demands. In parallel, management practices have evolved, and many hop yards now use drip irrigation where they have the capacity to dose fertilizer throughout the growing season. Recent data shows that excessive or late (post-bloom) N applications may cause a decline in cone quality with a decrease in alpha and beta acids and an increase in cone NO_3^- (Iskra et al., 2019). In response to these changing practices and increasing knowledge, growers and the hop industry have expressed a need for updated data on the rate and timing of nutrient uptake and improved methods of determining in-season nutrient status. Growers are also interested in micronutrient demands, in particular for zinc, boron, and iron.

METHODS

Three hop yards of Cascade cultivar, located in Marion County, Oregon, were selected for this project. All yards were under drip irrigation. In each yard, three sampling zones were established and considered as replicates. In total, there were three yards with three replicates each, n=9. The following data was collected in the 2020 season: pre-season and post-harvest soil samples (March 12 and September 21, respectively) at 0-8” and 8-24”, biomass and nutrient concentration samples at seven time points, petiole N, P, K at four time points, nutrient availability as measured by plant root simulator probes, hop yield and hop cone quality. At time points 1 and 2, whole plant biomass was collected; at time points 3-6 biomass was partitioned into side arms and main stem; at the final sampling (i.e. harvest) biomass was split into side arms, side arm cones, main stem and main stem cones. Growers followed their own nutrient program for rates and timing based on individual goals and constraints, soil tests, and consultation with agronomists. The goal was to evaluate nutrient uptake and availability under business as usual standard practices (Table 1).

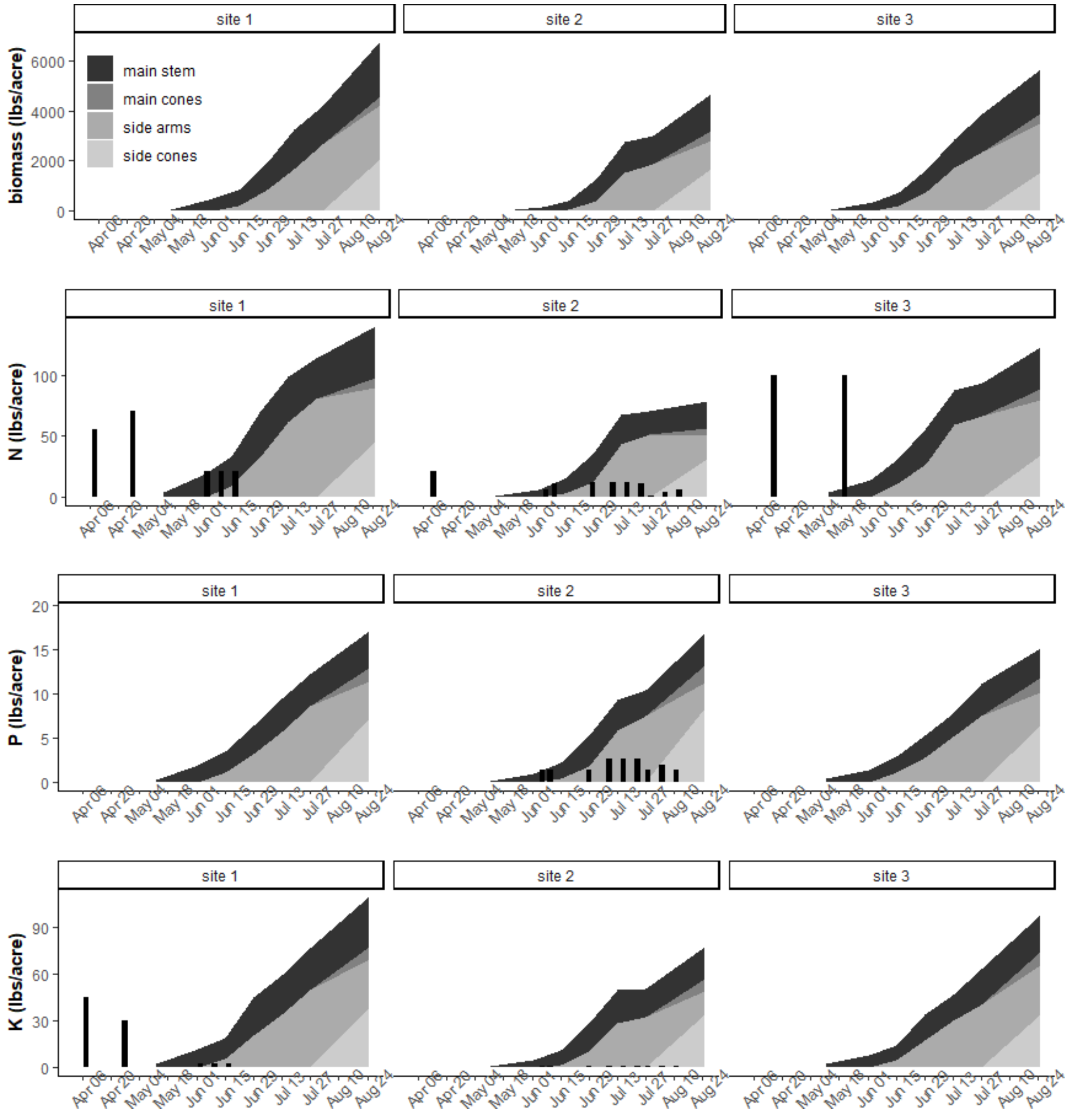
Table 1. Yard structure and management across the three sites in 2020

Yard Structure	
yard size	10-15 acres
yard age	planted 2013-2017
irrigation	drip
row cover cropping (winter/spring/summer/combo)	barley or diverse mix
row cultivation (approx. number of passes)	1.5 to 5 passes/season
2020 Management	
Mechanical pruning	28-Feb to 25-Mar
Chemical pruning	10-Apr to 28-Apr
training date	5-May to 7-May
number of fertilizer applications	2 to 12
irrigation sets per season	15 to 72
total irrigation inputs (gal/ac)	126,000 to 314,000 gal/acre
harvest date	26-Aug to 7-Sep
yield (bales/ac)	8 to 9.4 bales
2020 fertilizer application totals	**lbs/acre**
N	127 to 200
P	0 to 36
K	0 to 83
S	25 to 58
Mg	0 to 11
Ca	0 to 4
B	0 to 1

RESULTS AND DISCUSSION

Whole plant biomass accumulation ranged from 4675 ± 1020 lb/ac to 6781 ± 639 lb/ac, with a mean across sites of 5701 ± 1341 lb/ac (Figure 1 and Table 2). Whole plant N accumulation ranged from 78 ± 15 lb/ac to 140 ± 13, with an average across sites of 114 lb/ac N. Following N, K and Ca had the highest accumulation with around 100 lb/ac seasonal uptake. Mean P, S, and Mg were 16 ± 4, 24 ± 8, and 9 ± 2 lb/ac, respectively. Complete seasonal uptake data for all nutrients is given in Table 2.

Figure 1. Biomass, N, P and K accumulation and partitioning at each site (n=3 per site). Data was collected at seven time points. Immature cones were present at the sixth time point but were not separated, thus their biomass is included in the side arm and main stem category at this point. Fertilizer rate and timing is indicated as bars on the cumulative N, P and K uptake graphs.



The rate of nutrient accumulation and partitioning to side arms vs main stem and later to cones vs vegetative biomass did not differ greatly among the sites (Figure 1 and Table 2). Across all sites, side arm tissue accounted for the majority of uptake and nutrient accumulation, accounting for between 60-63% of biomass across the sites. Much of the side arm uptake could be attributed to the large amount of cones produced on side arms, accounting for more than 80% of cone biomass. Analysis of the cone biomass alone showed that on average 37% of biomass at harvest was in the cones, however the cones accounted for 56% of P, 45% of K and 44% of S and Zn, demonstrating that higher rates of these nutrients are being allocated to cones. In contrast, Mg and Ca were disproportionately allocated to vegetative biomass (Table 3).

Table 2. Nutrient accumulation at harvest in the different biomass components. Values are the means and standard deviation across all three sites (n=9).

	main stem	*stdev*	main cones	*stdev*	side arms	*stdev*	side cones	*stdev*	whole plant	*stdev*
					lb/ac					
biomass	1830	*530*	360	*190*	1740	*550*	1770	*390*	5700	*1340*
N	33	*12*	8	*5*	36	*14*	37	*8*	114	*34.5*
P	4	*1*	2	*1*	4	*1*	7	*2*	16	*3.9*
Mg	8	*3*	1	*1*	9	*4*	6	*1*	24	*7.6*
K	26	*7*	8	*5*	26	*9*	35	*8*	95	*22.8*
Ca	41	*12*	3	*2*	39	*14*	19	*4*	103	*26.3*
S	2	*1*	1	*0*	3	*1*	3	*1*	9	*2.3*
B	0.011	*0.002*	0.002	*0.000*	0.011	*0.002*	0.009	*0.002*	0.031	*0.006*
Fe	0.040	*0.015*	0.009	*0.007*	0.051	*0.022*	0.046	*0.011*	0.146	*0.047*
Zn	0.007	*0.004*	0.002	*0.000*	0.007	*0.002*	0.007	*0.002*	0.020	*0.006*

Table 3. Biomass and nutrient accumulation in cones only. Values are the mean across all three sites and sampling zones (n=9)

	main cones			side cones			all cones	
	lb/ac	% total biomass	% cone biomass	lb/ac	% total biomass	% cone biomass	lb/ac	% total biomass
biomass	360	6%	17%	1770	31%	83%	2130	37%
N	8	7%	18%	37	32%	82%	45	39%
P	2	13%	22%	7	44%	78%	9	56%
Mg	1	4%	14%	6	25%	86%	7	29%
K	8	8%	19%	35	37%	81%	43	45%
Ca	3	3%	14%	19	18%	86%	22	21%
S	1	11%	25%	3	33%	75%	4	44%
B	0.002	7%	20%	0.009	29%	80%	0.011	36%
Fe	0.009	6%	16%	0.046	32%	84%	0.055	38%
Zn	0.002	11%	25%	0.007	33%	75%	0.009	44%

Analysis of uptake rates, showed that peak uptake for most nutrients occurred in early July (Figure 2). As the season progressed, N uptake rates dropped quite sharply, while that of P and K remained relatively high. Given that the cones accumulated greater amounts of P and K and were developing during this latter part of the growing season, this likely drove the continued higher uptake of these nutrients. Peak K uptake occurred a bit earlier than with other nutrients and then remained steady around 1 lb/ac/day through the season. We do not have a good explanation for the drop in micronutrient uptake rates seen in B and Fe at the end of July; this may be an artifact of sampling, dust deposition, or may reflect true changes in plant demand.

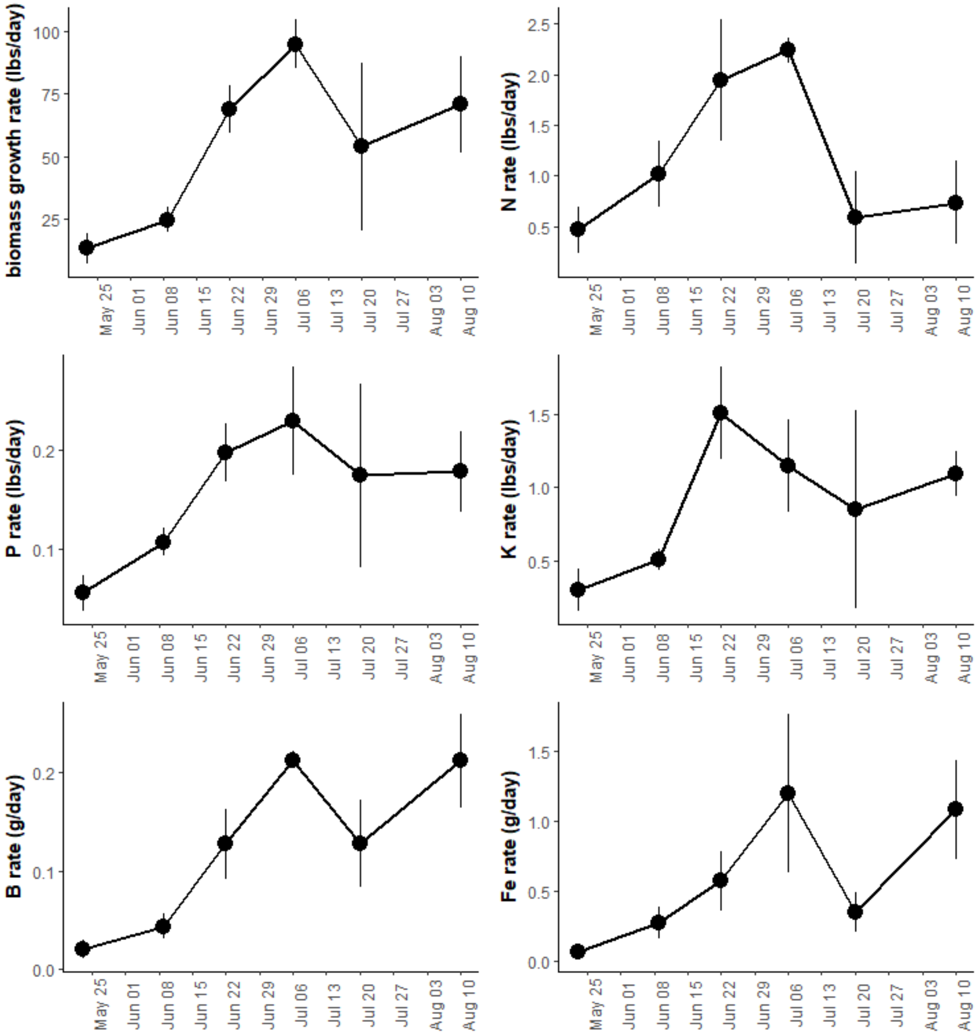
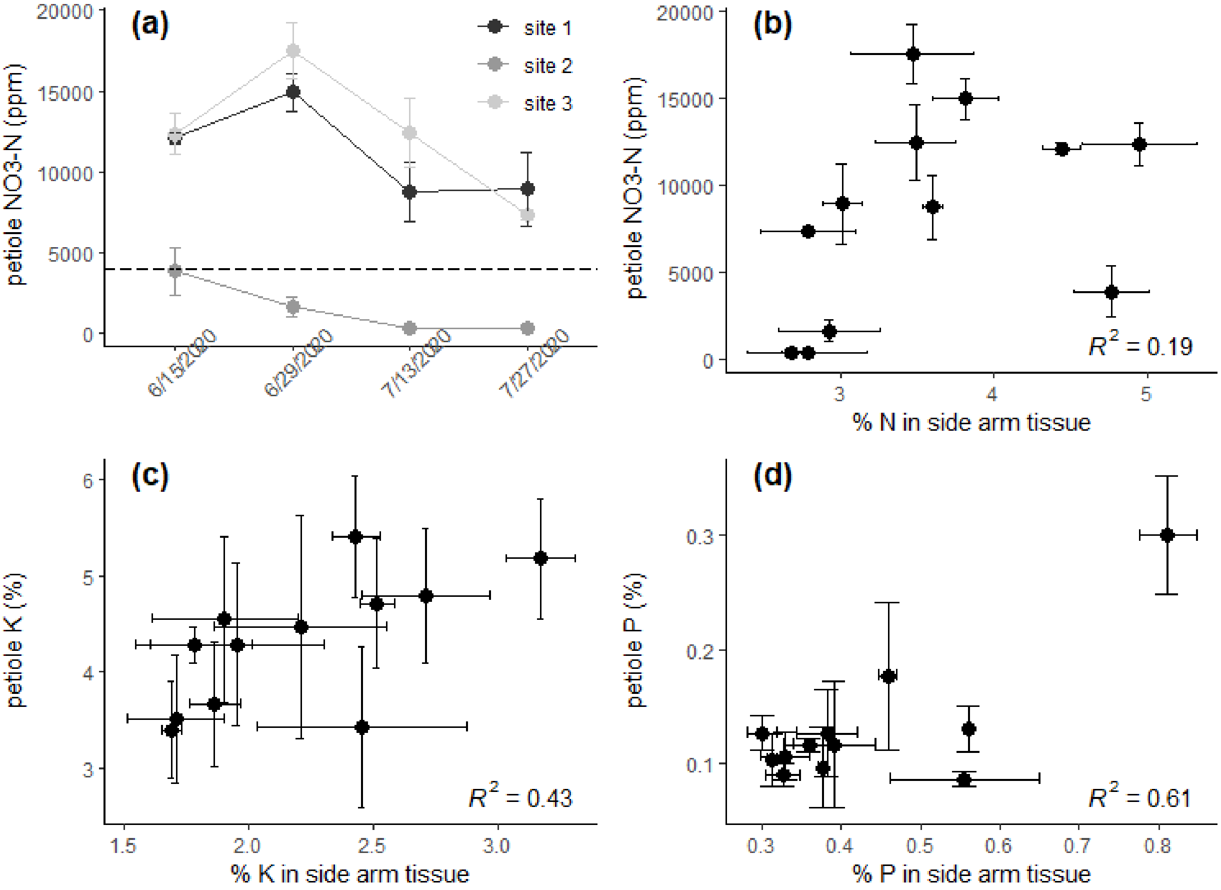


Figure 2. Biomass and nutrient uptake rates. Rates are on a per acre basis and are the mean ± stdev across the three sites.

The standard petiole sampling time for hops is around mid-June or when the hops are between ¾ to fully at the wire, indeed this was right at our first petiole sampling date on June 15th. While data to support sufficiency or deficiency thresholds based on petiole tissue tests is scant for hops, we do have thresholds for NO3-N and these indicate a deficiency when less than 4000 ppm at this mid-June timing. Based on this, petiole data at site 2 was right on the cusp of being considered N deficient, while the other two sites were likely in N excess (Figure 3). Better linkages between petiole tissue data to plant deficiency/sufficiency status remains a need. We found that relationships between petiole tissue data and side arm tissue concentrations showed modest correlations for K, relatively poor correlations for N and likely for P when a potential outlier is excluded (Figure 3). More data and further analysis are needed to determine how petiole tissues can be better used as means to evaluate in-season nutrient status.

Figure 3. (a) NO_3-N in petiole tissue at the three sites over the four sampling points. (b-d) Comparison of side arm biomass nutrient concentration and petiole nutrient concentrations. A comparison with main stem tissue revealed similar patterns.



The aim nor design of this study was to compare practices between sites. However, some information can be gleaned from looking at the individual site date and management practices. Site 2, had the lowest rate but highest number off N applications at 127 lb/ac/season over 12 applications compared to 188 lb/ac/season over 5 applications and 200 lb/ac/season over two applications at sites 1 and 2, respectively. It is likely that site 2 was N deficient at times during the growing season, evidenced by petiole tissue data from this site. While grower reported yields were a bit lower for this site, hop cone total oil content, alpha and beta acid content (measures of quality) were all highest at this site. Further, hop cone NO_3^- concentration, a negative attribute for end consumers, was the lowest at this site. While preliminary, this data does indicate possible trade-offs between N application strategy, yield, and quality. Data from subsequent years will be used to build robust nutrient uptake and accumulation curves to help better guide timing and rate of fertilizer applications.

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ESTIMATING NITROGEN CREDITS FROM ORGANIC MATTER SOURCES IN ORCHARDS

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ABSTRACT

Addressing N availability from organic matter sources in orchards, and in turn estimating appropriate N credits used in nutrient budgets remains a challenge. Soil health practices like cover crops and organic matter amendments add organic matter (OM) to soil in order to improve water holding capacity and maintain N in orchard top soil, thereby reducing the potential for nitrate leaching. Organic matter added to the soil contains N, however the rate at which that N becomes plant available varies dramatically depending upon on the organic matter source. We reviewed twelve extension publications across the U.S. and extracted 90 data points estimating N availability coefficients for total N inputs from different organic matter sources at one or two years after application. Year one coefficients varied for different organic matter sources including compost from -8 to 28%, beef or dairy manure solids from 16 to 40%, poultry manure solids from 24 to 52% and cover crops from 8% to 48% of total N inputs. Less data was available for year two coefficients including one data point for compost at 5%, beef or dairy from 8 to 24% and poultry from 8 to 16%. Additional parameters need to be considered when estimating N credits from organic matter sources in orchards including 1) application in tree row or alleyway; 2) application postharvest before winter rains or in springtime; 3) proportion of orchard soil wetted by irrigation water and; 4) no-till practices or use of incorporation to manage organic matter. Different N sources offer growers options to balance nutrition for orchard crops. In combination with the right rate, timing and placement, the right N sources optimize productivity and minimize N losses.

INTRODUCTION

In California, orchard crops like almond (*Prunus dulcis*) are planted on over 1.3 million acres and rely heavily on fertilizer and irrigation water for high productivity. Almonds can effectively utilize different N sources to meet the high annual N demand for fruit and tree growth. Different fertilizer formulations like urea ammonium nitrate are widely and effectively used, and readily available for uptake. Yet, addressing N availability from organic matter sources in orchards, and in turn estimating appropriate N credits used in nutrient budgets remains a challenge. Soil health practices like cover crops and organic matter amendments add organic matter (OM) to soil in order to improve water holding capacity and maintain N in orchard top soil. Organic matter added to the soil contains N, however the rate at which that N becomes plant available varies dramatically depending upon on the organic matter source. Furthermore, a greater understanding of how N availability changes from one year to the next is needed.

Additional factors may need to be considered when estimating N availability from organic matter sources in orchards. These include use in the tree row or alleyway; the proportion of orchard soil wetted by irrigation water, and use of no-till or tillage of OM. The aim of the following is 1) to outline the finding of N availability coefficients available in research and extension literature and 2) to provide recommendations for updating grower decision support tools such as the UC CropManage platform and the California Almond Sustainability Program N calculator.

METHODS

We reviewed twelve extension publications across multiple land grant institutions in the United States (See references below) and extracted 90 data points estimating N availability coefficients defined as the percent of N available as ammonium or nitrate out of total N inputs from organic matter sources at one and more than one year after application. Additional data parameters collected when available included percentage of dry matter, carbon-to-nitrogen ratio (C:N), total N (TN) and the proportion of ammonium (NH4) to TN. Notes were made for examples that included incorporation with tillage or management of organic matter sources as no-till mulch. Results are reported independent of management practices employed. The N availability coefficients reported herein are designed to be unitless values to be multiplied by the total N contents of each organic matter source in dry mass per unit area.

RESULTS AND DISCUSSION

Year one coefficients varied for different organic matter sources including compost from -8 to 28%, beef or dairy manure solids from 16 to 40%, poultry manure solids from 24 to 52% and cover crops from 8 to 48% of total N inputs (Figure 1). Less data was available for year two coefficients including one data point for compost of 5%, beef or dairy manure solids from 8 to 24% and poultry from 8 to 16% (Figure 2). Studies specific to orchards are lacking, however Khalsa et al. (*Submitted*) report a range of -6 to 8% from composted sources in an almond orchard depending on the initial C:N.

Nitrogen losses via ammonia volatilization from surface application of manure is a primary finding to consider for orchards. Multiple extension publications report 100% of ammonium loss from manure when surface applied with no-till. The proportion of ammonium out of total N ranged from 0.0 to 6.7% for compost, 5.6 to 55% for beef and dairy, and 17 to 67% for poultry. No-till use of compost in orchards does not appear to be a significant path of ammonia loss. However, if growers opt to use manure, a factor of days until incorporation should be included.

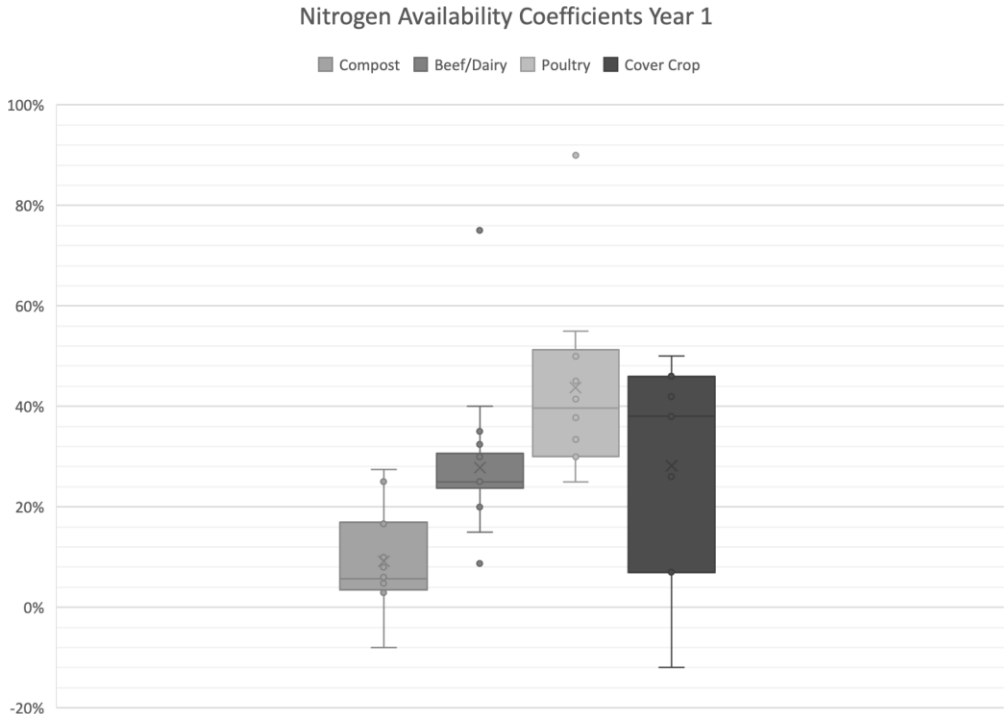

Figure 1. Box plots of nitrogen (N) availability coefficients defined as the percent of N available as ammonium or nitrate out of total N inputs for year one after application for organic matter sources including compost, beef and dairy, poultry and cover crops.

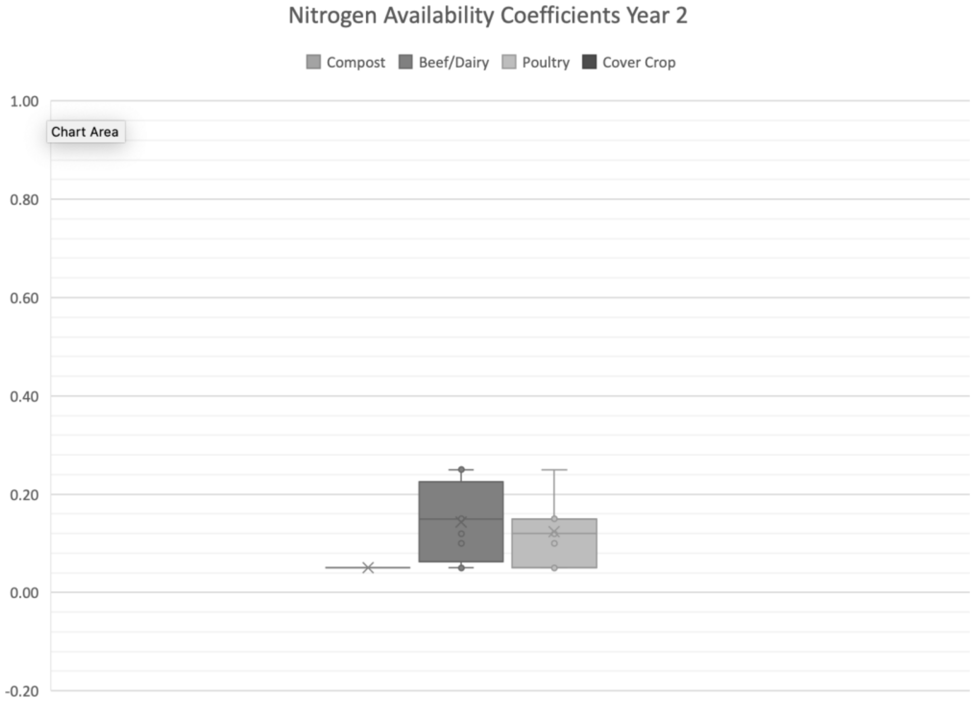

Figure 2. Box plots of nitrogen (N) availability coefficients defined as the percent of N available as ammonium or nitrate out of total N inputs for year two after application for organic matter sources including compost, beef and dairy, poultry and cover crop.

The current decision support tools in California like CropManage and the California Almond Sustainability Program N calculator require an update to accurately estimate N credits. The following are the most accurate quantification of N credits assuming all input parameters are available to the user of the decision support tool.

The following are examples that demonstrate parameters to collect for each organic matter source and ask the question, “What would be the N credit for the subsequent growing season?”:

Manure
Application rate in lbs/ac (AR)
Moisture in % (H2O)
Total N in % (TN)
Ammonium in % (NH4)
Tillage factor (tf)
1.00 = Incorporation 0 days after application
0.65 = Incorporation 1 day after application
0.50 = Incorporation 2 days after application
0.40 = Incorporation 3 days after application
0.30 = Incorporation 4 days after application
0.20 = Incorporation 5 days after application
0.20 = Incorporation 5 days after application
0.10 = Incorporation 6 days after application
0.00 = Incorporation 7 days after application

N Credit = AR * (1-H2O) * [([TN-NH4] * 0.25) + (NH4 * [tf])]
Example – In November, a grower applies 4 tons per acre of dairy manure at 30% moisture, 2.5% Nitrogen (0.5% ammonium) and incorporates the manure into the orchard alleyway 2 days after application.

8,000 lb/ac * (0.70 dry matter) * [([0.025 – 0.005] * (0.25)) + (0.005 * 0.50))] = 42 lb N/ac

Note – This approach may be used for all manure. The higher N coefficients reported above for poultry assume no losses from rapid incorporation. If the ammonium concentration and tillage factors are available, the same coefficient 0.25 may be considered for all manure sources.

Compost
Application rate in lbs/ac (AR)
Moisture in % (H2O)
Total N in % (TN)

N Credit = AR * (1-H2O) * (TN) * (0.10)

Example – In November, a grower applies 4 tons per acre of compost with a C:N between 11 to 13 at 30% moisture, 2.0% Nitrogen (0.0% ammonium) on the tree berm without tillage.

8,000 lb/ac * (0.70 dry matter) * (0.02) * (0.10) = 11 lb N/ac

Note – This example assumes compost C:N from 10 to 15, values higher than 15 may result in lower coefficients less than 0.10, equal to 0.0 or even negative leading to immobilization.

Cover crops
Biomass production in lbs/ac (AR)
Moisture in % (H2O)
Total N in % (TN)
Quality factor (CN)
0.50 = Cover crop with TN equal to 4.0%
0.46 = Cover crop with TN equal to 3.5%
0.42 = Cover crop with TN equal to 3.0%
0.38 = Cover crop with TN equal to 2.5%
0.26 = Cover crop with TN equal to 2.0%
- 0.12 = Cover crop with TN equal to 1.5%

N Credit = AR * (1-H2O) * (TN) * (CN)

Example – In March, a grower estimates a cereal rye cover crop stand of 6 tons per acre at 75% moisture, 2.0% Nitrogen.

12,000 lb/ac * (0.25 dry matter) * (0.02) * (0.26) = 16 lb N/ac

Note –A cover crop stand will depend greatly on winter rain fall. Furthermore, the quality factor for a cover crop will be affected by the developmental stage and termination date of the cover crop.

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REEVALUATING THE SMP BUFFER PH TEST FOR LIME RECOMMENDATIONS IN OREGON

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ABSTRACT

Soil testing labs in the Pacific Northwest are considering non-hazardous alternatives to the Shoemaker-McLean-Pratt (SMP) buffer method for lime requirement estimation (LRE). While alternative LRE methods have been adopted in other parts of the U.S., they have not been evaluated for Oregon soils. The goal of this study was to evaluate several LRE methods for Oregon agricultural soils, using the lime incubation method for actual lime requirement. Twenty-four acidic soils (pH ≤ 5.5) from Oregon agricultural fields were mixed with lime at rates equivalent to 0, 1, 2, 4, 6, 8, and 10 ton acre^{-1}, and were incubated for 90 days at 72° F. Lime requirement estimation methods evaluated included SMP buffer, Sikora buffer, Modified Mehlich buffer, and Single Addition of $Ca(OH)_2$. Incubation lime requirement and LRE methods were evaluated for the pH targets of 5.6, 6.0, and 6.4.

The mean amount of lime required to meet the target pH of 6.0 was 2.0 ton acre^{-1} for E. Oregon loess silt loams (n=3), 2.7 ton acre^{-1} for W. Oregon valley floor loams (n=14), 3.0 ton acre^{-1} for C. Oregon volcanic loamy sand (n=1), 5.9 ton acre^{-1} for W. Oregon foothill silty clay loams (n=4), and 7.4 ton acre^{-1} for W. Oregon vertic clays (n=2). The SMP, Sikora, Modified Mehlich, and $Ca(OH)_2$ methods were each correlated against incubation lime requirement, respectively producing mean R^2 values of 0.92, 0.92, 0.89, and 0.74 across pH targets. While these preliminary findings suggest that the Sikora buffer method could be a suitable replacement for SMP in Oregon, other buffer methods and calculation approaches will be evaluated before a new LRE method for Oregon can be adopted.

INTRODUCTION

The buffer pH test currently recommended for making lime requirement estimates (LRE) in Oregon is the Shoemaker, McLean, and Pratt (SMP) method (Anderson et al. 2013). This recommendation is based on a 1971 evaluation of the SMP method for Oregon soils by laboratory lime incubation (Peterson 1971). The SMP test requires the use of regulated hazardous materials, namely para-nitrophenol and potassium chromate. Because of this, commercial soil test labs serving Oregon have recently expressed interest in transitioning to a non-hazardous alternative test.

Since the development of the SMP method in 1961, several non-hazardous LRE methods have been developed. Some methods involve replacing the hazardous components in existing methods in a way that maintains the original method characteristics as much as possible. Examples of this include the Sikora modification of the SMP method (2006), the Sikora-Moore modification of the Adams-Evans method (2008), and the Modified Mehlich method (Hoskins and Erich 2008). Other non-hazardous methods estimate lime requirement without the use of buffers. The Single Addition of $Ca(OH)_2$ method calculates LRE based on the pH response of a soil slurry to the addition of a strong base (Liu et al. 2005). Other methods calculate LRE using multivariate models that combine multiple soil test parameters, such as organic matter content and KCl extractable Al (LeMire et al. 2005; McFarland 2016).

In order to replace the SMP method in Oregon, candidate LRE methods must be evaluated. The objective of this project was to conduct a lime addition lab incubation study to compare the effectiveness of SMP, Sikora, Modified Mehlich (MM), and Single Addition of $Ca(OH)_2$ methods for estimating LRE on western and eastern Oregon agricultural soils.

METHODS AND MATERIALS

Twenty-four acidic soils (pH<5.5) were collected from various agricultural regions in Oregon, with an emphasis on tall fescue fields in the Willamette Valley. Soil samples were separated into five categories based on region and relevant characteristics (Table 1). Vertic clay loams originate from the Willamette Valley, and have higher clay content compared to other soils in the area. Foothill silty clay loams are also from the Willamette valley, specifically the foothills on the western side of the Cascade mountain range. Valley floor loams are all other soils collected from the Willamette Valley. Loess silt loams were collected from the Palouse region of eastern Oregon. The volcanic loamy sand was collected from Deschutes County in central Oregon.

Lab-grade calcium carbonate was mixed with 200 g aliquots of soil at rates of 0, 0.231, 0.461, 0.922, 1.384, 1.845, 2.306 g, which is equivalent to 0, 1, 2, 4, 6, 8, 10 tons acre^{-1} (assuming a bulk density of 1.3 g cm^{-3} and 15 cm depth, or 81.2 lb ft^{-3} and 5.91 in. respectively). Treatments were replicated four times in a complete randomized design. Soil-lime mixtures were incubated in resealable bags for 90 days at room temperature (~73° F). Soils were maintained at 75 – 105% of field capacity (as determined by pressure plate analysis) during incubation. The combination of 24 soil types, seven lime treatments, and four replications resulted in 672 experimental units for the incubation study. At the end of the 90 day incubation, soils were air-dried and analyzed for 1:2 water pH using a pH electrode to determine actual lime requirement ("incubation LR"). A third-order polynomial was fit for each soil to estimate the amount of lime needed to meet the target pH values of 5.6, 6.0, and 6.4. These LR estimates at each target pH level were used to evaluate the effectiveness of candidate LRE methods to predict the amount of lime needed to reach each pH target.

Table 1. Summary of soil parameters and lime requirement for 24 Oregon agricultural soils collected from the 0-6 inch soil depth. $\bar{x}$ is the mean measurement for each category. Clay was measured using the hydrometer method, and organic matter was measured using the Walkley-Black method (Gavlak et al. 2005).

Regional Soil Class	**Clay (%)**		**Organic Matter (%)**		**KCl Ext. Al mg kg^{-1}**		**Incubation LR ton acre^{-1} to reach pH 6.0**	
	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range
Vertic Clay Loams (n=2)	45	43 - 47	6.9	6.8 – 7.0	16.9	7.8 – 26	7.4	7.0 – 7.8
Foothill Silty Clay Loams (n=4)	50	44 – 53	9.1	7.7 – 10.3	8.4	2.2 – 11	5.9	4.7 – 7.1
Valley Floor Loams (n=14)	23	15 – 40	4.1	3.3 – 6.7	5.8	0.6 – 11	2.7	1.7 – 4.0
Loess Silt Loams (n=3)	17	14 – 20	4.0	3.2 – 5.4	0.6	0.2 – 1.0	2.0	1.2 – 2.7
Volcanic Loamy Sand (n=1)	10	-	5.9	-	5.5	-	3.0	-

The same 24 soils used in the incubation study were also used to evaluate the SMP buffer (Gavlak et al. 2005), the Sikora buffer (2006), the Modified Mehlich buffer (Sikora and Moore 2014), and the Single Addition of $Ca(OH)_2$ method (Sikora and Moore 2014). Unincubated soils were used for the evaluation. Each soil analysis was replicated three times. Soils were also analyzed for clay content, organic matter, extractable aluminum, manganese concentration, and other variables that may be used to further improve estimation of lime requirement for these soils.

RESULTS

Lime Incubation

Soil pH response to lime applications varied widely among the five Oregon agricultural regions (Figure 2). The soil pH for the foothill silty clay loams and the vertic clays increased linearly from 0 to 10 ton lime/acre, while soil pH for the valley floor loams and the loess silt loams appeared to stop increasing between 7 to 8 ton acre^{-1}.

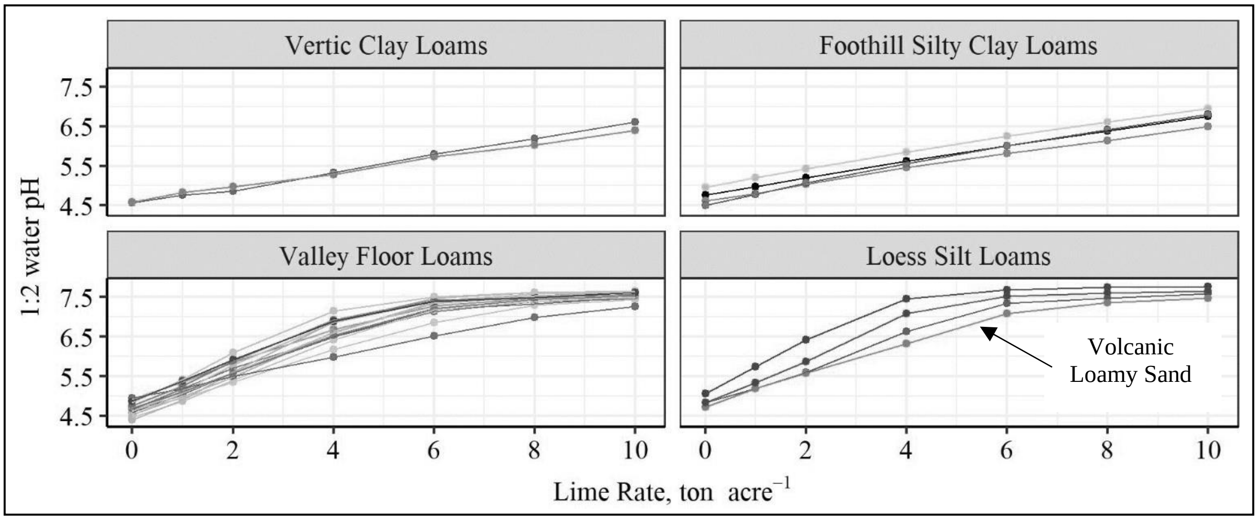

Figure 2. Soil pH response to increasing lime application rate for 24 Oregon soils following a 90 day lab incubation. Each line represents one soil, with each point representing the pH achieved at each lime rate.

Candidate LRE Methods

Buffer pH was well correlated to the incubation lime requirement for both SMP and Sikora for all soil categories evaluated at the pH targets of 5.6, 6.0, and 6.4, (Figure 3). The R^2 values were also similar between Sikora and SMP for each pH target, illustrating that the Sikora method would produce results with similar accuracy to the SMP buffer.

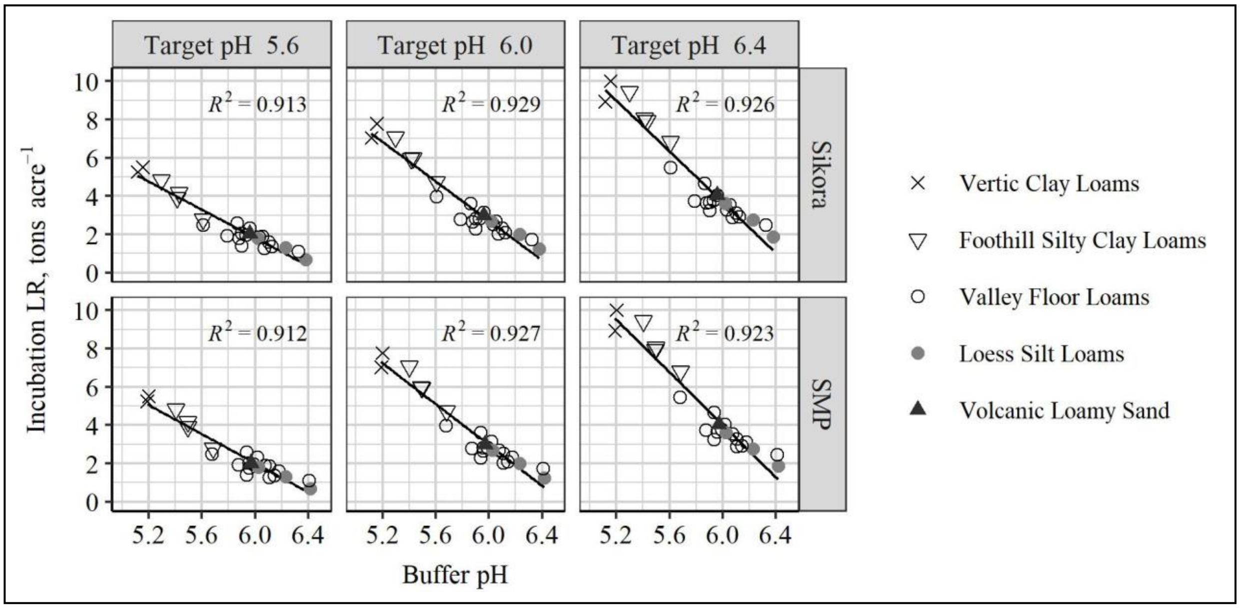

Figure 3. Correlation between incubation lime requirement and SMP and Sikora buffer pH. Sikora results are on the top row of graphs, with SMP below.

Modified Mehlich BpH was also well correlated to incubation lime requirement, but not as strongly as SMP or Sikora (Figure 4). Lime requirement estimates were also calculated from BpH values according to equations from Mehlich 1976. These LRE values correlated to incubation lime requirement with R^2 values of 0.90, 0.89, and 0.87 for pH targets of 5.6, 6.0, and 6.4 (Figure 4).

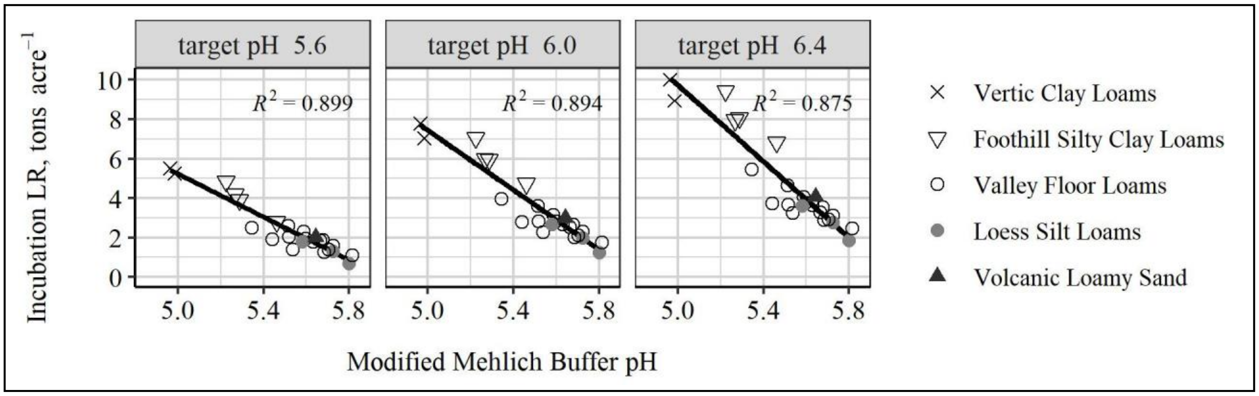

Figure 4. Correlation between incubation lime requirement and Modified Mehlich buffer pH

The calculated LRE values produced by the Single Addition of $Ca(OH)_2$ method correlated with incubation lime requirement with R^2 values of 0.78, 0.73, and 0.70 across pH targets (Figure 5).

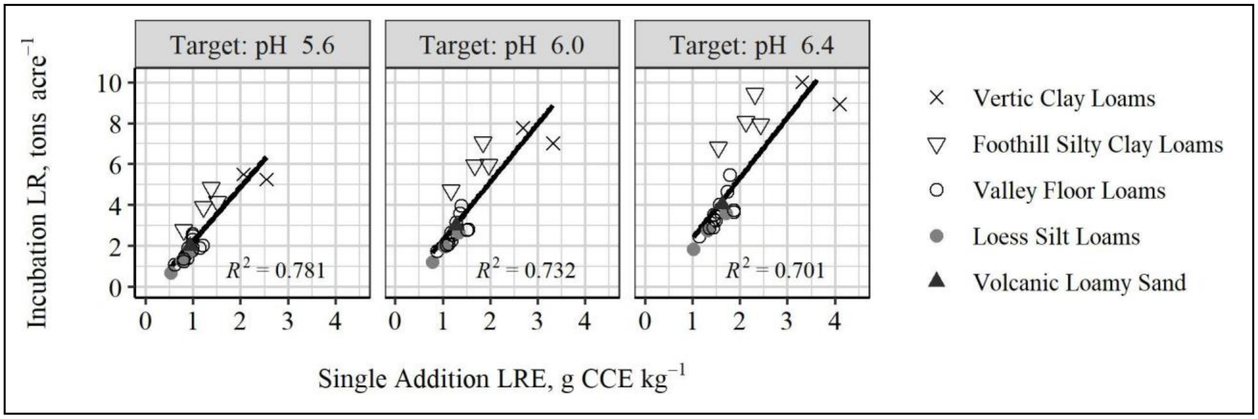

Figure 5. Correlation between incubation lime requirement and LRE determined by the Single Addition of $Ca(OH)_2$ method. CCE = Calcium Carbonate Equivalent.

A model incorporating 1:2 water pH and Sikora BpH was also evaluated. This model took the following form: !"# = %& + (&) + *) + +, where & and) are 1:2 water pH and Sikora BpH respectively, and %, (, * and + are fitting constants. Three models corresponding to pH targets of 5.6, 6.0, and 6.4 correlated to incubation lime requirement with R^2 values of 0.93, 0.94, and 0.94 respectively (data not shown).

DISCUSSION

Lime Incubation

Soils from the vertic and foothill categories had significantly higher incubation LR, and had more linear incubation response to lime rate, compared to soils from the other three categories.

This is likely due to the higher amount of clay and organic matter present in these soils. These soil components are known to contribute to CEC and soil pH buffering.

Clay mineralogy may also be an important factor for lime requirement. Both of the vertic clay soils, as well as five of the 14 valley floor soils are classified as having predominantly smectitic clay mineralogy. All the other soils collected are classified as having mixed mineralogy (Soil Survey Staff). This difference in mineralogy may partially explain why the vertic clay category had higher incubation LR compared to the foothill group, despite higher average clay and organic matter content in the foothill group.

Candidate LRE Methods

The critical criteria for recommending a replacement for the SMP method is that the new method must be as or more accurate than SMP. Of the alternative methods evaluated, only the Sikora method had an R^2 equivalent to SMP. This suggests that Sikora is a viable non-hazardous alternative to the currently recommended SMP buffer.

Other promising approaches to lime requirement estimation remain unevaluated in Oregon. Namely, the Sikora-2 method, and soil parameter-based multivariate models. Prior work suggests that soil test parameters such as soil pH, organic matter, and KCl extractable Al can be used to predict lime requirement (LeMire et al. 2005; McFarland 2016).

CONCLUSIONS

There is currently a desire to replace the SMP method with a non-hazardous alternative in Oregon. Three alternative methods were evaluated for their ability to predict incubation lime requirement for 24 Oregon soils. Of these, only the Sikora method had accuracy equivalent to the SMP method. Additional approaches to LRE determination will also be evaluated before LRE test recommendations are updated in Oregon.

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LONG-TERM SOIL PROFILE ACIDIFICATION: OBVIOUS AND HIDDEN DANGERS

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ABSTRACT

Soil acidification is occurring in the dryland farming region of the Northwest. Historically, soil acidification in the surface foot has been characterized; however, potential acidification of subsoil is unknown. We examined soil acidification for soil profiles (0 to 5 ft) at the R.J. Cook Agronomy Farm (92 ac) for 17 years following conversion from conventional tillage to continuous No-tillage (NT). Surface soil depths (0-12 in) acidified under continuous NT to below 5. Surprisingly, subsoil at depths of 3 to 5 feet were acidified in certain landscape positions prior to conversion to NT. Over 17 years, the acidified subsoil was ameliorated, and subsoil pH increased under NT. Large spatial and temporal variations in soil pH occurred throughout the soil profiles over the course of 17 years of continuous NT. Decreasing leaching of nitrate and bases through more efficient use of water and applied N are major management consideration.

INTRODUCTION

Soil acidification is a major cause of lost farm production throughout the world. Soils of the inland Pacific Northwest were initially near neutral in pH; however, agriculturally driven soil acidification has occurred in the region over time, primarily due to the increased use of N fertilizers. Currently, acidification is an issue of growing concern as more soils are at or below critical pH levels required for optimum yields of small grains and grain legumes. Research has primarily assessed changes in surface (0-12 in) soil pH with little attention to potential acidification of subsoil.

Over the last 40 years, reduced and no-till (NT) production has increase in the inland Pacific Northwest and significantly changed field-scale soil properties and hydrologic processes. As compared to plow-based systems, NT lacks the mechanical mixing of soil and promotes the surface stratification of residues, soil organic matter, immobile nutrients and pH. Furthermore, soil erosion is significantly curtailed under NT as surface runoff decreases and water infiltration increases. In addition, NT is often coupled with deep-band placement of fertilizers including N, a main driver of soil acidification.

In 1998, a long-term NT study was initiated at the Cook Agronomy Farm near Pullman, WA. One objective was to investigate field-scale changes in soil pH throughout the soil profile (0-5 ft) with samples collected in 1998 (initiation of NT), 2008, and 2015 to provide insights into the long-term impact of continuous NT in dryland, wheat-based systems.

METHODS

The research was conducted on a 92 ac field at the Washington State University Cook Agronomy Farm (CAF) near Pullman, WA (Fig. 1), which is also one of 18 USDA Long-Term Agroecological Research (LTAR) network sites. Previous to 1998, the farm produced a mix of small grain and pulse crops under conventional tillage. In 1998, the CAF was converted to continuous NT producing wheat, barley, pulse crops and canola. Nitrogen (N) fertilizer has been primarily deep band applied (3-4 in) since 1999, mostly as ammoniacal forms for all crops with the exception of grain legumes.

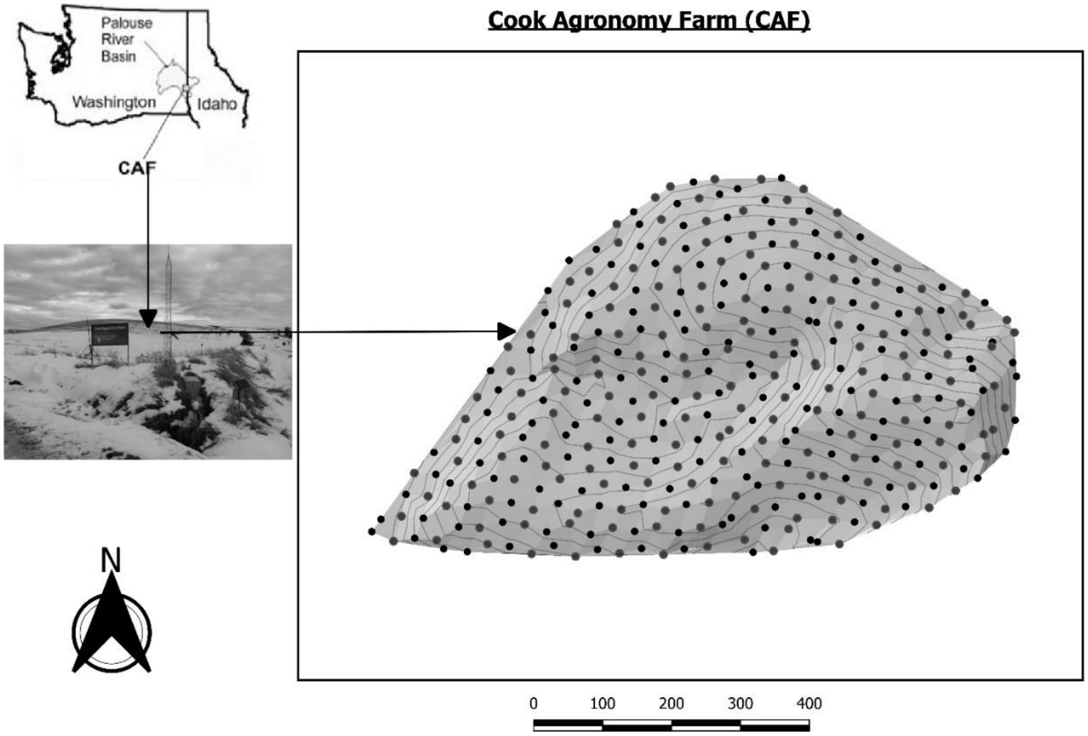

Fig. 1. Sampling points for the 92 ac Cook Agronomy Farm: Black and red dots represent 369 geo-referenced points whereas red dots represent samples (184) used in our study. Contour lines are created at 7 ft (2.5 m) intervals.

One hundred and eighty-four of the 369 geo-referenced sample locations were selected for this study (Fig. 1). Intact soil cores (0 to 5 feet) were collected at alternating points and divided into depth-increments of 0-10 cm (0-4 in), 10-20 cm (4-8 in), 20-30 cm (8-12 in) and then by soil horizon to 150 cm (5 ft). Samples were air-dried at room temperature, passed through a 2-mm sieve and analyzed for soil pH (1:1, soil:water). Analysis of variance was used to assess differences in soil pH over time for 3 soil series (Naff, Palouse, Thatuna). Spatial maps were created using inverse distance squared interpolation at relevant depths.

RESULTS AND DISCUSION

Soil pH in the surface foot (0-30 cm) decreased consistently over time and were below 5 for the surface 4 in (0-10 cm) depth-increment after 17 years (Figs. 2, 3, 4). Contributing factors to stratified soil pH were lack of mechanical mixing with tillage and deep-band placement of applied N fertilizer. Surprisingly, subsoil pH values of below 6 occurred in portions of the field in 1998, indicating that acidification was occurring under conventional tillage in portions of the field (Figs. 2, 5, 6). These locations were primarily in low elevation, bottomland areas where Thatuna soil is more prevalent. In addition, tremendous soil profile variability in pH occurred within a given soil type (Fig. 2). Contributing factors are likely leaching of nitrate-N as driven by field-scale surface run-off, infiltration and subsurface movement under conventional tillage. After initiation of NT, subsoil pH for 2 to 5 ft (60-150 cm) depths increased from 5.5 to over 6.5 from for much of the field (Figs. 2, 5, 6). Increases of subsoil pH under NT were likely driven by greater infiltration of water coupled with greater subsurface movement of nitrate and leaching of bases. Production systems that decrease N and base leaching by increasing water use and N use efficiency should be considered.

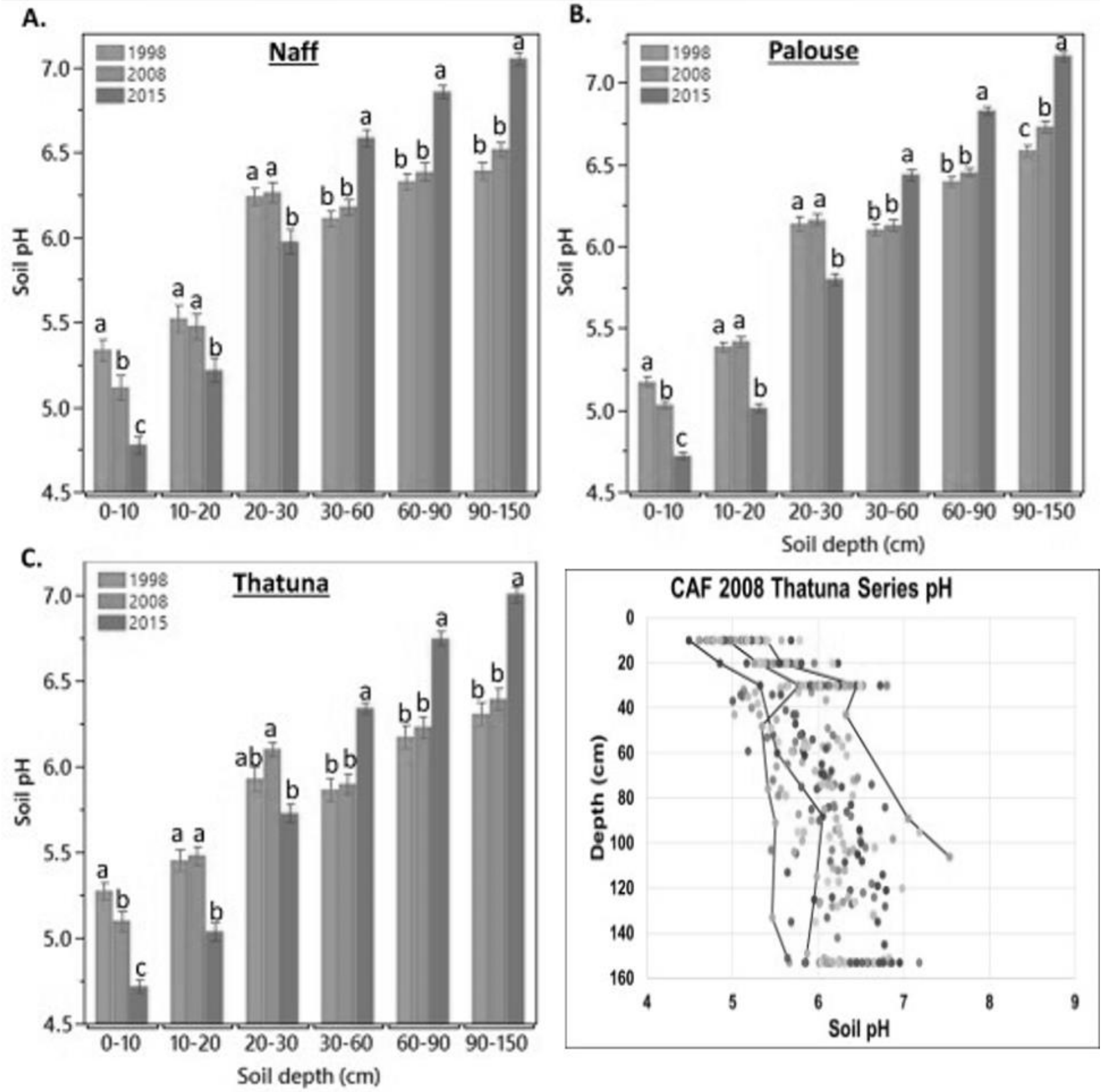

Fig. 2. Soil pH over time (1998, 2008, and 2015) at different soil depths in A. Naff, B. Palouse, and C. Thatuna series soil of Cook Agronomy Farm. Means sharing the same letter in bars within depth are not significantly different at a 5% significance level. Depth distribution of soil pH at points with Thatuna series in 2008.

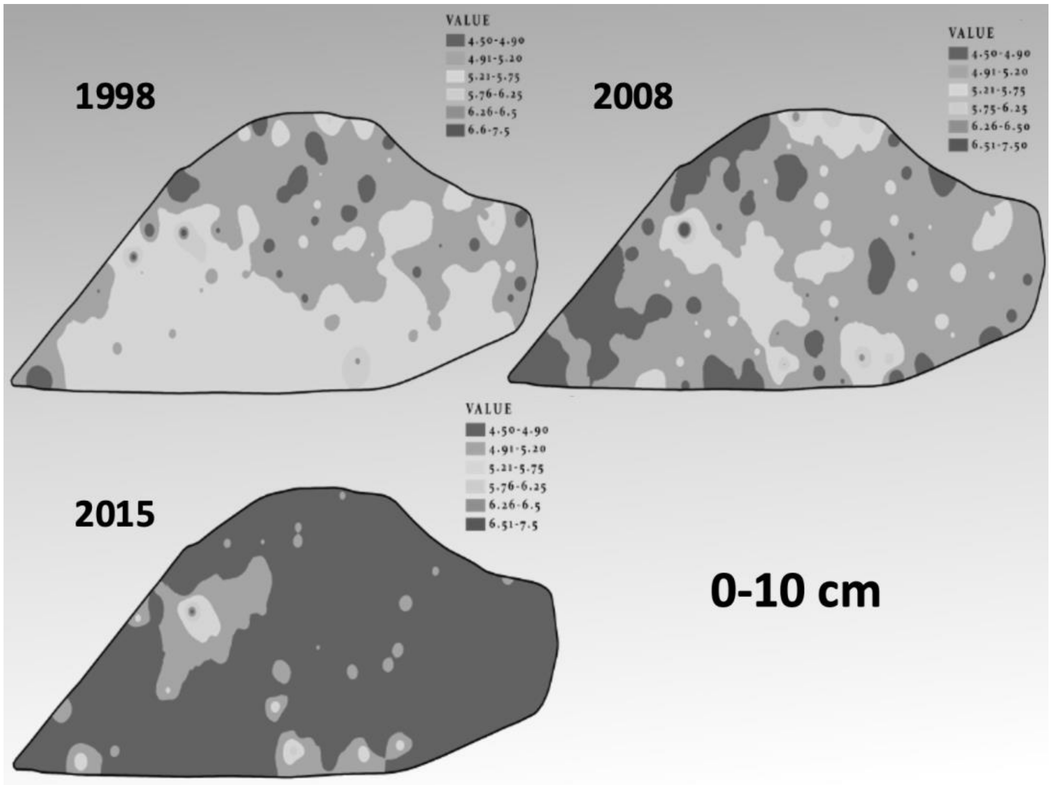

Figure 3. Soil pH in the surface 4 inches (0-10 cm) over the 92 ac Cook Agronomy Farm in 1998, 2008 and 2015.

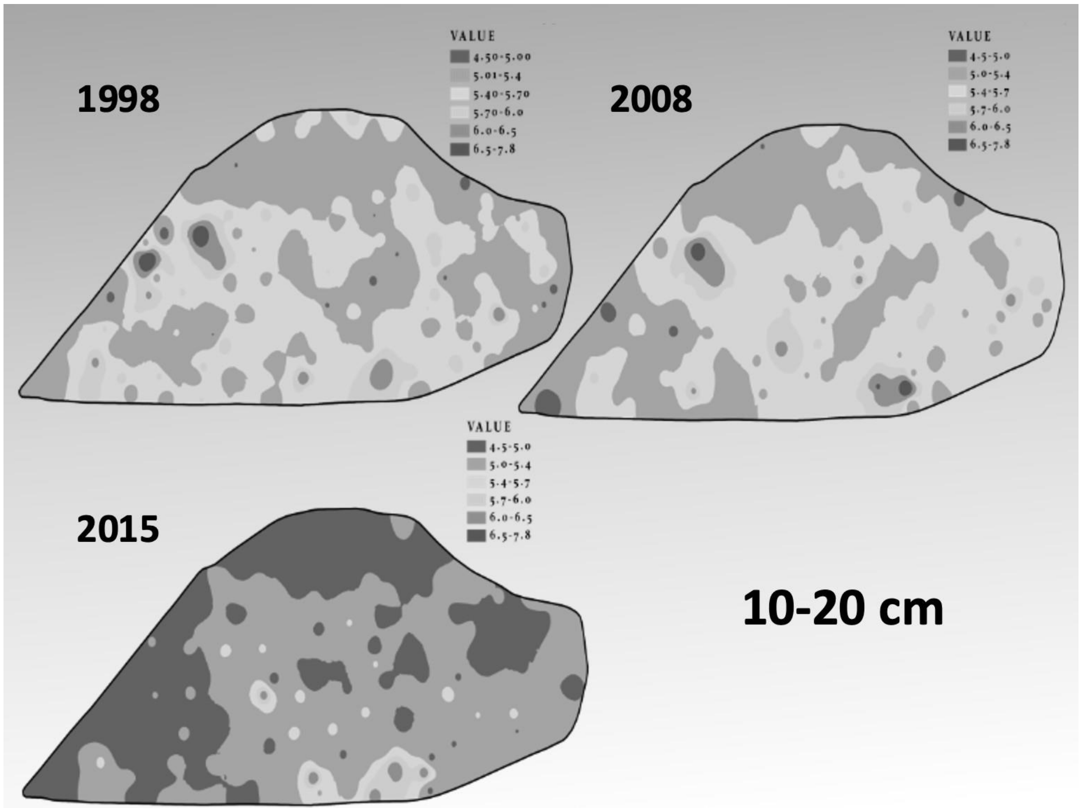

Figure 4. Soil pH in the surface 4-8 inches (10-20 cm) over the 92 ac Cook Agronomy Farm in 1998, 2008 and 2015.

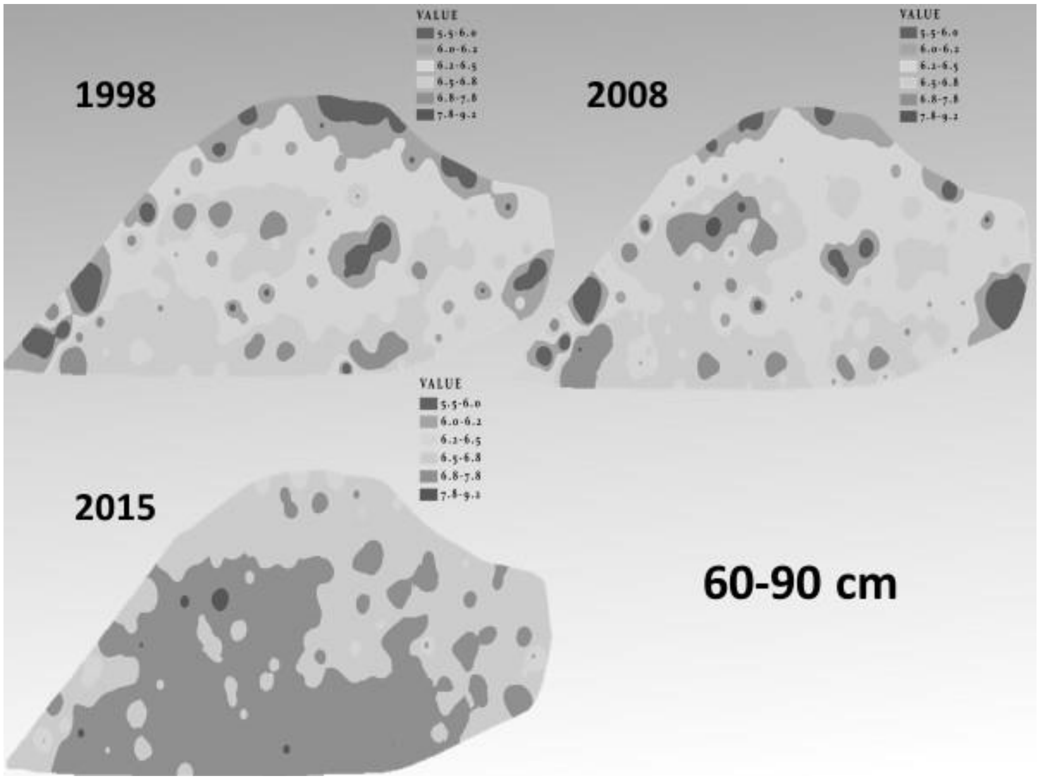

Figure 5. Soil pH in the subsurface 2-3 feet (60-90 cm) over the 92 ac Cook Agronomy Farm in 1998, 2008 and 2015.

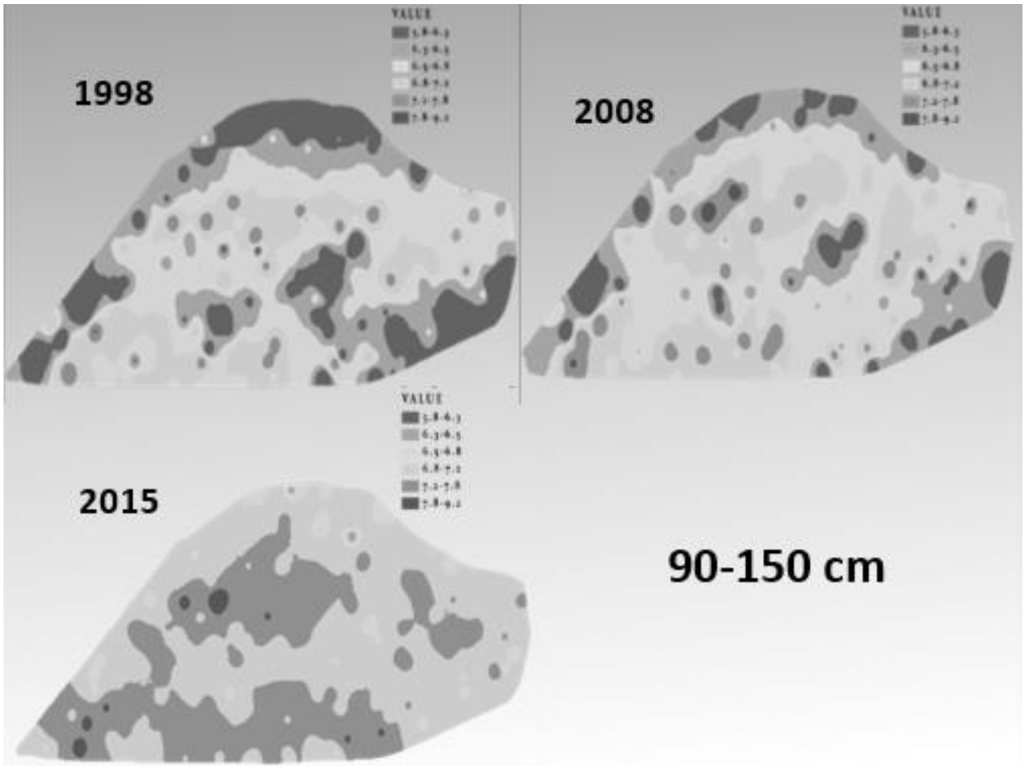

Figure 6. Soil pH in the subsurface 3-5 feet (90-150 cm) over the 92 ac Cook Agronomy Farm in 1998, 2008 and 2015.

EFFECTS OF LIME AND MICRONUTRIENT AMENDMENTS FOR ACIDIC SOILS OF THE INLAND PACIFIC NORTHWEST

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ABSTRACT

The soil pH of agricultural land in the Inland Northwest has reached critical levels, leaving tens of thousands of acres of previous prairie soil at pH <5.0 and unable to grow low pH and aluminum-sensitive crops. Some farmers in the region are beginning to use lime application to neutralize soil acidity. However, pH changes and liming can also change soil micronutrient availability to crops, and demand by crops. Therefore research to understand the interactions of soil amendments is imperative. This study assessed soil quality, crop yield, and economics of liming and micronutrient treatment for 6 years after application in the Palouse region of eastern Washington State. Plots were established in 2014 in a minimum tillage system with initial soil pH averaging 4.9 in the surface 0-3 in, 4.66 at 3-6 in, and 5.48 in the subsurface 6-12 in. Liquid lime was applied at 2000 lb $CaCO_3$/acre in September 2014 and micronutrients (B, Cu, Zn, Cl) were added September 2015 as a full factorial design to create four treatments: Lime + Micronutrients (LM), Lime Only (L), Micronutrients Only (M), and Control (C). Average soil pH at the surface 0-3 in was significantly higher in L and LM than M and C in 2015-2020. Crop yields increased in the order of LM > M ≥ L = C. Only combined LM significantly increased yield over the control for all crops: peas (2016) 26.0%, hard red winter wheat (2017) 6.7%, soft white winter wheat (2019) 15.2%, and spring barley (2020) 10.4%. Micronutrient levels in barley grain were higher in M and LM. These results support taking a more holistic approach to managing soil nutrients when addressing soil acidification.

INTRODUCTION

Declining soil pH, or soil acidification, is a growing concern in agricultural systems throughout the world. The Palouse region of the Inland Northwest (includes eastern Washington, northeast Oregon, and northwest Idaho) is one such area where the agriculturally driven decline of soil pH is an increasingly limiting factor to crop production (Mahler et al., 2016; McFarland et al., 2015). Acidifying practices like the repeated use of nitrogen fertilizers, intensive tillage practices, and removing large amounts of crop biomass from fields have driven soil pH from the near-neutral levels of the native soil to current levels that are at or below the thresholds for the region’s major crops, including winter and spring cereals (pH 5.2 – 5.4), oilseeds (5.5) and grain legumes such as peas, chickpeas, and lentils (5.4 – 5.6) (Mahler and McDole, 1987). Soil pH is often referred to as a “master variable”, because it affects numerous other processes in soil and indicators of soil quality, such as nutrient availability, aluminum toxicity, soil biotic populations and activity, and fate of herbicides, all of which are contributing to the production limitations on acidifying Palouse soils (McFarland et al., 2015; Brown et al., 2008).

Lime application is a commonly used tool to counter low soil pH, increase base saturation and nutrient availability, and reduce aluminum toxicity for some agricultural soils (Thompson et al., 2016). However, adoption of liming in the Inland Northwest has been very low for many reasons. Geologically, the region has few sources of liming materials; transportation and source development increase the cost of lime in the region. Growers do not already own the needed equipment and, due to additional soil health deficits, liming alone does not always lead to crop yield increases (Godsey et al., 2007; Brown et al., 2008). There can be difficulty getting liming materials to reach acidified layers quickly in no-till systems (Tao et al., 2018), and buffering capacity of soils throughout the region vary (McFarland et al. 2020). Additionally, acidification and liming can both cause changes in short- or long-term availability of plant nutrients and leave these valuable elements vulnerable to permanent loss from the soil. Liming without attention to micronutrient nutrition may not improve crop yield or overall soil functioning and can even exacerbate micronutrient deficiency, despite neutralizing pH (Fageria et al., 2012).

This research aimed to quantify long-term soil and crop response to lime and micronutrient applications in a minimal-tillage cropping system in the Palouse, to further our understanding of tools to combat soil acidification problems in this region.

MATERIALS AND METHODS

The research site was located on a commercial farm in Walla Walla county, Washington, with silt loam soil and annual precipitation averaging 19 inches. Randomized plots 10 ft x 100 ft of lime (L) versus control (C) were established in September 2014. Lime treatment was 2000 lb of ultra-micronized liquid CaCO3, applied using an ultra terrain vehicle equipped with a boom buster spray nozzle. No tillage was conducted immediately following the lime application; peas and chickpeas were seeded the following spring.

Soil was sampled from all plots in the spring 2015 with hand probes; samples were divided into 0-3 in, 3-6 in, and 6-12 in layers for analysis. Soil sampling continued in this manner from select plots each spring thereafter.

Table 1. Micronutrients applied in September 2015

Element	**Rate** (lb/acre)	**Cost** ($/acre)
Boron	1.1	11.00
Copper	0.79	19.80
Zinc	1.13	18.00
Chloride	16	8.50
Potassium*	21.5	

*Potassium Chloride (KCl) was carrier solution for the other nutrients

New treatments were added after harvest 2015 based on concurrent research and observations in the region regarding interactions with lime and micronutrient applications. Soil tests from 2015 confirmed deficiencies of micronutrients at the study site; boron (B) averaged 0.11 ppm (<0.2 ppm is considered "very low" and 1-3 lb B/acre additions are recommended), zinc (Zn) average 0.41 ppm (the recommended level is >1.5 ppm), and copper (Cu) averaged 1.1 ppm recommended level can be ≥1.4) (Horneck et al., 2011). Therefore, micronutrients were added across half of lime and control treatments resulting in a factorial design with treatments of: Lime + Micronutrients (LM), Lime Only (L), Micronutrients Only (M), and Control (no lime and no micronutrients, C). The micronutrient solution was added to the soil surface in September 2015 at the rates indicated in Table 1; no tillage was performed immediately after application and peas were planted the following spring.

Each year from 2016, crops were seeded and fertilized according to the farmer practices within this minimal tillage system. The crops and harvest years were as follows: peas in 2016, hard red winter wheat (HRWW) in 2017, soft white winter wheat (SWWW) in 2019, and spring barley in 2020 (spring peas were grown in 2018 but harvest data was not collected). Crop yields were determined by weighing grain harvested from a center strip within the plots; nutrient levels in barley grain (2020) were determined by Best Test Analytical Services.

RESULTS AND DISCUSSION

Initial soil pH ranged 4.7 – 5.2 in the surface 0-3 in, 4.5 – 4.8 at 3-6 in, and 5.4 – 5.6 at 6-12 in. This stratification, with lowest pH located in the seeding zone is common for no- and low-till systems in the region, as this is where fertilizers are routinely injected (Brown et al., 2008; Tao et al., 2018). Lime application significantly raised the pH in the surface 0-3 in layer, up to an average of 5.6 at the first sampling, 6 months after application. The pH of the surface layer for limed treatments was higher again at the 2016 sampling (average 6.13) and remained significantly higher than the control through 2020 (Figure 1). Soil below 3 in showed no change in pH over the 6 years of sampling in any treatments. This is consistent with other studies in no-till systems and the relatively low rate of lime application (Godsey et al., 2017). Brown et al. (2008) increased pH for the 0-2, 2-4 and 4-6 in depth in a Palouse soil two years after surface applying lime, but application rate was much higher at 5800 lb CCE/acre. We observed a slight increase in control pH over time (0-3 in), which was likely due to drift from seeding (across the 10ft width of plots). Correlated with the increase in pH, there was also a decrease in exchangeable aluminum in the surface layer (0-3 in) of limed plots; the difference was significant from 2015-2017 (Figure 4).

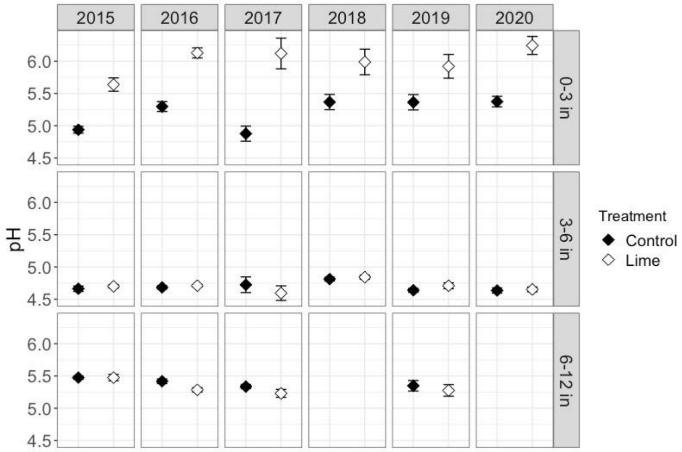

Figure 1. Soil pH at three depths (0-3 in, 3-6 in, 6-12 in) over six years. Error bars indicated standard error of the mean.

There was no yield difference between L and C plots in 2015 peas and chickpeas. Yield differences were observed after micronutrient treatments were added. In 2016 peas and 2019 SWWW, M and LM produced significantly higher yields over C (Figure 2). In 2017 and 2020, only LM produced significantly higher yields over C. LM consistently produced the largest yield, and it was the only treatment to significantly outyield control plots every year. Treatment M often produced higher yields than treatment L, though they were always statistically similar. The largest yield responses were observed in peas in 2016; LM yielded 26% higher than C, L yielded 10% higher than C, and M yielded 18% higher than C (Table 2). Legumes are known to be more sensitive to low soil pH and aluminum toxicity; research also indicates micronutrients can help alleviate Al toxicity in peas (Rahman et al., 2018; Yu et al., 2000).

Table 2. Mean crop yields for each treatment, with percent increase over the control. HRWW=Hard red winter wheat; SWWW=soft white winter wheat. Means with the same letter within a year are not statistically different at $p \leq 0.05$ as determined by Tukey HSD tests.

Treatment	**2016 Pea Yield**		**2017 HRWW Yield**		**2019 SWWW Yield**		**2020 Barley Yield**	
	lb/acre	% over C	bu/acre	% over C	bu/acre	% over C	bu/acre	% over C
Control	1625±43 a		122±2 a		111±2 a		119±3 a	
Micronutrients	1909±74 bc	18%	126±2 ab	3.4%	122±3 bc	9.8%	123±4 ab	3.3%
Lime	1789±66 ab	10%	125±1 ab	2.5%	116±2 ab	4.5%	125±3 ab	5.4%
Lime+Micronutrients	2045±45 c	26%	130±1 ab	6.7%	128±2 c	15%	131±3 b	10%

Six harvests after a single lime application and five harvests after micronutrient application, the LM treatment is still producing significant increases in crop yield as observed in the barley harvest from 2020. Despite only a small increase in crop yield from lime only treatments, there is visual evidence of improved crop growth in limed plots in early spring and greater biomass throughout the growing season (Figure 3). It is possible that the pH neutralization in the surface layer allows for better growth and root development for young plants, but crops still encounter nutrient limitations and therefore yields are still limited in L treatments. No differences were observed in HRWW protein in 2017 nor barley crude protein levels in 2020.

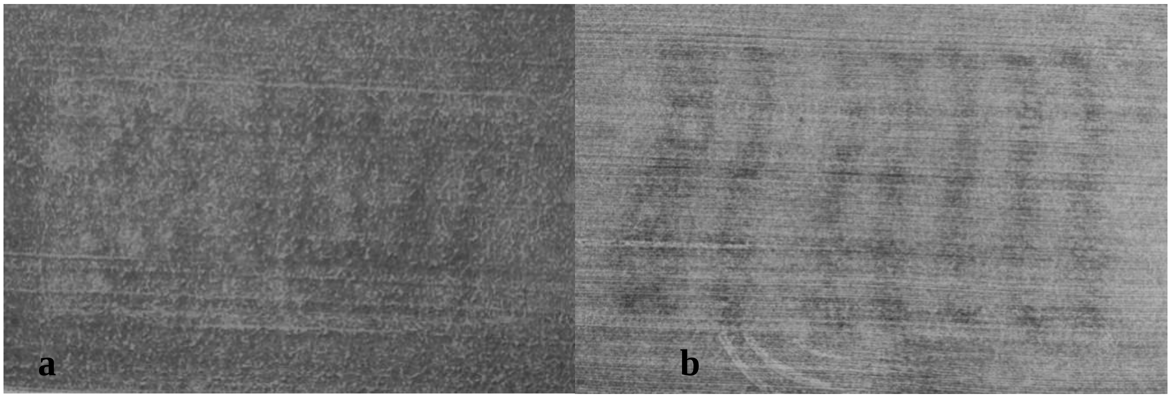

Figure 3. Photographs taken with a drone of (a) peas growing in June 2018 (no harvest data) and (b) barley growing in May 2020 show crop growth improvement along the length of plots limed in 2014, compared to unlimed plots.

The crop yield results from this study are consistent with other fields that received similar treatments; Carter and Wegner (2017) reported no differences in yields after the first year in only limed versus unlimed plots, but the following year micronutrient and lime+micronutrient treatments resulted in 16% and 18% yield increases in soft white spring wheat respectively, and 5.5% and 6.5% increases in soft white winter wheat. Brown et al. (2008) also had no treatment effects on crop yields for 3 years from a one-time surface or subsurface lime application when it was applied with regular N fertilization or N plus S fertilization.

Micronutrient applications were also apparent in subsequent soil tests and crop harvests. Boron significantly increased in 0-3 in and 3-6 in layers for M and LM, and LM was higher than M most years (Figure 4). Zinc followed similar patterns; it was significantly higher for 0-3 in soil that received micronutrients for 2016, 2017, and 2019, and highest in LM. Copper also increased in the 0-3 in surface layer for plots with micronutrient treatments (M and LM) (Figure 4). Even with the micronutrient additions, soils in this study area remained in the “low” category of 0.2-0.5 ppm for boron and under the “sufficient” category for zinc (Horneck et al., 2011), so this field may still benefit from future micronutrient additions. Zinc and copper were also significantly higher in barley grain (2020) from treatments with micronutrients.

Potassium chloride was used as a carrier for application of the other micronutrients, but we do not think potassium (K) drove the observed yield increases. Soils in the Palouse generally contain more than adequate levels of potassium (>250 ppm), especially those that retain residue. This soil averaged 800 ppm K in the surface layer, 541 ppm at 3-6 in and, 538 ppm at 6-12 in, and soil K did not change with treatment or time. While chloride can provide some benefit to wheat through reduced disease severity (Koenig, 2005; Horneck et al., 2011), soil chloride levels were not affected by micronutrient treatments in this study.

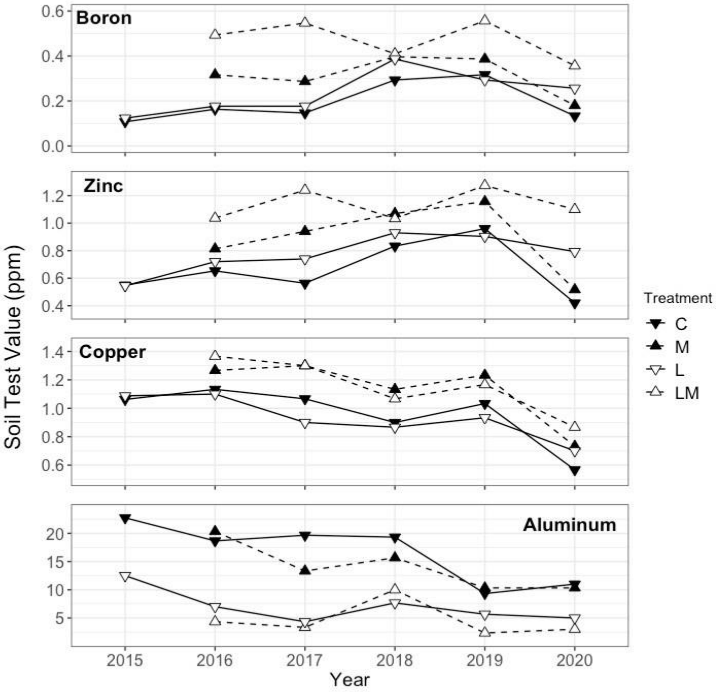

Figure 4. Available aluminum and select micronutrients in 0-3” soil. Dashed lines are treatments receiving micronutrients; white symbols are treatments receiving lime.

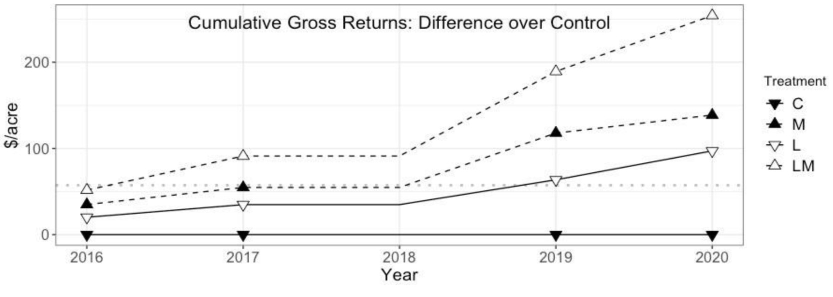

Figure 5. Cumulative gross returns over the control treatment, using actual crop prices each year. Dotted line represents the input cost of micronutrients.

Based on crop prices for the years of this study, the micronutrients had nearly paid for themselves by the 2nd harvest after application (yield boosts 2016-2017 resulted in an extra

$55/acre gross; total cost of micronutrients was $57.3/acre); after 4 harvests micronutrients had supplied a net extra $81.4/acre (Figure 5). The LM treatments have accumulated an extra $254/acre, which does not yet cover the cost of this rate of ultra-micronized lime ($415/acre) plus micronutrients (note this data is missing a year of pea harvest; the 2016 pea harvest from LM grossed an extra $52/acre). Using other type of lime may decrease cost, but may also affect the benefits to soil and yield. More research on the long-term economic balances from more studies - including micronutrients and various rates and sources of lime – are needed.

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POSTER ABSTRACTS

DAIRY MANURE AND FERTILIZER EFFECTS ON MICROBIAL ACTIVITY OF AN IDAHO SOIL

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Dairy manure applications that have occurred in the past can have long-term lingering effects on crop production. Understanding the cause is important for current and future management practices. This study was conducted to assess selected microbial activity among past manure application rates. In a past study (2014-2016) in Kimberly Idaho, historic manure applications have been shown to have significant positive and negative effects on sugar beet production. The manure treatment history (2004 to 2009) was manure applied at a total cumulative amount of 0, 135, 238 dry Mg/ha. The 0 Mg/ha treatment received commercial fertilizer based on University of Idaho recommendations from 2004 to 2009. Starting in 2019, these main plots were divided in to thirds and three N rate treatments were applied annually. In spring 2020, soil samples were collected from the 0-15 and 15-30 cm depth from the highest N rate treatment of each past manure treatment. The soil samples were analyzed for β-glucosidase, β-glucosaminidase, phosphomonoesterase, arylsulfatase enzymes and autoclaved citrate extractable (ACE) soil protein assay. β-glucosidase, β-glucosaminidase, phosphomonoesterase, arylsulfatase enzymes, and ACE were higher for the 135 and 238 dry Mg/ha manure treatments than the 0 dry Mg/ha manure treatment (fertilizer only). Manure last applied 11 years ago, still has a significant effect on the soil microbial activity.

VINEYARD SOIL HEALTH: WHAT SOIL PROPERTIES ARE MOST IMPORTANT?

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Washington is the second leading producer of wine grapes (Vitis vinifera) in the US, with over 60,000 acres in vineyards. With such a substantial acreage, it is crucial to know how management practices may affect soil and vine health in wine grape systems. Soil health indicators and threshold values have been extensively studied in commodity crops in the Midwest and the northeastern US, but there is much less information available for specialty crops in the Pacific Northwest.

Soil health indicators and properties such as bulk density, aggregate stability, total and active carbon pools, and nitrogen pools serve an essential role in regulating root growth, nutrient cycling, and water and air movement. However, the impact of these soil health indicators on other crop pressures, such as pests and pathogens, is not widely understood. Vines in Washington are own-rooted and, therefore, susceptible to root-knot nematode (Meloidogyne hapla) damage. These endoparasites cause galls and alter nutrient uptake, and further affect vine growth. Damage from these nematodes can destroy vines young to old and can be detrimental to production in subsequent years. Our objective was to determine the impacts of soil health indicators on parasitic nematode populations.

We used a survey approach to sample on producer-identified "good" and "poor" fields on similar soil types. Soil sampling occurred at a time optimal for sampling juvenile root-knot nematode based on a growing degree day model. Samples were analyzed for key soil health indicators such as aggregate stability, available water holding capacity, permanganate oxidizable carbon (C), mineralizable C, potentially mineralizable nitrogen, bulk density, pH, and texture. Producers also provided management histories for each field through a questionnaire. Multivariate analyses were used to determine the effects of management on soil health indicators and correlations between soil physical properties and root-knot nematode populations.

The results of this study will be used by producers to make informed decisions on soil management and to develop soil health assessment scoring curves that are relevant to wine grape systems in semi-arid regions of the western US.

SOIL HEALTH AND ECOLOGICAL RESILIENCE ON THE PALOUSE

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Healthy soil is critical for global food security and other essential ecosystem services but is threatened by processes of soil degradation, with at least 33% of global croplands estimated to be moderately or highly degraded. Current soil health assessments provide insight into soil functional performance but often lack diagnostic criteria that assess management effects on soil function over time. We integrate soil health assessments with ecological resilience theory to better understand management impacts on soil degradation in a 9-year study comparing four different farming systems in dryland eastern Washington State. This study focuses on soil erosion, organic carbon (C) depletion, and acidification, the three main soil degradation processes in the study region that are also relevant worldwide. The farming systems compared are (i) a 3- year annual cropping rotation with no-tillage (Conventional), (ii) a 3-year annual mixed crop-livestock rotation with no-tillage (Mixed), (iii) a 9-year organic mixed crop-livestock system of 3 years hay and 6 years annual crops with reduced tillage (Organic Crop), and (iv) a 9-year organic mixed crop-livestock system of 6 years hay and 3 years annual crops with reduced tillage (Organic Hay).

We identified one soil health indicator for each soil degradation process of interest, using the Revised Universal Soil Loss Equation (RUSLE 2) to assess erosion rate, C concentration to monitor organic C depletion, and pH to assess acidification. Each soil health indicator was monitored during the 9-year study and compared to an ecological threshold, which if crossed, indicates a decline in function. We found that linking soil health and ecological resilience is a useful strategy to identify soil health indicators of interest in a specific area. Additionally, land managers can understand the sustainability of their systems and make better management decisions, increasing the adaptive capacity of their farming system.

In our 9-year study, we found that the Organic Hay system had the most improvements over time for organic C concentration, followed by the Organic Crop system, while the other treatments both showed decreases in organic C concentration. The Mixed system was the only system that experienced a net increase in pH, while pH in the other systems decreased. The greatest decrease in pH occurred in the Organic Crop system. The results for erosion rate using the RUSLE 2 model are incomplete at this time. The preliminary results from this study indicate that farming practices may improve certain soil health conditions, but not others, so that tradeoffs must be examined when making management decisions.

DEVELOPING A SOIL HEALTH ASSESSMENT FRAMEWORK FOR SPECIALTY CROP SYSTEMS AND SOILS OF WASHINGTON STATE

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To ensure productive soils, agricultural sustainability, and food security, it is vital to maintain and improve soil health. However, over the decades, intensive agricultural practices have led to a decline in soil health. While most of these intensive agricultural practices negatively affect soil health, research has shown that it is possible to resuscitate soils with practices such as over cropping, and crop rotation. Much of the research on soil health in the US has been done in agronomic systems of the Midwest and Northeast. This study aims at better understanding soil health indicator benchmarks and management options in irrigated specialty cropping in the Columbia Basin and Yakima Valley of Washington.

In this study, the effects of agricultural management practices in improving soil health are being studied. This is being done by conducting on-farm soil health assessment surveys of major specialty crops (potatoes, onions, sweet corn, wine grapes, tree fruit, pulses, and hops) in the state of Washington. Across these specialty crops, each participating farm was asked to identify a pair of best and poor fields. Soil samples were collected from each site and analyzed for key soil health indicators such as permanganate oxidizable carbon (C), mineralizable C, soil protein, bulk density, pH, electrical conductivity, and organic matter. Producers provided management history information on each site through questionnaires. The responses from the questionnaires and the results from the laboratory analysis of the soil were then analyzed using multi-variate analyses to determine trends or effects between management practices and key soil health indicators.

Results from this study are expected to give a better understanding of how soil health can be improved with agricultural management practices.

SOIL HEALTH CHANGES FOLLOWING TRANSITION FROM AN ANNUAL CROPPING TO PERENNIAL MANAGEMENT-INTENSIVE GRAZING AGROECOSYSTEM

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Management-intensive Grazing (MiG) on irrigated, perennial pastures has steadily increased in the western US due to pressure for reducing public lands grazing, overall declining land available for pasture, and decreasing commodity prices. However, there are still many unknowns regarding MiG and its environmental impact, especially with regards to soil health. Over a two-year period, we studied changes in soil health under a full-scale, 82 ha pivot-irrigated perennial pasture system grazed with ~ 230 animal units (AUs) using MiG. Soil analysis included 11 soil characteristics aggregated into the Soil Management Assessment Framework (SMAF), which outputs results for soil biological, physical, nutrient, chemical, and overall soil health indices (SHI). Over time, positive impacts were observed in the chemical and biological SHI due to decreases in salt content and increases in microbial and enzymatic activities. Soil organic C (SOC) remained unchanged, yet positive biological SHI changes are likely precursors to future SOC increases. The chemical and nutrient SHI increased in the soil surface due to reductions in salt content in conjunction with increased plant-available soil P, potentially due to salt leaching via irrigation and pre-study inorganic P fertilizer application in conjunction with manure deposition due to MiG, respectively. Finally, a negative impact was also observed in the physical SHI, driven primarily by increasing bulk density due to hoof pressure from cattle grazing. If managed correctly, compaction issues can be avoided, with MiG systems having potential success in supporting grazing while promoting soil health for environmental and economic sustainability.

COVER CROP SUITABILITY FOR HIGH ALTITUDE SPECIALTY CROP ORGANIC FOOD PRODUCTION

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There is a growing interest in certified organic, specialty crop food production. With a larger population demanding organic products and organic products offering a higher premium for the producer, farmers are exploring the transition to organic farming. Organic producers in southeastern Wyoming face multiple challenges in environments with high elevation, low precipitation, and have a short growing season. These challenges include management of persistent weeds, maintaining biodiversity, and implementing rigorous soil health plans in order to maintain the organic certification. One way to help these producers is through growing cover crops. Cover crops are plants (either planted as a monoculture or in mixes) grown during non-crop periods that provide multiple benefits, including soil organic matter (SOM) increase, soil aeration, improving soil aggregation, preventing soil nutrient loss, soil surface cover, and weed competition/smothering. Cover crop monocultures and mixtures have been studied in areas of large agriculture production but careful design of cover crop mixes for non-dryland, specialty crop producers is needed. For areas like southeastern Wyoming, cover crops should germinate quickly, at cooler soil temperatures and produce large amounts of biomass to aid in weed competition and smothering, soil organic matter increase and erosion prevention. The overall goal of this study was to evaluate how cover crop monocultures and mixtures might help organic producers overcome the above mentioned challenges. Two monoculture cover crops; Berseem Clover (Trifolium alexandrinum) and Phacelia (Phacelia tanacetifolia), along with three cover crop mixtures; Mycorrhizal Mix, Cool Season Nitrogen Fixer Mix, and Cool Season Biomass Building Mix were grown under irrigated garden conditions at the University of Wyoming, in Laramie, Wyoming. These cover crop treatments were evaluated for weed suppression and nutrient competition, soil health impact and soil water retention. Preliminary results demonstrate cover crops providing good weed smothering and competition for soil nutrients while not compromising soil moisture.

IMPACT OF SOIL HEALTH PRACTICES IN AN IRRIGATED AGROECOSYSTEM

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Regional farming practices in cold semiarid irrigated agroecosystems with short growing seasons are shifting to reduced tillage and overhead irrigation to stay economically viable, but more research is needed on the impact of soil health practices such as crop diversification, reduced tillage, and livestock integration on soil physical and chemical properties in these systems. A multi-year study from 2014-2020 in the Bighorn Basin of Northwest Wyoming used a three-crop rotation (diversification compared with the typical beets-barley rotation) of edible dry beans, malt barley, and sugarbeets, along with conventional and minimum tillage, and cover crop treatments after barley harvest to evaluate the effects of these practices on soil health. Minimum tillage included strip tilling sugarbeets and dry beans, allowing barley stubble and volunteer regrowth to persist through the winter, and direct harvesting dry beans instead of undercutting and windrowing. Cover crops included replanting barley after barley harvest or planting a four-species mix. Livestock integration involved utilizing barley regrowth or cover crop biomass as hay. Four varieties of dry beans were set into the long-term rotation framework to evaluate nitrogen fixation and yield parameters. The experiment was duplicated under full and 75% of full irrigation to evaluate whether yield gaps would narrow as soil health improves. Crop growth, quality, and yield and soil health indicators were assessed in the 2020 growing season. Results indicate that the amount of N fixed by the edible dry beans varied by variety, tillage, and irrigation. Sugarbeet yield and quality was affected by tillage practice. The type of cover crops after barley harvest affected amounts of labile soil organic matter and biologically available nitrogen. Cover crops with more species in the mix had increased forage quality. While additional data is being compiled for presentation, our preliminary findings suggest crop diversification in cash crop rotations and adding annual fall cover crops after barley harvest creates forage opportunities for livestock integration, while improving specific soil health parameters in the short term and that soil health management practices may affect dry bean variety choice.

EFFECTS OF SEMIARID WHEAT AGRICULTURE ON SOIL MICROBIAL PROPERTIES: A REVIEW

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Agricultural management decisions on factors such as tillage, fertilization, and cropping system determine the fate of much of the world’s soils, and soil microbes both mediate and respond to these changes. However, relationships between management practices and soil microbial properties are poorly understood, especially in semiarid regions. To address this knowledge gap, we reviewed research papers published between 2000 and 2020 that analyzed soil microbes in semiarid wheat fields. We aimed to determine if and how soil microbial properties reliably respond to management, and how these properties may indicate changes in soil health and promote carbon (C) sequestration. We found that reducing tillage increases microbial activity as much as 50% in top soil layers and stratifies both bacteria and fungi by depth. Higher cropping intensity (reduced fallow) benefits C storage, microbial activity and biomass, and particularly fungi, which can be three times greater under continuous wheat than wheat-fallow. Chemical and organic fertilizers both increase bacterial activity, though organic inputs provide lasting benefits by promoting C storage and fungal as well as bacterial biomass. We found microbial properties to be sensitive indicators of long-term changes in soil health and productivity, as long as sampling and analyses are tailored to the system studied.

IS RESIDUE MANAGEMENT AN IMPORTANT FACTOR IN THE SOIL HEALTH OF PERENNIAL GRASS SEED PRODUCTION SYSTEMS?

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Residue management in agricultural systems is a crucial pathway of nutrient and organic matter flow and is predicted to affect soil health indices. In Western Oregon, perennial grasses for seed are a major crop, occupying roughly 150,000 ha in the Willamette Valley. Current estimates are that 80-85% of producers remove straw residue, exporting more than 650,000 US tons of straw annually. The primary objectives of this study were: i) evaluate soil health outcomes under residue retention and removal practices in tall fescue seed production, and ii) explore relationships between soil health measures and key soil/site properties in tall fescue seed production. This dataset represents a real world application of soil health measurements to look at management practices in grower fields. The study was conducted in a survey style by interviewing growers on their management and field history and identifying fields with contrasting history but similar soil type and of similar stand age.

We sampled 28 fields consisting of 14 comparisons between continuous straw retention or removal. Pairs were identified based on: field age, grass species, geographic proximity and similarity in mapped soil series. Fields ranged in size from 3-127 acres and between 3-14 years in age. Three transects were analyzed per field; each transect consisted of 10 samples from the 0-8” depth pooled together for a composite sample. Samples were analyzed by the Central Analytical Lab at Oregon State University. In brief, soils were analyzed for: pH, electrical conductivity (EC), organic matter % (OM), total carbon (TC), total nitrogen (TN), Mehlich-3 extractable K, P, Mg, Ca, texture, potentially mineralizable nitrogen (PMN), permanganate extractable carbon (active C), wet aggregate stability, cation exchange capacity (CEC), soil respiration, bulk density and penetration resistance (PR).

Data showed that most of our measured soil health indices did not change with straw management. In fields with straw retention, we did observe increased K and soil respiration relative to straw removed fields. Many soil health indices were significantly influenced by soil clay content and to a lesser degree, stand age. Regression of soil health variables with clay content or stand age often showed stronger patterns and more often significant correlations were observed under full straw management. For example OM significantly increased with stand age under full straw only; respiration increased with clay content in full straw only. While regression analysis often indicated significant relationships, r2 values were often <0.50 and clay content was not evenly distributed across the dataset.

SENSOR-BASED NITROGEN FOR SPRING WHEAT

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Management of nitrogen (N) fertilizer during wheat production needs to vary depending on the variety as they have different N requirements. Though many growers prefer planting older varieties that they are already familiar with, increasing the knowledge on N requirements of newly released varieties will help to improve the adoption of these varieties by growers. Therefore, the main goals of this study were to assess grain yield, grain N uptake and N use efficiency (NUE) of new and traditional spring wheat varieties supplied varying rates of N and to evaluate N uptake and NUE of the same varieties using ground- and aerial-based (UAV; Unmanned Aerial Vehicle) data. To achieve these goals, six spring wheat varieties [two hard red spring (HRS: SY Basalt and Jefferson), two hard white spring (HWS: UI Platinum and Dayn), and two soft white spring (SWS: UI Stone and Seahawk)] were planted at Parma R&E Center in Spring 2019 and each variety was supplied with varying rates of N (0, 50, 100, 150, 200, 250, and 300 kg N ha^{-1}) as granular urea (46-0-0) at planting. Plant biomass, height, chlorophyll content, biomass production estimate as Normalized Difference Vegetative Index (NDVI), and N content were measured at 2-3, 5-6, and 10 feekes stages while grain yield and grain N content were measured at maturity. According to the results, HRS-Jefferson and HWS-Dayn outperformed the respective HRS-SY Basalt and HWS-UI Platinum as they had higher grain yield, grain N uptake, and NUE especially at greater N application rates. The SWS- Seahawk also appeared to have greater grain yield and grain N uptake than HWS-UI Stone at all N application rates. There was a strong correlation between NDVI and spring wheat plant N uptake suggesting UAV based methodology as a promising technology for agricultural remote sensing applications. The results of this study indicate the need for further refining N recommendations for spring wheat production based on varietal differences.

STACKING AND INTERSECTING NUTRIENT 4RS AND USING IN-SEASON CANOPY HEALTH AND PETIOLE NITRATE ANALYSIS ON RUSSET BURBANK POTATOES

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The 4Rs of nutrient management is a global outreach with an aim to improve the sustainability of major cropping systems and the environment. The objective for this project is to evaluate individual and stacked 4R management practices and how they intersect in Russet Burbank potato at a field near Grace, Idaho in 2020. Nitrogen (N) fertilizer treatments included all combinations of two sources [urea vs polymer coated urea (PCU)], two rates (207 vs. 247 kg ha^{-1}), and two timing/placements (all applied at emergence vs. 84% at emergence + 16% fertigation simulation) compared to an untreated control. Measurements included: four samplings for in-season petiole nitrate and NDVI and measurements of crop yield and quality (data not shown). In-season measurements indicate that the crop was very responsive to N fertilizer. Petiole nitrate results were similar across all fertilized treatments with the exception of the positive control (full rate of urea applied at emergence), which had excessive levels. healthy plants were grown using polymer coated urea (PCU). There were no significant differences in NDVI for the fertilized treatments until the last sampling date (Aug. 28). All of the treatments with PCU applied at emergence performed as well as the timing treatment (Grower Standard Practice of full rate of urea split applied), but the other urea treatments had significantly lower canopy health (as indicated by NDVI). The low rate of urea applied all at emergence was worse than all other treatments. This in-season data suggests that PCU is a reliable N source for potato even at reduced rates, with no advantage of split application. Crop yield and quality will provide further validation of this observation.

EVALUATING NUTRIENT UPTAKE AND PARTITIONING FOR HYBRID CARROT SEED PRODUCTION IN CENTRAL OREGON

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Hybrid carrot seed production is prominent in Central Oregon, however plant nutrient uptake dynamics in this crop are not well understood. The aim of this research was to evaluate nutrient uptake and partitioning during the production cycle of a modern Nantes-type hybrid carrot. Trials were conducted in two commercial carrot seed production fields planted to ‘Nantes 969’. Below- and above-ground plant biomass was destructively sampled and separated into roots, tops, and umbels throughout the growing season, seed samples were collected at harvest. Biomass yield and nutrient content was evaluated throughout the growing season. All plant tissue was analyzed for total N, P, K, S, Ca, Mg, Na, Zn, Fe, Mn, Cu, and B concentrations. Mean whole plant nutrient uptake at crop maturity for N, P2O5, K2O, S, Ca, Mg, and Na was 122, 31, 204, 14, 94, 34, and 22 lb ac^{-1} , respectively; Zn, Fe, Mn, Cu, and B uptake was 0.14, 1.77, 0.37, 0.03, and 0.27 lb ac^{-1}, respectively. Our findings highlighted the importance of Cu in initial crop establishment, of N, K, Zn, and Fe in crown development, and of P and Zn in seed development, based on nutrient uptake amount relative to the other nutrients uptake during that period. This information is available as a resource to agronomists, crop advisors, and growers who are interested in optimizing nutrient management practices for hybrid carrot seed production.

SOIL ORGANIC CARBON AND NITROGEN DYNAMICS UNDER DRYLAND SORGHUM IN NEW MEXICO

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Sorghum [Sorghum bicolor (L.) Moench] serves as a low-cost alternative to corn (Zea mays L.) in semi-arid regions of the world because of its high N and water use efficiencies. However, there has been a concern regarding N loss to the atmosphere as nitrous oxide (N2O) from semi-arid drylands. This study investigated various soil C and N components, including CO2 and N2O emissions, and crop yield with a dairy compost (13.5 Mg ha^{-1}) and four rates of chemical N fertilizer (0, 22.4, 44.8, and 67.3 kg ha^{-1}) in dryland sorghum. There was no significant difference in soil C and N fractions among N fertilizer rates, although compost addition numerically increased soil C storage and 67.3 kg ha−1 N rate resulted the highest yield in both years. Potential nitrogen mineralization (PNM) was negatively related to crop yield and positively related to grain N content. Soils with greater inorganic N and PNM had a lower carbon dioxide (CO2) emissions, while soils with greater potential C mineralization (PCM) had lower N2O emissions. The results of this study show no significant improvements in yield of dryland sorghum in the semi-arid environment of southern Great Plains in the short term. However, compost and 44.8 kg N ha^{-1} applications appeared to be beneficial when both yield and quality were compared.

NEW HYDROPONIC SYSTEM FOR TESTING MINERAL NUTRIENT DEFICIENCIES: QUINOA

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

DRYLAND ORGANIC WINTER WHEAT IMPROVEMENT BY THE INCLUSION OF COMPOSTED CATTLE MANURE AND COVER CROPS

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Organic agriculture in semi-arid environments can face several challenges in order to produce a successful crop. These include nitrogen and phosphorus deficiencies, moisture limitations, and high weed competition. Organic winter wheat (Triticum aestivum, L.)-fallow systems can be amended with composted cattle manure and with green manure from cover crops grown in the fallow phase to help increase wheat yields and quality. Cattle manure can improve soil health with the addition of valuable nutrients and organic matter to soil. Green manure contributes to soil organic matter, reduces fitness and survivability of weeds, and adds nitrogen to the system if leguminous. If these two amendments are combined into one system, synergistic benefits can be observed with an increase in crop performance, soil nutrient retention, and weed suppression. This was tested with a single application of four rates of composted cattle manure in 2015 followed by annual cover crop planting in the fallow phase each spring. One trend in soil nutrient cycling occurred with plant-available phosphorus. The presence of living roots in soil affected the amount of plant-available phosphorus in the system. As the rate of composted cattle manure increased, so did the amount of plant-available phosphorus. Phosphorus found in composted cattle manure can be a critical way to recycle phosphorus and extend its presence in semi-arid environments. Over the two-year period of this study, soil water increased as the rate of composted cattle manure increased on several of the sampling dates, suggesting improvements to soil structure. The use of cover crops did not benefit this cropping system in the way that was hypothesized. Cover crops depleted soil water and inorganic nitrogen and did not suppress weed growth. Minimal interactions were observed between composted cattle manure and cover crop usage, suggesting minimal synergy between the two management practices. Results from this study, however, show that precipitation and composted cattle manure may create an interaction that affects wheat yield. Further research for this is on-going.

IMPROVING CORN NITROGEN MANAGEMENT RECOMMENDATIONS IN THE NORTHWEST U.S.

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The current nitrogen (N) fertilizer recommendations for corn in the Northwest U.S. were developed from limited research (14 potential site-years) in the 1970's and 1980's. New data is needed to improve N fertilizer recommendations. Between 2010 and 2017, 17 N rate studies were conducted. Fifteen site-years were conducted for corn grain and 9 site-years for corn silage. Research was conducted on diverse soil types, tillage systems, irrigation systems, and corn within diverse crop rotations. Fertilizer treatments all included a control (no added N fertilizer) and a range of added N (4 to 6 N rate treatments ranging from 0-400 kg/ha). Each study yield response to N input will be evaluated to fine-tune N management recommendations.

STATIC RANGE NITROGEN MANAGEMENT IN NORTHWEST U.S. SUGARBEET PRODUCTION

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Nitrogen (N) management is important in sugarbeet production. This paper presents data to support a shift from a yield-based N management approach to a static range N management approach in the Northwest U.S. Production data and research show that yield-based N management can result in over application of N. Past research has been critical to improving and understanding sugarbeet N nutrition. However continued research is needed so cumulative data can be evaluated to improve management practices. From 2005 to 2019, studies from 20 locations (20 site-years) were conducted by agronomists from The Amalgamated Sugar Company (TASCO) and scientists at the USDA-ARS Northwest Irrigation and Soils Research Laboratory to evaluate the effect of N supply (fertilizer N + spring soil residual N (Nitrate N + Ammonium N) on sugarbeet production in the Pacific Northwest. Eleven of the site-years had a significant relationship between N supply and ERS yield. Nine of the site-years did not have a significant relationship between N supply and ERS yield. The amount of N supply needed to maximize yields in the 11 responsive sites research studies was within N supply range of 129 to 258 kg/ha (115 to 230 lbs N/acre). Using the past yield-based N management approach (3.5 kg N/metric ton beet [7 lbs N/ton beet]), recommended N supplies would have ranged from 213 to 325 kg/ha (190 to 290 lbs N/acre) from 2005 to 2019. Data shows that needed N supplies to maximize yields have not increased as yields have increased over time. Variation in the needed N supplies are likely due to spatial and temporal variability, and producer knowledge of the fields will help them dial in the needed N supply, preventing over supply of N.

ENHANCED EFFICIENCY PHOSPHORUS FERTILIZERS

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Phosphorus (P) is essential for plants. However, first-year phosphorus fertilizer uptake by plants is low, resulting in economic and environmental impacts. Developments with P Enhanced Efficiency Fertilizer (EEF) sources show improved uptake efficiency and increased yield and/or crop quality, while reducing environmental risk. Research with EEFs (including organic acids, maleic itaconic copolymer, and struvite) all show these improvements, especially when: 1) soil test P concentrations are low, 2) rates are reduced (typically ~50%), and 3) applied to soil with extreme acidity or alkalinity/calcareous. On average, there is a 5% increase in yield/quality over the studies summarized herein. In all cases, if the cost of these materials is too high it may negate any economic advantage with increased yield/quality. Struvite has an added societal advantage in that it is created from recycled materials from wastewater streams, reducing resource consumption. The use of P EEF has potential if used properly and cost is not excessive.

ENHANCED EFFICIENCY NITROGEN FERTILIZER: COATED UREA

B.

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Nitrogen is the most common fertilizer applied to crops, as it is typically the limiting nutrient in plants. However, about half of the nitrogen added to soil as fertilizer is either emitted to the atmosphere as ammonia, nitrous oxide or other gaseous forms, or finds its way into surface or ground waters as nitrate (Kibblewhite, 2007). The inefficient use of fertilizers depletes natural resources, and increases atmospheric emissions and environmental pollutants. With the use of enhanced efficiency fertilizers; however, these costs can be mitigated. Enhanced efficiency fertilizers release nitrogen at a rate similar to that of the plant's natural uptake, thus allowing more efficient fertilizer usage and greater yields. While enhanced efficiency fertilizers often cost more upfront, they require less fertilizer and fewer applications, thus becoming the more economical option over time. The following is a concise literary review of efficient nitrogen fertilizer types.

IS MITIGATION OF DROUGHT STRESS BY ZINC OXIDE NANOPARTICLES DRIVEN BY A NANO- SPECIFIC MECHANISM OR ALLEVIATION OF MICRONUTRIENT DEFICIENCY?

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It has been reported that zinc oxide (ZnO) nanoparticles (NPs) can promote drought tolerance in crops when used as soil amendments. However, many of these experiments were conducted in Zn-deficient growth media with no comparison to currently available Zn fertilization methods, making it unclear if the benefits from adding ZnO NPs were caused by a nano-specifc mechanism or simply by the mitigation of a micronutrient deficiency. A review of the literature shows that of 12 published experiments considering the effects of ZnO NPs on plant health, 5 out of 6 studies that did not include a comparison to currently available Zn fertilizers reported a beneficial effect, with the other study reporting mixed effects. In contrast, of 6 studies that included comparisons to currently available Zn fertilizers, only one reported a positive effect, with 4 reporting neutral or mixed effects and one reporting negative effects. The trends in the literature suggest that the benefits reported from the use of ZnO NPs may result from the mitigation of a micronutrient deficiency and not from a nano-specific mechanism. Preliminary studies conducted in Zn- sufficient growth media have failed to detect a benefit for wheat seedlings experiencing drought stress, again suggesting that ZnO NPs may simply mitigate a micronutrient deficiency. This work demonstrates the need to compare new agronomic technologies with currently available products and production methods.

15NITROGEN UPTAKE AND USE EFFICIENCY IN CORN IN RESPONSE TO FERTILIZER RATE AND TIMING

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Urea fertilizer applications at planting are becoming increasingly common for U.S. upper Midwest corn (Zea mays L.) production but wet spring conditions may result in significant nitrogen (N) fertilizer loss. Split-applications may avoid wet conditions and improve fertilizer uptake and use efficiency. Six field studies were performed to determine the effect of urea fertilizer rate and application timing on fertilizer- derived N (FDN) and soil-derived N (SDN) plant uptake over two consecutive growing seasons. Fertilizer treatments were 0, 45, 135, and 225 kg N ha^{-1} applied at planting, and a split-application of 45 kg N ha^{-1} planting and 90 kg N ha^{-1} at the four collared leaf stage (V4). Five atom% labeled ^{15}N urea was applied to microplots within each fertilized treatment. Aboveground plant samples were collected at V8, R1, and R6 in the first year and R6 the second year. Plant FDN and SDN uptake was limited at four sites following wet spring conditions that favored N loss. The percentage of total N uptake as FDN was greatest closest to the time of fertilizer application but decreased over time as SDN increasingly became the dominant N source. The split-application significantly improved FDN uptake over the 135 kg N ha^{-1} treatment but did not improve total N uptake in the first year at any site illustrating the importance of SDN for corn production. Fertilizer N use efficiency using the isotopic method (FNUE$_{15N}$) was 2.8 to 43.3% across all sites where 0.8 to 10.4% was in the stover, 1.8 to 31.4% was in the grain, and 0.1 to 0.7% was in the cob at the end of the first year. At the end of the second year, approximately 0.5% of the originally applied FDN was in the stover, 1.5% was in the grain, and 0.2% was in the cob. Partitioning of FDN into the stover, grain, and cob fractions was similar in both years between the 135 kg N ha^{-1} single application at planting and the 45/90 kg N ha^{-1} split where approximately 26% of the FDN taken up was in the stover, 72% was in the grain, and <7% was in the cob. This study illustrates the importance of ensuring adequate N availability through fertilization, but ultimately, the soil-crop system should be managed for SDN uptake as >61% of the total N uptake was from the soil.

NITROGEN AND WATER MANAGEMENT FOR OPTIMIZED SUGAR BEET YIELD AND SUGAR CONTENT

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Sugar beet (SB) production is based on maximizing: root yield, and sucrose content, and sucrose recovery efficiency. Efficient nitrogen (N) and water management are key for successful SB production. Nitrogen deficits in the soil can reduce root and sugar yield. Overapplication of N can reduce sucrose content and increase nitrate impurities which lowers sucrose recovery. Application of N in excess of SB crop need leads to vigorous canopy growth, while compromising root development and sugar production. Excessive irrigation can increase SB root weight, but lower sugar content. Remote sensing is a promising tool for in- season N and water management, and in-season prediction of SB yield and quality. Crop sensors can accurately measure SB biomass production and top N content. Spectral indices correlated with N rates applied to SB can be used for in-season prediction of SB yield and quality and to make N management decisions. The goal is to improve water and N use efficiency for agronomically, economically, and environmentally sustainable SB production by combining traditional and novel, state-of-the-art methodologies. The objectives were: 1) to analyze the effects of water and N fertilizer rates on yield and quality of SB, 2) to explore the potential of using ground- and aerial-based (UAVs) data for SB N and water content monitoring, and 3) to access the feasibility of predicting SB root yield and recoverable sugar using hand-held and UAV-based sensors. Field trial was carried out at Parma R&E Center in 2019. The SB variety BTS 2570 was planted in April at 22 inch row spacing, and 8 inch seed spacing into 40 ft long plots each containing 4 rows of SB. Treatments were arranged in a RCBD with 6 replications. Nitrogen was applied at 100, 200, and 300 lb N per acre, as urea (46-0-0) at planting. Irrigation was supplied via subsurface drip irrigation system based on daily ET (evapotranspiration) adjusted using SB crop-specific coefficients, at two levels: 100% and 50%. Matrice 100 UAV ((DGI, Los Angeles, CA) equipped with Red edge M camera (MicaSense Inc., Seattle, WA) was utilized for aerial imagery. MicaSense Atlas (MicaSense Inc., Seattle, WA) and Pix4Dmapper image analysis software (Pix4D, Prilly, Switzerland) were used to process UAV-based data. Preliminary results indicate that 1) 200 lb N per ac in combination with 100% ET-based irrigation maximized both SB root yield and estimated recoverable sugar (ERS); 2) Increasing N to 300 lb N per ac did not further increase SB root yield and ERS; 3) SB biomass: all UAV-derived spectral indices performed equally well, and were excellent estimators of plant height and leaf N content; 4) Accuracy of SB root yield and ERS prediction from UAV spectral indices improves substantially from June to July. Preliminary conclusion: UAV-based data can be successfully used to estimate SB root yield and ERS in-season.