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Phosphorus Rate Effects With and Without AVAIL® on Dryland Winter Wheat in an Eroded Calcareous Soil

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PHOSPHORUS RATE EFFECTS WITH AND WITHOUT AVAIL® ON DRYLAND WINTER WHEAT IN AN ERODED CALCAREOUS SOIL

by

Ryan C. Hodges

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

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ABSTRACT

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in an Eroded Calcareous Soil

by

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Utah State University, 2019

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Soluble phosphorus fertilizer precipitates rapidly after application on alkaline, calcareous soils. A fertilizer additive known as AVAIL® (J.R. Simplot Company) is purported to keep applied phosphorus fertilizer more available to plants by binding soil cations, thereby reducing precipitation reactions. In a soil high in base cations, this could prove useful due to the attraction of AVAIL® with cations such as Ca^{2+}, but is fairly unstudied for dryland wheat production on alkaline, calcareous soils. The objective of this study was to evaluate the effect of low-rate fertilizer treatments with AVAIL® on dryland small grain yield on alkaline, calcareous, eroded hillslopes in a fallow-wheat crop rotation. Two experiments were conducted to determine the treatment on yield and grain quality for (1) spring broadcast application of mono-ammonium phosphate (MAP; 11-52-0) fertilizer (2017), and (2) fall banded application of MAP at planting (2018). Fertilizer treatments were the recommended rate (60 lbs/ac) or one-half the recommended rate (30 lbs/ac) for dryland small grain, with or without AVAIL® (four treatments), replicated four times in a strip-block design in 2017 and replicated 3 times in a randomized

complete block design in 2018. Erosional severity was used as experimental blocks (non-eroded, slightly eroded, highly eroded, and depositional slope segments). Hillslope segmentation allowed for correlating between calcium carbonate, organic matter, and yield levels across treatments. In the broadcast study there was no statistically significant yield advantage of any treatment at any level of erosional severity, saving a grower $20.30/acre by applying 30 lbs/acre of MAP. However, 30 lbs/acre of MAP with AVAIL® showed similar yields to 60 lbs/acre of MAP without AVAIL®, saving a grower $6.42/acre over the standard practice. Results from the banding study also indicate no statistically significant yield advantage of any treatment at any level of erosional severity, saving a grower $15.37/acre by applying 30 lbs/acre of MAP. Neither treatment with AVAIL® had greater yield or profit than those without AVAIL®. Profit for the 60 lbs/acre of MAP treatment narrowly outperformed 30 lbs/acre of MAP by $1.73/acre. This indicates that growers may be able to reduce phosphorus use under dryland growing conditions with optimal fertilizer placement.

(141 pages)

PUBLIC ABSTRACT

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

Ryan C. Hodges

Soluble phosphorus fertilizer is bound in the soil rapidly after application in soils high in calcium. A fertilizer additive known as AVAIL® (J.R. Simplot Company) is purported to keep applied phosphorus fertilizer more available to plants by binding to soil minerals such as calcium, magnesium, and iron, thereby reducing phosphorus binding. This could prove useful due to the attraction of AVAIL® with cations such as Ca^{2+}, but is fairly unstudied for dryland wheat production on alkaline, calcium-rich soils. The objective of this study is to evaluate the effect of low-rate fertilizer treatments with AVAIL® on dryland small grain yield on calcium-rich, eroded hillslopes in a fallow-wheat crop rotation. Two experiments were conducted to determine treatment effects on yield and grain quality for (1) above-ground dispersed (broadcast) application of mono-ammonium phosphate (MAP; 52% P_2O_5 content) fertilizer in the spring (2017), and (2) fall application of MAP incorporated with the seed (banded) at planting (2018). Fertilizer treatments were the recommended rate (60 lbs/ac) or one-half the recommended rate (30 lbs/ac) for dryland small grain, with or without AVAIL® (four treatments), replicated four times in a strip-block design for the 2017 experiment and replicated 3 times in a randomized complete block design for the 2018 experiment. Experimental blocks were assigned to hillslope erosional severity groups. The erosional severity groups were

designated (non-eroded, slightly eroded, highly eroded, and depositional slope segments). Hillslope segmentation allowed for correlations between calcium carbonate, organic matter, and yield levels across treatments. Results from the broadcast study indicate that there was no yield advantage of any treatment at any level of erosional severity, saving a grower $20.30/acre by applying 30 lbs/acre of MAP. However, 30 lbs/acre of MAP with AVAIL® showed similar yield to 60 lbs/acre of MAP without AVAIL®, potentially saving a grower $6.42/acre over standard growing practices. The incorporated study also indicated that there was no reliable yield advantage of any fertilizer treatment at any level of erosional severity, saving a grower $15.37/acre by applying 30 lbs/acre of MAP. Neither treatment with AVAIL had greater yield or profit than those without AVAIL. Profit for the 60 lbs/acre of MAP treatment narrowly outperformed 30 lbs/acre of MAP by $1.73/acre, indicating that growers may be able to reduce phosphorus use under dryland growing conditions with optimal fertilizer placement.

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Ryan C. Hodges

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INTRODUCTION

Of the Mountain States (Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, and Wyoming), total acreage in planted winter wheat was 5,526,000 acres (16% of the US) and total acreage harvested was 4,870,000 (19% of the US) in 2017 (National Agricultural Statistics Service, 2017). These values represent the importance of winter wheat in local agriculture, and an appropriate soil fertility plan, which considers crop needs and environmental effects of the Intermountain West, is the driving factor behind a successful system. Proper fertility management calls for regulating a cropping system's nutrient requirements to allow for the adequate supply of all essential plant nutrients for optimal growth and maximum yield while minimizing fertilizer loss and environmental contamination, and promoting economic sustainability. Variations in cropping systems require flexibility in fertilizer management practices to meet these requirements (Stark and Hopkins, 2015).

Soils across Utah and the Intermountain West tend to have substantially higher amounts of calcium carbonate, or limestone, reaching levels as high as 65% by weight at some agricultural sites. Many dryland wheat growers consistently face the challenge of meeting crop needs for adequate levels of phosphorus before being immobilized via sorption and precipitation in the highly calcareous soils. Those who grow dryland wheat on sloped landscapes are at a further disadvantage due to the loss of organic matter, soil structure, and key nutrients caused by plow layer runoff and erosion. Movement of organic matter-rich topsoil from convex hilltops and back slopes, to areas of deposition directly reflect yield variation along hillslopes (Verity and Anderson, 1990).

Applying organic matter to promote soil structure or growing a cover crop for erosion control are ideal methods for promoting soil health and structure to a conventional crop, but are not always practical for dryland winter wheat production. Cover crops can absorb much needed soil moisture intended for fall planting of winter wheat, yet, the addition of manure creates not only a risk of non-point source pollution but also substantially increases costs due to its transport to growing sites and distribution over a landscape, making its use non-viable. There are additional benefits that organic matter has on the availability of phosphorus to plants, such as the desorption of P from soil mineral surfaces or the solubility of calcium phosphates by organic acids, the aforementioned reasons to not apply organic matter create a need for an alternative solution.

The application of phosphorus fertilizers is the primary source of phosphorus for dryland small grain production. However, in dryland environments of the Inter Mountain West, considerations such as Phosphorus placement, timing of fertilizer application, fertilizer additives, types of phosphorus fertilizers, erosion effects, and the effect of calcareous soil on the availability of phosphorus to plants must be taken into account in order to mitigate these limiting factors of the intermountain west.

To meet the phosphorus sufficiency level required by dryland wheat, growers must choose an appropriate fertilizer and application rate, and decide how and when to apply it to maximize grain production and quality. The two main methods of phosphorus fertilization for calcareous soils are incorporating with the seed at planting and banding with a knife after planting (Larson and Herron, 2003). Banding is the preferred method for fertilizer application, especially for an immobile soil nutrient like phosphorus in a

calcareous soil where the calcite can bind phosphorus, but an "emergency" broadcast application of fertilizer in the spring isn't unusual and may also be considered. In fact, band-applied P can be at least twice as effective as broadcast due to deep rooted crops (Hopkins *et al*., 2018). In a low P soil of Southwest Nebraska seed application of P fertilizer (11-19-0) to winter wheat doubled profits compared with broadcast application, even though optimum P rates were slightly higher for seed applications than for

broadcast (Fiedler *et al*, 1989). The importance of banding is stressed in another study where 34 kg/ha of band applied P_2O_5 resulted in a yield response of 503 kg/ha whereas 34 kg/ha of row applied P_2O_5 resulted in a 134 kg/ha yield response (Lowrey *et al*, 1952).

There has been increased interest in the use of ammonium phosphate fertilizers due to the increase in P uptake when NH_4^+ is placed with P fertilizer. They are often used as direct application fertilizers, but row or seed application of diammonium phosphate (DAP) can cause seedling injury and root growth inhibition in calcareous or high pH soils. There have also been reports of improved crop response to monoammonium phosphate (MAP) compared with DAP on high-pH or calcareous soils as well as increased micronutrient availability in calcareous soils due to its low reaction pH, but these claims have not been substantiated (Havlin *et al.*, 2005).

Phosphorus use efficiency plays an increasingly important role as applied phosphorus is immobilized and fertilizer costs continually increase. The efficiency of P fertilizers in calcareous soils are generally poor due to reaction of P with Ca to form secondary minerals such as dicalcium phosphate dihydrite, octacalcium phosphate, and eventually hydroxyapatite (Havlin *et al.*, 2005). When soil moisture content is as low as

2-4% by volume, this process is expedited — as much as 20-40% of water-soluble P moves out of the granule within 24 hours. At field capacity, that value rises to 50-80% (Havlin *et al*, 2005), providing readily available P for immobilization within hours of field application. With the introduction of the dicarboxylic acid copolymer AVAIL® (J.R. Simplot Company), a fertilizer additive for phosphorus which acts by adsorbing multivalent soil cations surrounding applied P granules theoretically making P more available over time, there is potential for P fertilizers to remain more available over time for plant absorption.

While AVAIL® as a P additive has effectively increased yield of Norkotah potatoes in calcareous soil (high soil test P) (Tindall and J.R. Simplot Co., 2007) and in other staple crops such as rice (Dunn and Stevens, 2008), maize, collards, grass, wheat, onions, tomatoes, sweet corn, and canola (Gordon, 2005, 2007, and Murphy and Sanders, 2007), there has been little to no response on yield for both dryland winter wheat (Ward, 2010, and Chien *et al.*, 2014) or hard red spring wheat (Karamanos and Puurveen, 2011). In addition, the soil types used in Ward's (2010) observation were known to have low P values, but when referencing the Web Soil Survey, all were acidic to slightly alkaline with less than one percent or no calcite present. The study conducted by Karamanos and Puurveen (2011) also did not indicate high levels of calcite. Where there have been positive responses of polymer coated MAP are at the University of Arkansas. Yields produced when P was banded with the seed or broadcast were all significantly increased with AVAIL coating of MAP (30 lbs P_2O_5/ac, low soil P, pH 7) (Murphy and Sanders, 2007). In Australia, wheat data showed that polymer-coated MAP out performed MAP at

three different P rates on highly calcareous soil (70% $CaCO_3$) (Murphy and Sanders, 2007).

AVAIL® may also prove equally or more effective at lower P application rates where there are higher levels of plant available P and may potentially lower costs for the grower. The basis for this comes from recent research collected by Mooso *et al.* (2010), Dunn *et al.* (2008), and Shipp E. *et al.* (2017). Two enhanced efficiency fertilizer products (EEF) showed that they were no better than traditional P sources at standard rates, but a reduction in P rate by approximately 50% resulted in yield and crop quality increase by 5-8% in comparison to the traditional fertilizer applied at the same rate (Shipp E. *et al.,* 2017). In another study, a fertilizer rate of 25 lbs P_2O_5/ac, which is just 5 lbs P_2O_5/ac shy of one of our study's reduced rate treatments, the polymer coated treatment produced statistically greater yields than the uncoated treatment. Here, the reduced rate also produced statistically equivalent yields to 50 lbs P_2O_5/ac of uncoated TSP (Dunn *et al.*, 2008). A similar effect on yield with lower applications of phosphate fertilizer with AVAIL® was evident in Mooso *et al.* (2010).

Superficially, there doesn't seem be a lot of promise in AVAIL® on dryland winter wheat yield based on studies by Ward (2010) and Karamanos and Purveen (2011). However, observations made by Murphy and Sanders (2007) and Hopkins *et al.* (2010) show that AVAIL has the ability to improve P uptake efficiency and crop yield/quality in the presence of calcite with potatoes and wheat. This may also give some indication of yield potential in other crops planted in soils with similarly high levels of calcite and/or low levels of organic matter and soil test phosphorus (STP). For instance, the average response to AVAIL over untreated P fertilizer was 2.8% when including only the

relatively lower STP ($\leq$ 7 ppm P) sites (395 of 503) (Hopkins *et al.*, 2018). Lower STP rates can be indicative of extreme pH soils, low organic matter content, and high levels of calcite. While there may be a handful of studies in the literature on the effects of AVAIL® on wheat and other crops, and with calcareous soils, there is little research on the effects of AVAIL® on wheat in a soil with unusually high levels of calcite.

The objective of this study was to find what effects AVAIL® has with granular MAP when applied at the recommended rate for dryland small grain and half the recommended rate using two modes of application: as a mid-season broadcast, or banded and incorporated with the seed at planting; across varying degrees of organic matter and calcium carbonate content.

METHODS AND MATERIALS

Site Characteristics

All field related work of this study took place at the Godfrey Dryland Experimental Farm, a 29-acre farm located approximately 1.5 miles south of Clarkston (about 41°53'49.00" N, 112°02"53.00" W), Utah and is a recent addition to the Utah Agricultural Experiment Station. The Godfrey Dryland Experimental Farm has a Mean Annual Precipitation (MAP) of 17.49 in (440.4 mm), a Mean Annual Temperature of 50.1 ºF (10 ºC) (Utah Climate Center, 2018), and is at an elevation that ranges from about 1475 to 1483 m (4838 to 4866 ft). Precipitation and temperature data by month for both experiments are shown in Table 1 below.

Table 1. Cutler Weather Station (Utah Climate Center) is the closest operational station to the Godfrey Farm. Precipitation (inches) and temperature (ºF) data are given for the months encompassing the growing season of each experiment.

Cutler Dam, UT Weather Station

Experiment 1 (WE_17)			Experiment 2 (WE_18)		
	Mean Temp	Precipitation		Mean Temp	Precipitation
2016	°F	inches	2017	°F	inches
Aug	72.8	0	Aug	–	–
Sept	62.3	3.75	Sept	60.4	1.09
Oct	51.6	2.51	Oct	47.2	0.18
Nov	44.7	0.99	Nov	41.2	2.16
Dec	24.2	3.41	Dec	25.6	0.56
2017			2018		
Jan	18.1	4.51	Jan	31.3	1.1
Feb	32.3	4.53	Feb	31.6	0.5
Mar	43.8	1.65	Mar	37.6	1.43
Apr	46	2.61	Apr	48.8	2.41
May	55.8	0.7	May	60.2	1.22
June	69	0.37	June	69.3	0.04
July	79	0.03	July	78.3	0.3
Total Precipitation		25.06	Total Precipitation		10.99

The Farm is underlain by the Salt Lake Formation (Tertiary), which is dominated by weakly consolidated tuffaceous and calcareous sedimentary rocks. It can be assumed that the parent material explains the high levels of calcium carbonate in the area, which can be up to 45% in the soil profile (Collinston Series, USDA). Areas of severe erosion in the vicinity of Clarkston, UT expose the highly calcitic subsoil and can be visually identified by the presence of "white surfaces" as in Figures 1 and 2 of the Godfrey Farm. In reference to Figure 1, the research site consists of four soil series; Mendon-Collinston Complex - 0 to 30 percent slopes, eroded (MfE2), Mendon Silt Loam - 0 to 3 percent slopes (MeA), Mendon Silt Loam - 3 to 6 percent slopes (MeB), and Avon Silty Clay Loam - 0 to 3 percent slopes (ArA). The dominant Series of the research site is the Mendon Series (40% of MfE2, 95% of MeA, and 90% of MeB). SoilWeb reveals a dominance of argillic material to 61 cm before transitioning to horizons of calcium carbonate accumulation (Bk to 71 cm and Ck to 86 cm).

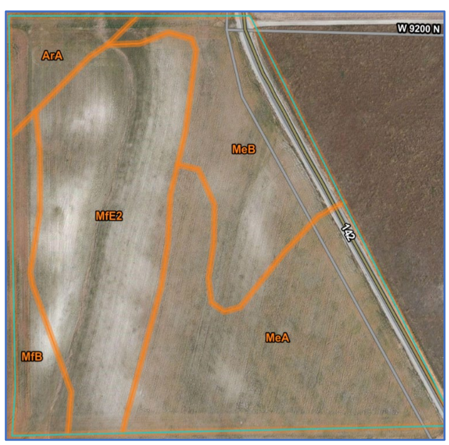


Figure 1. Soil series distribution.

In 2015, agricultural soil test analyses were performed on 50 soil cores taken to a depth of 3 ft and separated into one-foot increments. Core sample locations are shown in Figure 2. The following soil analyses were performed by Utah State University Analytical Laboratory:

- Ammonium Bicarbonate (Olsen) Extractable Phosphorus
- EPA 3050A Acid Digest for Total Phosphorus
- Ammonium Acetate extractable Potassium
- Saturated paste extractable Sulfur as Sulfate
- DTPA extractable Copper, Iron, Manganese, and Zinc
- Saturated Paste extractable salinity
- Organic Matter by Loss on Ignition
- Saturated Paste pH

For a perspective on the general soil health status of the site in relevance to the focus of this study, visual representations of 2015 results for extractable Phosphorus (Olsen), Organic Matter content (%), and pH (saturated paste) to a depth of 1 foot are shown in Figures 3, 4, and 5, respectively. All core samples were dried and homogenized prior to analysis (Hodges *et al*, 2017).

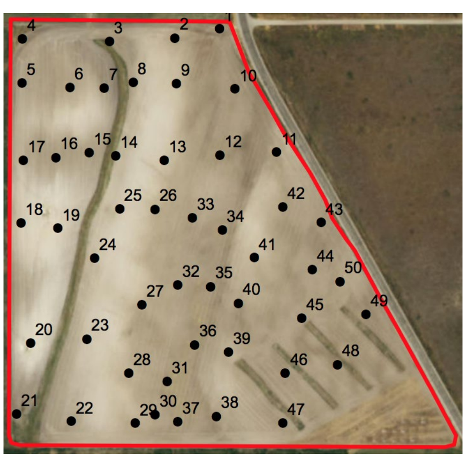


Figure 2. Soil core locations.

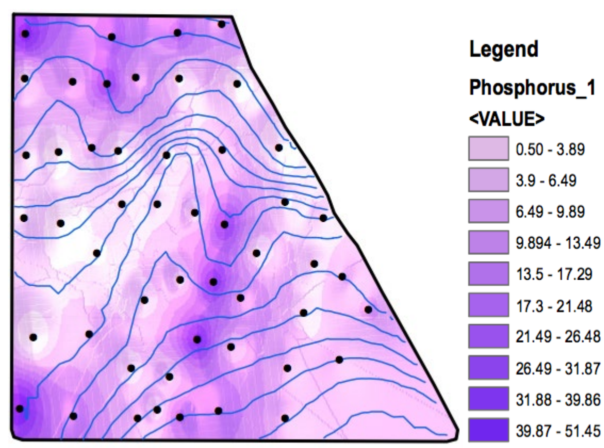


Figure 3. Extractable Phosphorus to 1 ft (mg/kg).

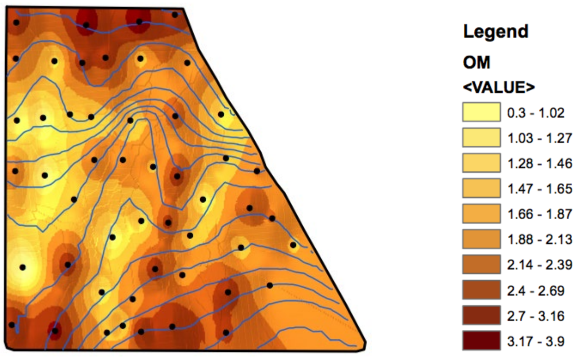


Figure 4. Organic Matter to 1 ft (%).

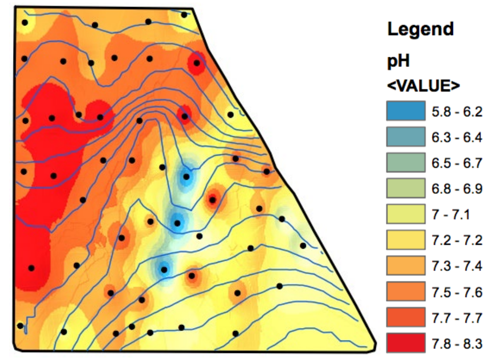


Figure 5. pH to 1 ft (saturated paste).

The Farm is surrounded by property used for dryland winter wheat production and has been used in dryland agricultural production prior to the University's acquisition of the property. Therefore, this site is an ideal location for experiments designed to measure and analyze the effects of fertilizers, erosion, and parent material on dryland small grain production.

Fertilizer Treatments

The fertilizer used for the experimental treatments is granular monoammonium phosphate (MAP), 11-52-0 (52% P_2O_5). Two rates of MAP were used: the recommended rate (60 lbs/acre P_2O_5) and half the recommended rate (30 lbs/acre P_2O_5) for dryland small grain, according to the Utah Fertilizer Guide (2010) when STP ($NaHCO_3$ Soil Test Procedure - mg/kg = ppm) is 0 - 3 ppm. A total of four treatments were used for both experiments of this study; recommended rate of MAP (60 lbs/acre P_2O_5), half the recommended rate of MAP (30 lbs/acre P_2O_5), recommended rate of MAP (60 lbs/acre P_2O_5) with AVAIL®, and half the recommended rate of MAP (30 lbs/acre P_2O_5) with AVAIL®. The AVAIL® treated fertilizer was provided by J.R. Simplot Company (Boise, ID) and treated with the AVAI®L product prior to our acquisition. The AVAIL®

product was applied at a rate of 0.25% or ½ gallon of AVAIL® per ton of granular phosphate fertilizer, was evenly sprayed on the granular phosphate fertilizer prior to mixing with other fertilizer material, and was done in a rotating cement mixer. Detailed mixing instructions are provided on the company's website (J.R. Simplot Company, 2015).

For both experiments, the positive control treatment is the full recommended rate of MAP. Allowing for a negative control of no fertilizer application (0 lbs/acre P_2O_5) for both experiments would be beneficial in the sense that we could quantify the difference between the effects of extractable (available) soil phosphorus and the fertilizer treatments, but it is assumed that in no circumstance, would a grower not apply some level of phosphorus, by any source or means of application, to a dryland small grain crop in the Intermountain West. In fact, a grower would likely apply no less than the recommended amount of phosphate fertilizer in an attempt to accommodate for the soil's inherent capacity to fix phosphate due to its high level of calcite content. Therefore, the recommended rate of MAP fertilizer is our baseline control treatment.

Experiment 1: Spring Broadcast Applied Treatments

Experiment 1 was abbreviated throughout the study as WE_17 (Wheat Experiment 2017). For WE_17, we used a hard red winter wheat variety called Lucin CL as our response crop. It was developed by Dr. David Hole, of the Utah Agricultural Experiment Station, and released in 2011. Some of its advantages include high yield, Clearfield technology resistance, and resistance to Dwarf Bunt. Lucin CL grows fairly tall and is used for bread flower and in artisan breads (Lucin CL Wheat, 2009).

The experiment followed a fallow year in a wheat-fallow rotation. Planting took place in August 2016 at a seeding rate of 60 lbs/acre using a double disc seed drill with 8-inch spacing. The total planting area was 1.42 acres. Planting methods for both experiments following common conservation practices by planting perpendicular to the slope of the terrain to mitigate erosion. A starter application of 35 lbs N/acre of granular urea was applied to the entire field by method of broadcast using a 5-foot wide Gandy drop spreader towed behind a four-wheeler. After planting, the field was subjectively blocked into four levels of erosional severity.

The first experiment was planted over a catena of the Godfrey Farm with noticeable variation in calcium carbonate and organic matter content. The “peak” of the catena within the experiment was subjectively determined and marked. The block east of the “peak” was relatively flat and was designated as “Flat”. The area west of the peak made up ¾ of the experiment plot, sloped down to the west, and draped over the shoulder slope, back slope, and foot slope of the catena. The shortest distance between the peak and the western edge of the experiment plot at the base of the hill was 213 ft. This distance was broken up into three even lengths and was blocked from west to east as “Foot”, “Back”, and “Shoulder”, with block separation perpendicular to the slope, according to their positions on the catena as seen in Figure 6.

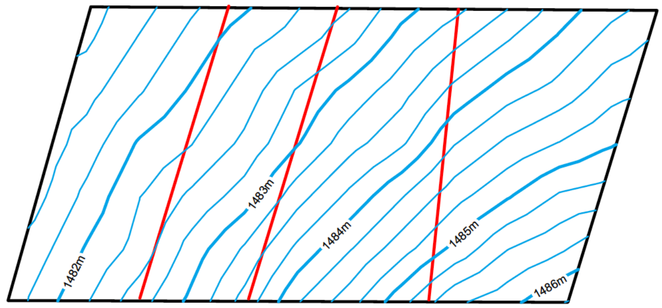


Figure 6. Experiment 1 blocked into four levels of erosional severity.

The four fertilizer treatments were applied to WE_17 on 06 April 2017, perpendicular to the slope to reduce cross-treatment effect during potential events of erosion. Like the starter urea, these treatments were applied to the entire field by method of broadcast using a 5-foot wide Gandy drop spreader towed behind a four-wheeler. The treatments were replicated four times and randomized across the field, creating a Strip-Plot or Strip-Block Design as seen in Figure 8. The experiment used the following effects parameterization equation with its Hasse Diagram (Figure 77) of the appendix:

$$y_{ijkl} = \mu + P_i + (R_P)_k + B_j + (R_PB)_{jk} + \varepsilon_{l(ijk)}, \text{ where:}$$

- y_{ijkl} is the response to fertilizer i, blocked factor j, and Strip-Block factor.
- μ is an arbitrary level of mean response.
- P_i is the Phosphorus fertilizer factor, i = 4 levels
- $(R_P)_k$ is the replication of P_i, k = 4 levels
- B_j is the erosional severity block, j = 4 levels
- $(R_PB)_{jk}$ is the mixed effect
- $\varepsilon_{l(ijk)}$ is the Strip-Plot effect, samples = 3
- In this model, factors involving P_i and S_j are fixed effects. Terms involving R_P [$(R_P)_k$, $(R_PB)_{jk}$ and $\varepsilon_{l(ijk)}$] are all statistically independent random effects.

Of the Hasse Diagram, (E) represents three samples taken per treatment-block mixed effect. When the effects of soil characteristics on yield were analyzed in either experiment, numerical values for three soil samples within a treatment-block mixed effect

were averaged and given a mean value. All statistical computations were completed using SAS University Edition (SAS Institute Inc., 2018). A probability level of 90% was considered to be the lowest at which statistical significance occurred.

Each strip replication across the field was 10 ft wide x 250 ft long. Each treatment was given an identifying color for quick reference while in the field. Treatment color designations are shown in Table 1 and treatment layout for WE_17 is visible in Figure 8.

Treatment	Color
MAP @ 60 lbs/acre	Green
MAP @ 30 lbs/acre	Yellow
MAP @ 60 lbs/acre w/AVAIL	Blue
MAP @ 30 lbs/acre w/AVAIL	Red

Table 2. Experiment 1 treatment color designations.

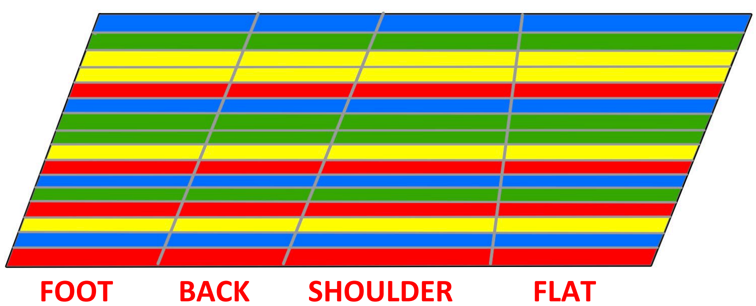


Figure 7. Fertilizer treatment layout for WE_17 with block titles.

Throughout the study, the presence of various weeds was an ongoing issue. Like any conventional wheat grower, we removed as many weeds as possible throughout the duration of the experiment in order to mitigate the effect that the weeds would have on

our results due to diverted moisture and competition for space. On 22 March 2018 the experiment was sprayed with the recommended rate of 2,4-D LV-4, and hand weeding followed to remove as many additional weeds as possible. The types of weeds we encountered were Dyers Woad, Russian Thistle, Field bindweed, Russian knapweed, cereal rye, Shepherd's purse, Spurrey, and Bur buttercup. The Bur buttercup was present in the early spring and was left unsprayed. It tends to have shallow root depth and dies as the growing season eases into the summer months when there is reduced precipitation. The cereal rye was hand weeded as it showed, and the rest of the weeds listed were sprayed with herbicide.

Harvesting of the plant material took place on 21 July 2017 and was harvested by hand. For each cross-treatment plot (displayed in Figure 8) three 2 ft x 2 ft areas were selected by hand tossing a 2ft x 2 ft PVC square into the plot.

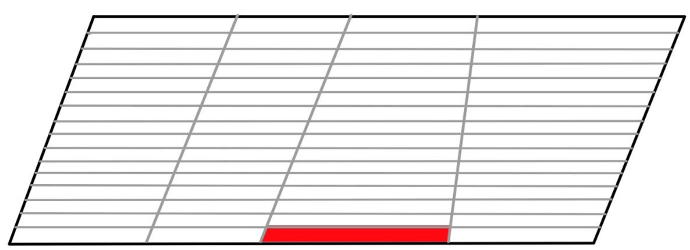


Figure 8. The red area represents a cross-treatment plot for a single block in Experiment 1.

The PVC square was then adjusted to include three rows of wheat to maintain consistency throughout the experiment. Three measurements for plant height were taken within the square and averaged. Using a hand sickle, all plant material within the PVC square was harvested at the base of the stem. This method of data collection and harvest

was done three times per cross-treatment plot and each plot was replicated four times across an erosional severity block. Because of the low amount of plant material collected in a single PVC square, the plant material collected for each of the three PVC squares per plot were combined, and all plant related measurements made were given a single value per replication per block for statistical analysis. Plant material was then taken to the laboratory for processing and further analysis. The following plant analyses were completed for each cross-treatment plot:

- Average plant height at harvest
- Total biomass dry weight
- Grain weight per sample
- Grain protein content by NIR scan
- Plant phosphorus content by Nitric Acid digest

After measuring total stem count and total biomass dry weight, wheat samples were threshed and grain sample weight was recorded. The four replications of grain sample weight per erosion block were averaged numerically and extrapolated to determine total yield (bu/acre) for each fertilizer treatment. Grain samples were then homogenized and sub-samples of 90-100 grams of grain were ground. Roughly 30-50 grams of the powdered grain sub-samples were measured for protein content. Plant phosphorus content was the last measurement taken for plant material in this experiment. Per instruction by the Utah State Analytical Laboratory (USUAL), 50 leaves were randomly selected from a harvested cross-treatment plot of plant material at maturity. The 50 leaves were then ground and homogenized using a blender which kept all plant material contained. Ground plant samples were then put through a modified Nitric/Hydrogen Peroxide digest (Gavlak *et al.*, 2005) and later sent to the USUAL for

analysis for phosphorus content (modified instructions of the Nitric/Hydrogen Peroxide, Wet Ashing Open vessel method were provided by the USUAL).

After all plant material had been harvested from the field, soil cores were taken at the exact locations where plant material was harvested for analysis. Soil cores were taken to a depth of 1 foot and kept separated to maintain individuality. Each sample was dried, ground to pass a 0.25 mm sieve, and homogenized for a representation of how soil characteristics across the catena had an effect on yield and other measured plant values. The following is a list of analyses made of the soil material:

- Saturated Paste pH
- Saturated Paste extractable salinity
- Ammonium Bicarbonate (Olsen) Extractable Phosphorus
- EPA 3050A Total Soil Phosphorus
- Organic Matter by Loss on Ignition (SKALAR Carbon Analyzer)
- Calcium Carbonate content (SKALAR Carbon Analyzer)

Both the Saturated Paste pH and extractable salinity measurements were done in accordance with the *Soil, Plant and Water Reference Methods for the Western Region* manual (Gavlak *et al.*, 2005). Samples were taken to the USUAL to be analyzed for extractable phosphorus using the Sodium Bicarbonate method (Gavlak *et al.*, 2005). Total carbon and inorganic carbon contents were analyzed using a SKALAR Carbon Analyzer. Values for Inorganic Carbon content accounts for total calcium carbonate content of the soil samples. The difference between Total Carbon and Inorganic Carbon provides Organic Carbon content for the soil samples. An estimate of total organic matter content is Organic Carbon (%) x 1.80, assuming that soil organic matter is 55.6% Carbon.

Different levels of erosional severity on a catena will present unique variations in morphology, consisting of various amounts of organic matter and calcium carbonate, among other features. For each block of erosional severity, soil cores were taken to a depth of three feet with color features characterized for a basic horizonation of each block.

Experiment 2: Band Applied Treatments

Experiment 2 was abbreviated throughout the study as WE_18 (Wheat Experiment 2018). For WE_18, we used a soft white winter wheat variety called UI Magic CL+ as our response crop. UI Magic CL+ was produced by the University of Idaho and is considered as having the top-end yielding potential of the variety. It grows short, has a very high test weight, and herbicide resistant through Clearfield technology (UI Magic CL+, 2010). Ideally, we would have used the same wheat variety as in Experiment 1, but it was unavailable.

The experiment followed a fallow-wheat rotation. Planting took place on 26 September 2017 at a seeding rate of 60 lbs/acre using an 8-foot-wide, 3-point Tye seed drill with 8-inch spacing. Simultaneous application of the MAP fertilizer was banded and incorporated with the seed. Total planting area was 0.54 acres. As a rule of thumb, planting of dryland winter wheat in the Intermountain West typically takes place before 20 September, but a lack of soil moisture to germinate the crop prevented that from happening for this experiment as well as for local growers. The Tye drill was fixed at an application rate of 30 lbs/acre for the fertilizer treatments, so all replications that required the recommended rate of MAP (60 lbs/acre) required a second pass-over with the Tye drill with the seeding bucket closed. Again, all replications were planted perpendicular to

the slope of the terrain to mitigate erosion. Like the first experiment, 35 lbs/acre of urea was applied using a 5-foot wide Gandy drop spreader towed behind a four-wheeler. This occurred in the spring of the growing season versus immediately after planting.

The second experiment was directly north of the first experiment and also draped over a catena. To maintain consistency, experiment 2 was also blocked into four levels of erosional severity based on position within the catena. The “peak” was subjectively determined and the area to the east of the “peak” was designated as the “Flat” block. Three blocks west of the “peak” were then created and titled based on hill slope position; from west to east, “Foot”, “Back”, and “Shoulder”, as seen in Figure 9. Like experiment 1, block separation was perpendicular to the slope.

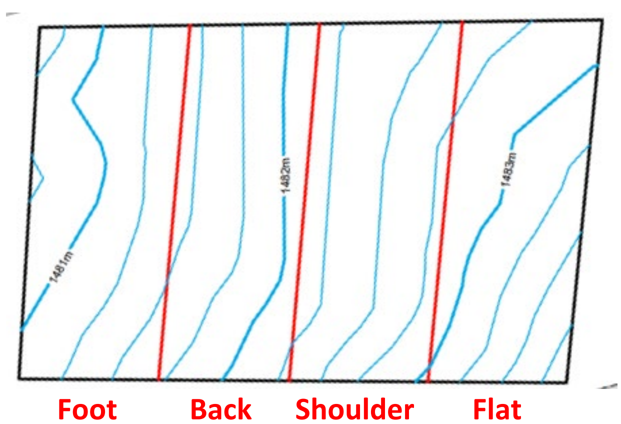


Figure 9. Experiment 2 blocked into four levels of erosional severity.

In this experiment, each treatment was replicated three times per block of erosional severity, and replications were randomized within each block, creating a Randomized Complete Bock Design as seen in Figure 12. The experiment used the

following effects parameterization equation with its Hasse Diagram (Figure 78) of the Appendix:

$$y_{ijkl} = \mu + P_i + B_j + PB_{ij} + (R_P)_k + \boldsymbol{\varepsilon}_{l(ijk)}, \text{ where:}$$

- y_{ijkl} is the response to fertilizer *i*, blocked factor *j*, and the randomized block factor.
- μ is an arbitrary level of mean response.
- P_i is the Phosphorus fertilizer factor, i = 4 levels
- B_j is the erosional severity block, j = 4 levels
- PB_{ij} is the mixed effect
- $(R_P)_k$ is the replication of P_i, k = 3 levels
- $\boldsymbol{\varepsilon}_{l(ijk)}$ is the RCBD effect, samples = 3
- In this model, factors involving P_i B_j, and PB_{ij} are fixed effects. Terms involving R_P [$(R_P)_k$ and $\boldsymbol{\varepsilon}_{l(ijk)}$] are all statistically independent random effects.

Of the Hasse Diagram, (E) represents three samples taken per replication per treatment-block mixed effect. All statistical computations were completed using SAS University Edition (SAS Institute Inc, 2018). A probability level of 90% was considered to be the lowest at which statistical significance occurred.

Each replication was 14 ft wide by 35 ft long. Each treatment was assigned the same color as in the first experiment displayed in Table 2. The fertilizer treatments and seeding was done perpendicular to the slope and were separated by 2-ft fallow gaps to mitigate cross-treatment effect due to erosion, as in Experiment 1.

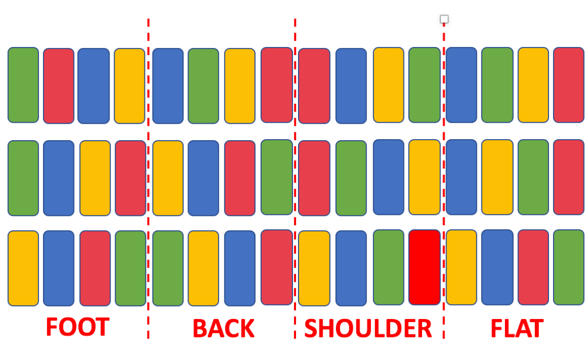


Figure 10. Fertilizer treatment layout for WE_18 with block titles.

The same weeds seen in Experiment 1 were visible and were treated similarly in Experiment 2. Bur Buttercup was most present in the 'Flat' block, Bindweed was most present in the 'Back' and 'Shoulder' slopes, and Russian Thistle was seen across the entire field. Russian Thistle created the most crop pressure in the field and within the experimental plots. Applying 2,4-D LV-4 before the crop's boot stage was desired, but the Russian Thistle did not emerge until after this stage. So, in lieu of applying 2,4-D LV-4 across the crop in order to avoid any yield related issues, Russian Thistle within plots was hand weeded. All weeds between plots and in row spaces were treated with glyphosate.

Harvesting the plant material took place on 18 July 2018 and was harvested by hand. For each cross-treatment plot three 2 ft x 2 ft areas were selected. A 2ft x 2 ft PVC square was first hand tossed into a plot (displayed in Figure 11). Each plot was replicated three times across an erosional severity block.

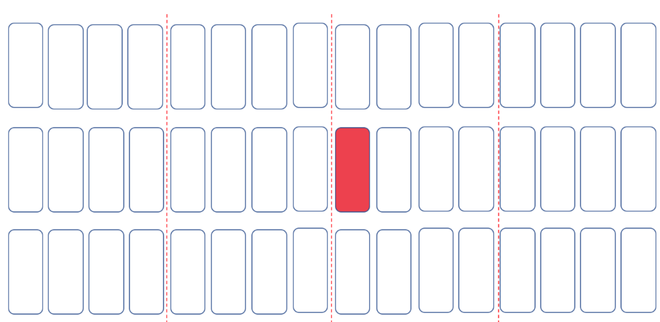


Figure 11. The red area represents a cross-treatment plot for a single block in Experiment 2.

In-field measurements, plant harvesting, soil sampling, and laboratory measurements and analyses for Experiment 2 followed the same methods as in

Experiment 1. Like Experiment 1, core samples were also taken from each block of erosional severity from Experiment 2 in order to be able to visualize the level of erosion in our experiments. Experiment 2 required two analyses of plant phosphorus. Harvesting leaf tissue to measure plant phosphorus took place on 05 June 2018, when the crop reached its post-boot stage, as well as at full maturity at harvest on 18 July 2018, like Experiment 1. Sampling of leaf tissue at post-boot did not take place in Experiment 1. The intention of doing two measurements of plant phosphorus at different stages of the crop's life for the second experiment was to quantify a change or difference in the plots' plant phosphorus levels between post-boot stage and harvest, if any.

RESULTS

Experiment 1: Spring Broadcast Applied Treatments

Blocked Pedon Descriptions

Figure 12 below represents the profiles of each block of erosional severity for Experiment 1 to a depth of 3 ft. In addition, each horizon color shown was referenced and is accurate to the Munsell Soil Color Book.

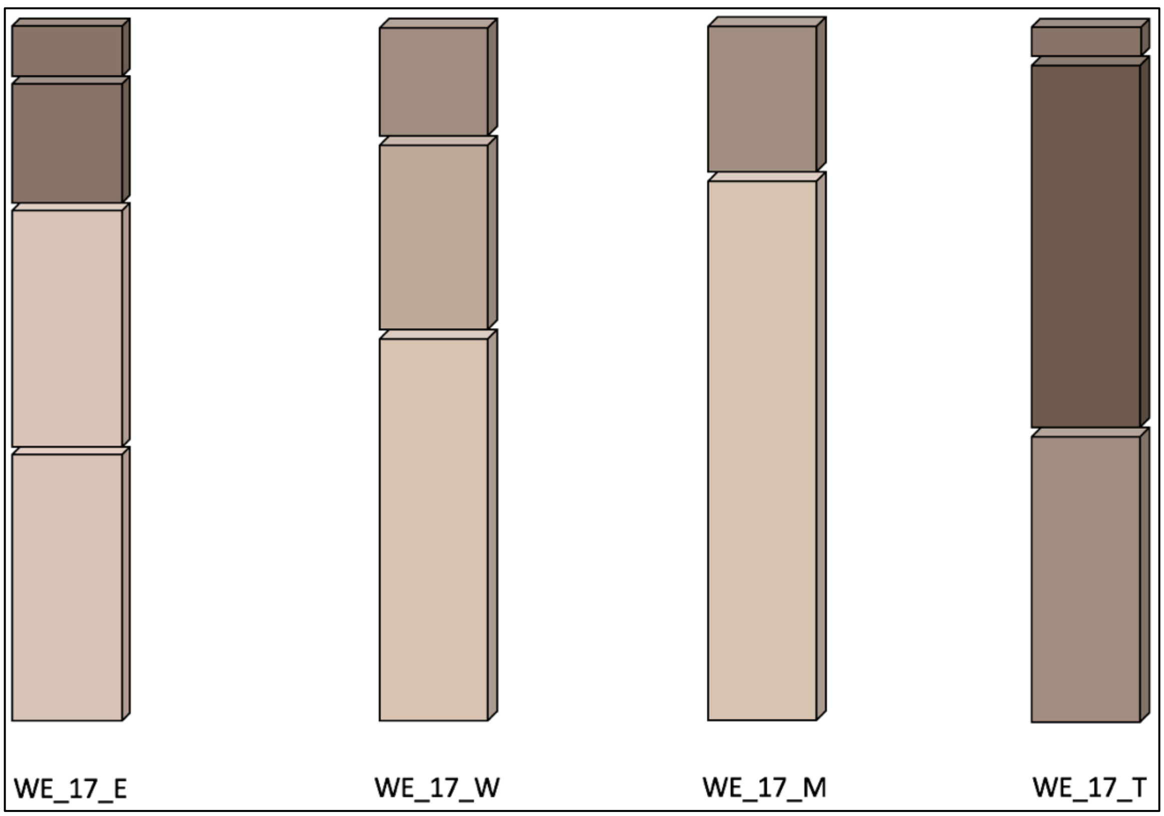


Figure 12. Soil profiles for WE_17 blocks of erosional severity. The following letter for each profile name delineates the block from the experiment: E- East of peak, Flat block; W- West of peak, Slightly eroded block (shoulder slope); M- Mid, Highly eroded block (back slope); and T- Toe, Toe block (toe slope). Each block pedon above represents a profile depth of 3 ft.

Treatment Effects on Yield

There was statistically no difference in yield between fertilizer treatments within any block of erosional severity and are illustrated in Scheffe test results for each block in Figures 13 through 16. P-values for the Non-Eroded, Slightly Eroded, Highly Eroded, and Depositional blocks were 0.331, 0.107, 0.4998, and 0.6324, respectively. P-Values and significance between treatments from other results will be given but will not include their respective Scheffe Grouping Figures. ANOVA box plots of yield are shown in Figures 79 to 82 of the Appendix.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	87.43848
Critical Value of F	3.49029
Minimum Significant Difference	21.396

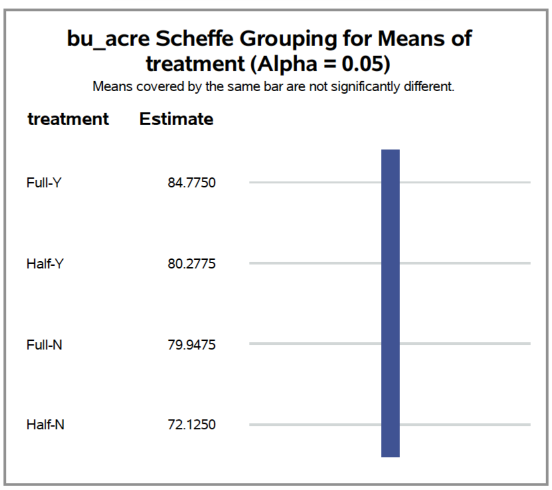


Figure 13. WE_17 Scheffe grouping of the Non-Eroded block for yield (bu/acre).

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	110.8166
Critical Value of F	3.49029
Minimum Significant Difference	24.087

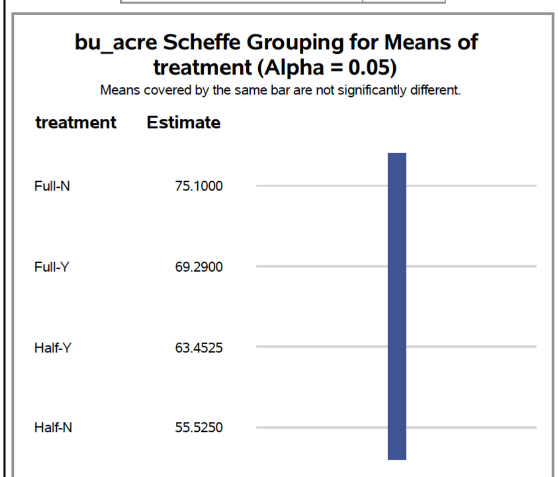
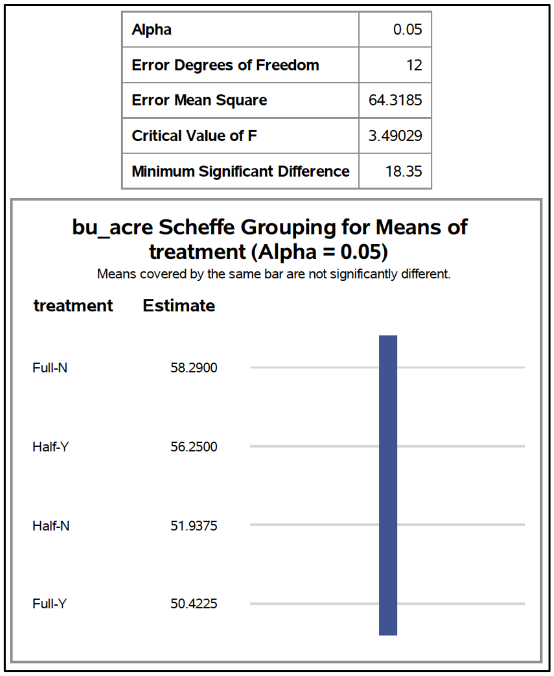
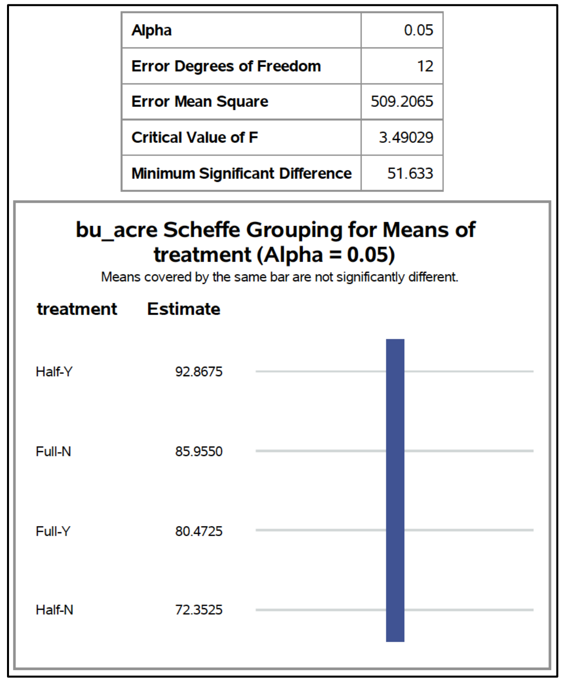


Figure 14. WE_17 Scheffe grouping of the Slightly Eroded block for yield (bu/acre).



Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	64.3185
Critical Value of F	3.49029
Minimum Significant Difference	18.35

Figure 15. WE_17 Scheffe grouping of the Highly Eroded block for yield (bu/acre).



Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	509.2065
Critical Value of F	3.49029
Minimum Significant Difference	51.633

Figure 16. WE_17 Scheffe grouping of the Depositional block for yield (bu/acre).

Generally speaking, blocks of erosional severity with the highest likelihood of producing the greatest yields are the Slightly Eroded and Depositional segments, as visualized below in Figure 19. A GLIMMIX procedure was performed using SAS where yield was averaged across each block of erosional severity, regardless of the treatment, and a logarithmic transformation of least squares means (LSM) was performed. The predicted yield (bu/acre) for erosional block comparison of LSM is illustrated in Figure 17.

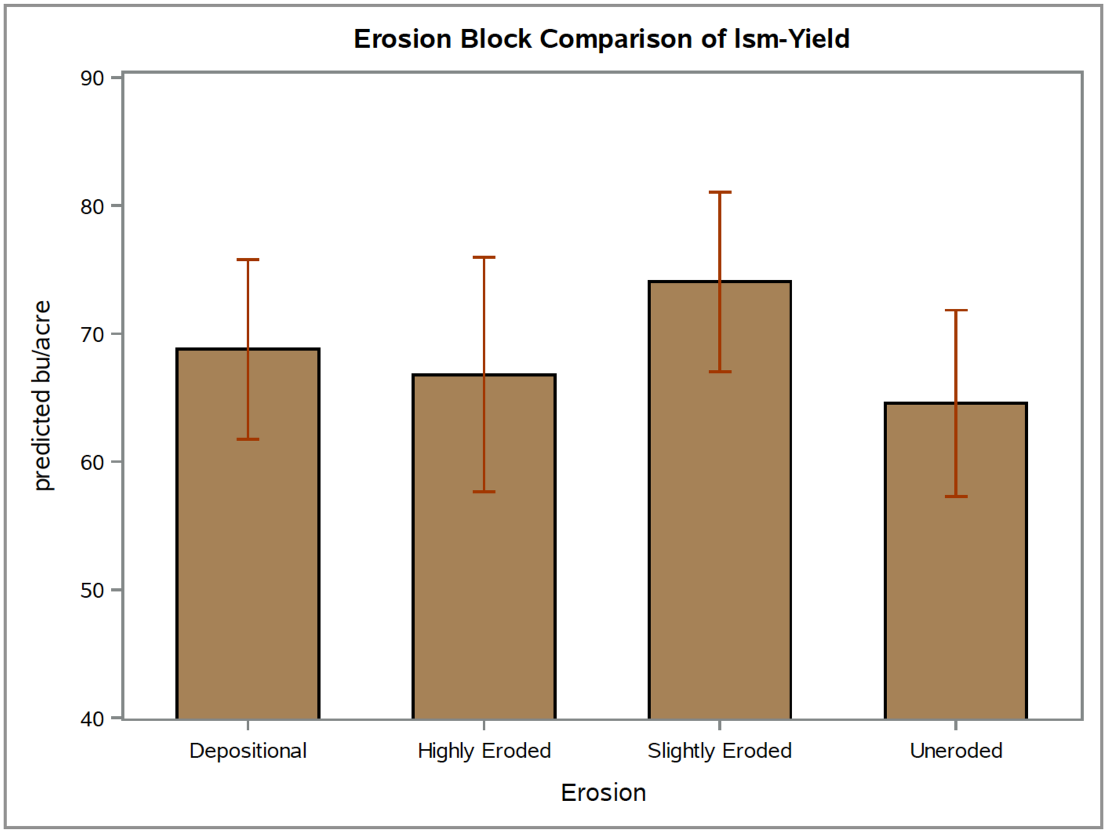


Figure 17. WE_17 Erosional Severity block comparison of LSM for yield (bu/acre). Red bars represent +/-2 degrees of freedom.

Although not significant, the advantage of the recommended rate of MAP over half the recommended rate of MAP when applied as a spring broadcast was 11.8 bu/acre (Figure 18). Amending the full recommended rate of MAP with AVAIL actually had a negative impact on grain yield by -3.6 bu/acre, whereas amending half the recommended rate of MAP with AVAIL had a positive effect on yield by 10.2 bu/acre. It is worth noting, however, that no matter how well one treatment performed over another, in no instance was one statistically significant from another.

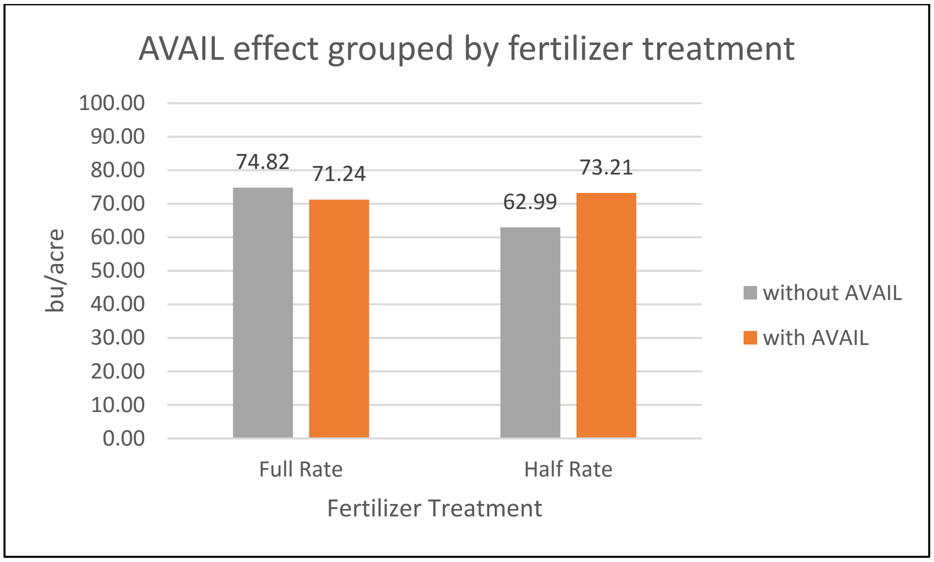


Figure 18. WE_17 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment across all levels of erosional severity.

Yield (bu/acre) results were separated by levels of erosional severity in Figures 19 through 22 below with Figure 19 representing yield at the top of the hill and Figure 22 representing yield at the base of the hill. Calcium Carbonate and Organic Matter contents of each erosional severity block are provided in the Figures' captions. In the non-eroded block, AVAIL had a positive impact on both fertilizer treatment levels with the full rate with AVAIL showing the greatest yield at 84.78 bu/acre. Of the slightly eroded block (Figure 20), there was a positive response to AVAIL when applied with half-rate (7.92 bu/ac), but a negative response with the full rate (-5.81 bu/ac). The full rate without AVAIL showed the greatest yield at 75.1 bu/acre. Of the highly eroded block (Figure 23), AVAIL response to yield was similar to the slightly eroded block. The full rate without AVAIL also had the highest yield response; 58.29 bu/acre. Yield results in the depositional block (Figure 22) also displayed a similar trend where AVAIL had a positive

impact of yield for the half rate (+20.52 bu/ac) and a slightly negative impact on the full rate (-5.49 bu/ac).

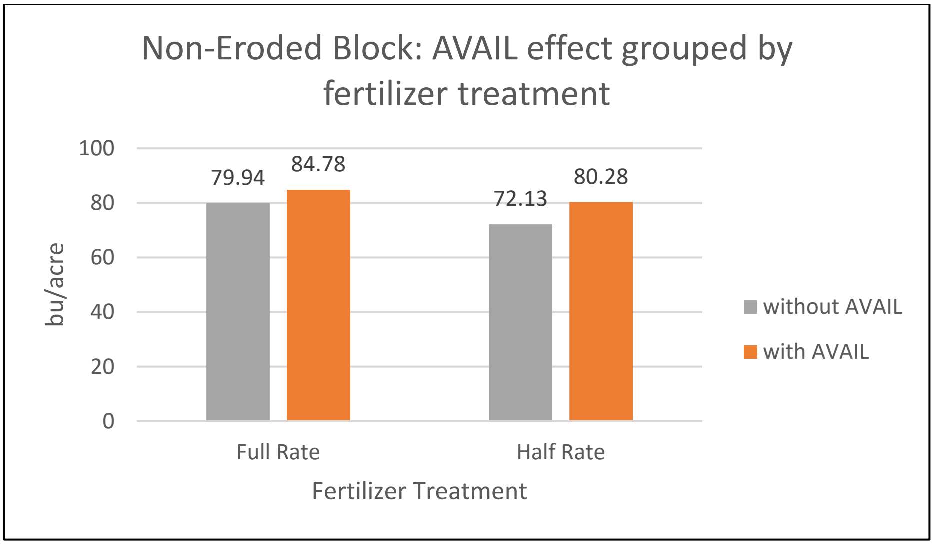


Figure 19. WE_17 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment for the Non-Eroded block. Mean $CaCO_3$ and OM contents are 0.15% and 2.93%, respectively.

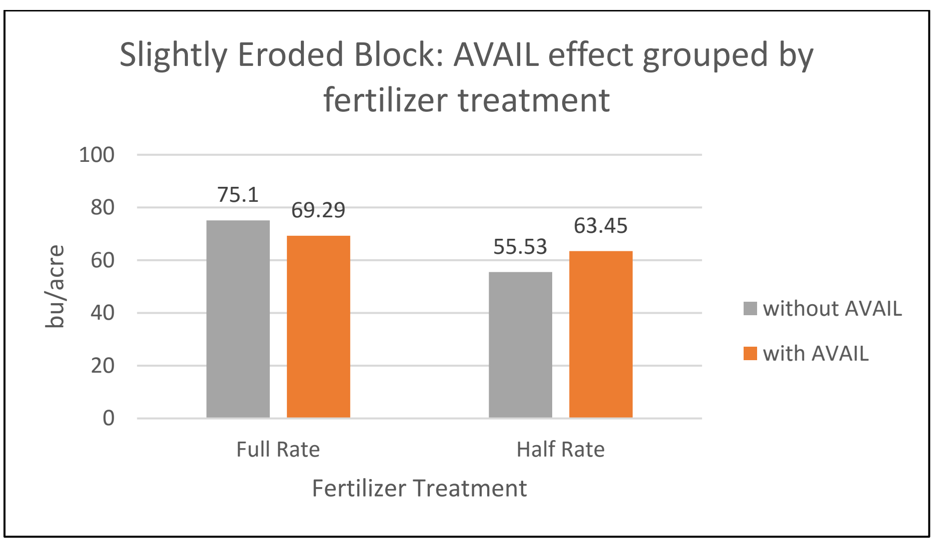


Figure 20. WE_17 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment for the Slightly Eroded block. Mean $CaCO_3$ and OM contents are 1.3% and 2.17%, respectively.

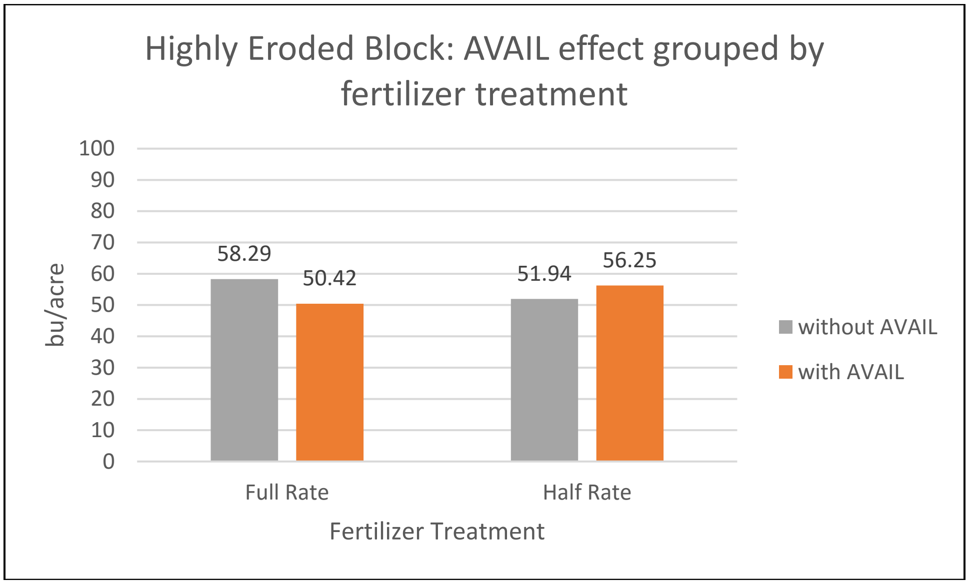


Figure 21. WE_17 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment for the Highly Eroded block. Mean $CaCO_3$ and OM contents are 2.56% and 1.74%, respectively.

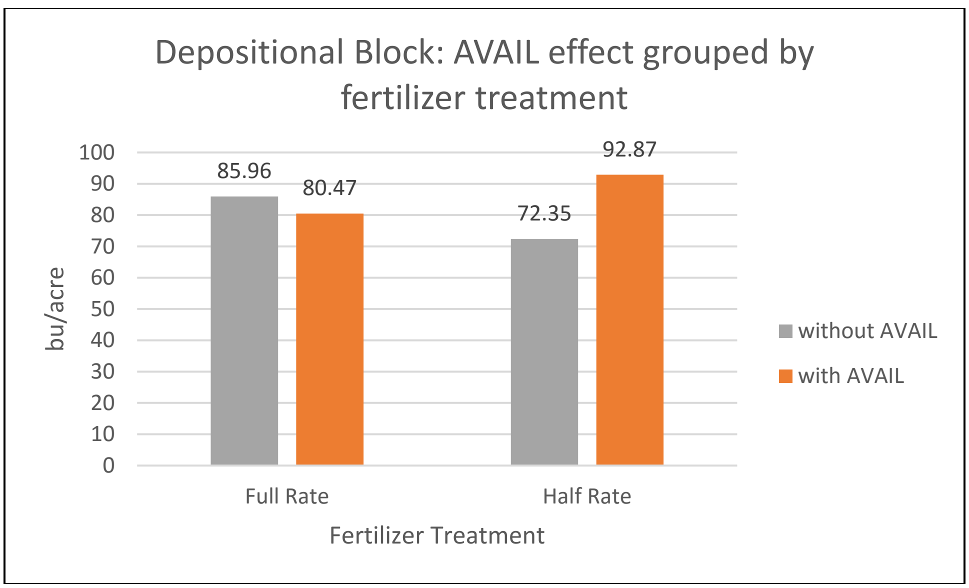


Figure 22. WE_17 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment for the Depositional block. Mean $CaCO_3$ and OM contents are 0.43% and 2.98%, respectively.

Using a costs and returns template created by USU Extension for hard red winter wheat (Holmgren and Pace, 2016), we were able to produce estimates of profit for each fertilizer treatment across the entire experiment, which may prove helpful for growers who produce on hilly landscapes who want to see the total effect of any one treatment used in this experiment. Table 3 shows these estimates with the Full rate without AVAIL producing the highest yield of 74.82 bu/acre, but the Half rate with AVAIL actually returned with the greatest profit at $169.49/acre. Revenue of grain per bushel was determined when all plant material had been harvested for analysis, and “other costs/acre” does not include storage costs. Protein content had been defaulted to 12% to prevent fluctuation in monetary benefit or deduction.

Table 3. Wheat Experiment 2017 (broadcast fertilizer) cost analysis. Yield values in bu/acre for each treatment are mean values across the four block of erosional severity. "Other costs/acre" include operating costs outlined in USU Extension's Costs and Returns template (Holmgren and Pace, 2016). Protein content is defaulted to 12% (no monetary benefit or deduction).

Treatment	bu/acre	Revenue at $4.55/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Total Profit $/acre
Full rate without AVAIL	74.82	$ 340.44	$ (28.18)	$ (149.20)	$ (177.38)	$ 163.07
1/2 rate without AVAIL	62.99	$ 286.59	$ (14.21)	$ (142.87)	$ (157.08)	$ 129.51
Full rate with AVAIL	71.24	$ 324.14	$ (33.06)	$ (146.17)	$ (179.23)	$ 144.91
1/2 rate with AVAIL	73.21	$ 333.12	$ (16.68)	$ (146.95)	$ (163.63)	$ 169.49

The same costs and returns template was applied to each level (block) of erosional severity in Table 4 (pg 56) that is seen in Table 3. Each block includes the average amount of calcium carbonate and Organic Matter. In the non-eroded block, the Full rate with AVAIL had the greatest yield and profit, although, the Half rate with AVAIL produced just 4.5 bu/acre and $2.27/acre less (OM= 2.93%, $CaCO_3$= 0.15%). In the slightly eroded block, the Full rate without AVAIL had both the greatest values in yield and in profit by 5.82 bu/acre and $28.98/acre (OM= 2.17%, $CaCO_3$= 1.3%). In the highly eroded block, the Full rate without AVAIL produced the greatest yield at 58.29 bu/acre, but the Half rate with AVAIL produced the greatest profit at $98.95/acre by $3.04/acre (OM= 1.74%, $CaCO_3$= 2.56%). The depositional block showed similarities with the non-eroded block (OM= 2.98%, $CaCO_3$= 0.43%). The Half rate with AVAIL produced the greatest yield and profit at $92.87 bu/acre and $250.83/acre, respectively.

Plant Measurement Correlations

A Correlation procedure was done in SAS between the different plant measurements made in Experiment 1 in order to see how much one plant measurement was associated with another. Correlations of plant measurements broken up by blocks of erosional severity or treatments was unnecessary, and finding correlations across the entire experiment provided a larger sample size (N=48). Figures 23 and 24 demonstrate the correlations below.

- Plant Height = plant_ht
- Stem Count (plant density) = Stem_Cnt
- Total Plant Weight (total biomass) = Total_PW
- protein content = protein
- Plant Phosphorus content = plant_P

All plant measurements made, with the exception of protein content (%), are highly and positively correlated with each other. All positively correlated plant measurements have P-values < .0001.

Pearson Correlation Coefficients, N = 64 Prob > |r| under H0: Rho=0					
	plant_ht	**Stem_Cnt**	**Total_PW**	**protein**	**plant_P**
plant_ht	1.00000	0.63194 <.0001	0.80219 <.0001	-0.09460 0.4572	0.49098 <.0001
Stem_Cnt	0.63194 <.0001	1.00000	0.88526 <.0001	-0.14508 0.2527	0.49027 <.0001
Total_PW	0.80219 <.0001	0.88526 <.0001	1.00000	-0.12187 0.3374	0.58342 <.0001
protein	-0.09460 0.4572	-0.14508 0.2527	-0.12187 0.3374	1.00000	-0.08806 0.4890
plant_P	0.49098 <.0001	0.49027 <.0001	0.58342 <.0001	-0.08806 0.4890	1.00000

Figure 23. WE_17 plant measurement Pearson correlations. Within each box, the top value is the correlation number (a) between the plant measurements in the top row and left column, where $-1 \leq a \geq 1$. The bottom value is its P-value.

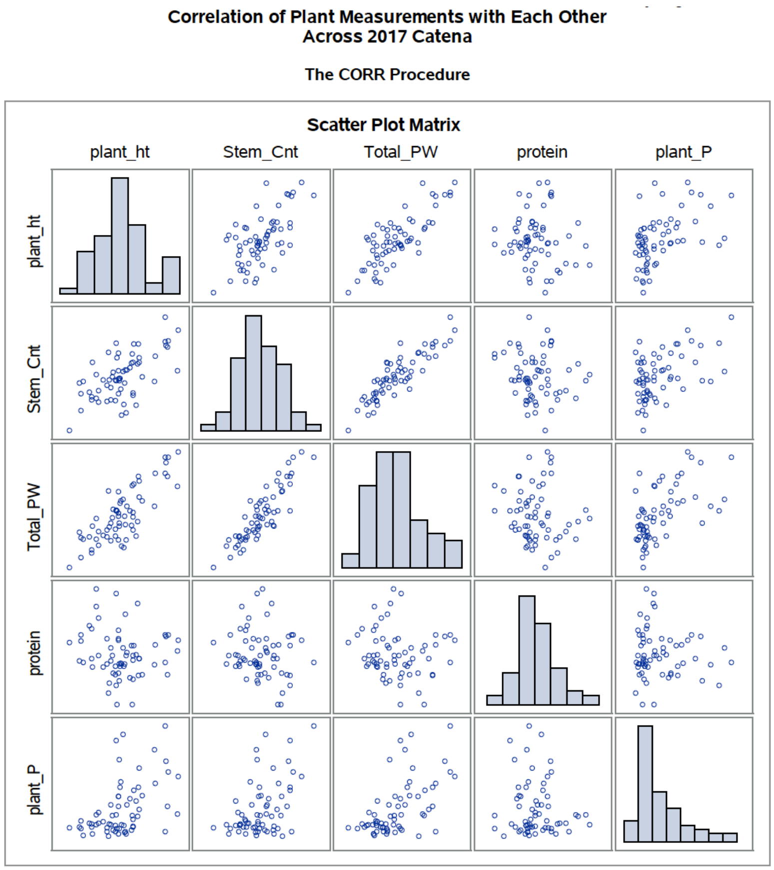


Figure 24. WE_17 plant measurement scatter plot correlations. A scatter plot matrix displaying correlations between different plant measurements shown in the top row and left column.

Plant Height at Harvest

There was no statistically significant difference between the dependent variable plant height and the treatments as fixed factors among the Flat and Depositional blocks of the catena with P-Values of 0.3021, and 0.8126, respectively. Interestingly, there was statistical significance between plant height and fertilizer treatments for the Slightly Eroded and Highly Eroded blocks of the catena with P-Values of 0.0054 and 0.0411, respectively. In the Slightly Eroded block, 60 lbs/acre of MAP without AVAIL (29.13 in) was not significantly different from 30 lbs/acre of MAP with AVAIL (27.39 in). The recommended rate of MAP without AVAIL was, however, statistically significant from

the two treatments with the lowest plant height means: 60 lbs/acre of MAP with AVAIL (27.18 in) and 30 lbs/acre of MAP without AVAIL (26.54 in). Of the Highly Eroded block, 60 lbs/acre of MAP without AVAIL (27.81 in) did rank first in plant height but was not statistically significant in plant height from the other treatments. It is worth noting that 30 lbs/acre of MAP with AVAIL was not statistically significant from the other treatments in any block of erosional severity, and also had the highest plant height average over other treatments in the Depositional block (29.26 in). Correlating box plots of plant height variation within levels of erosional severity are shown in Figures 83 to 86 of the Appendix.

Total Biomass Dry Weight

From the Proc ANOVA procedure, there was no statistical significance between the dependent factor - total biomass dry weight, and the four fertilizer treatments among all levels of erosional severity. What is similar between results for biomass weight and plant height is that, generally speaking, most treatments are similarly ranked for the two measurements within their respective block of erosional severity. Correlating box plots of total biomass dry weight variation within levels of erosional severity are shown in Figures 87 to 90 of the Appendix.

Plant Density

There is no statistical significance between the four fertilizer treatments for the Non-Eroded, Highly Eroded, and Depositional blocks with respect to plant density. In the Slightly Eroded block, the recommended rate of MAP without AVAIL was statistically significant from the treatment with the lowest plant density, half the recommended rate of MAP without AVAIL. No other two fertilizer treatments differed

significantly in plant density. The Slightly Eroded segment was the only block that was statistically significant with a P-Value of 0.0136. The Non-Eroded, Highly Eroded, and Depositional blocks had P-Values of 0.3013, 0.7857, and 0.6317, respectively. Correlating box plots of plant density variation within levels of erosional severity are shown in Figures 91 to 94 of the Appendix.

Grain Protein Content

The Highly Eroded block was the only block where the dependent variable Grain Protein Content was statistically significant with the fertilizer treatments with a P-Value of 0.0420. The Flat, Slightly Eroded, and Depositional blocks were not statistically significant with P-Values of 0.4333, 0.3214, and 0.9143, respectively. Correlating box plots of grain protein content variation within levels of erosional severity are shown in Figures 95 to 98 of the Appendix.

Plant Phosphorus Content

The following four figures display the relative statistical significance between the four fertilizer treatments for each level of erosional severity. These figures also represent plant P values of leaf material at harvest. Each treatment was not statistically significant from each other in any level of erosional severity on the catena. All blocks were not statistically significant with the lowest P-value being the highly eroded block at 0.2332.

In Experiment 2, plant leaves were taken at post-boot stage as well as at harvest. Including all 48 samples of the experiment, it was evident that there was an averaged reduction of 90% in plant leaf phosphorus between post-boot stage and harvest due to resource diversion. We can expect that a similar percentage reduction in plant P occurred

in Experiment 1. Correlating box plots of plant phosphorus content variation within levels of erosional severity are shown in Figures 99 to 102 of the Appendix.

Soil Characteristics and Effects on Yield

In the following sections in this experiment of the Results, various characteristics of the soil including pH, Electrical Conductivity, labile soil phosphorus, Organic Matter, and Calcium Carbonate content, will demonstrate their effects on grain yield. While grain yield results can be narrow-mindedly determined to be a cause of the fertilizer treatments, dynamic soil environments in an open system experiment ensure this is not the case. We expect Calcium Carbonate and Organic Matter content to have an effect on crop yield, but by understand the extent of these factors and others of the catena will permit a deeper understanding of the treatment effects on crop yield. Results from the Type III Tests of Fixed Effects on yield produced from the SAS Proc GLIMMIX procedure is shown below in Figure 25.

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
MAP_rate	1	52.6	7.52	0.0083
AVAIL	1	52.71	0.07	0.7899
EC	1	54.91	14.87	0.0003
pH	1	54.78	0.13	0.7166
OM	1	54.43	12.05	0.0010
CaCO3	1	53.75	2.50	0.1196
OM*CaCO3	1	54.9	6.89	0.0112
soil_P	1	54.13	5.43	0.0236

Figure 25. Type III Tests of Fixed Effects on Yield for Experiment 1.

Soil phosphorus is shown to have a statistically significant effect on yield with a P-Value of 0.0236. Organic Matter (OM) and the multiple effect OM*$CaCO_3$, have statistically significant effects on yield with P-Values of 0.001 and 0.0112, respectively, with Electrical Conductivity (EC) having the lowest P-Value of 0.0003. $CaCO_3$ alone as a fixed effect was marginally non-significant with a P-Value of 0.1196. Whether AVAIL was present or not was not statistically significant with a P-Value of 0.79, whereas the rate at which MAP was applied as a broadcast was significant with a P-Value of 0.008.

Soil Characteristics and Effects on Profit

Results from the Type III Tests of Fixed Effects on profit produced from the SAS Proc GLIMMIX procedure is shown below in Figure 26. A positive shift in P-Value strength from MAP rate to AVAIL occurred when considering profit versus yield. Fixed factors related to unaltered soil conditions (EC, pH, OM*$CaCO_3$ and Olsen P) have P-Values that remain unchanged when considering their effects on profit (Figure 26).

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
MAP_rate	1	52.6	1.91	0.1726
AVAIL	1	52.71	0.35	0.5569
EC	1	54.91	14.87	0.0003
pH	1	54.78	0.14	0.7098
OM	1	54.43	12.03	0.0010
CaCO3	1	53.75	2.52	0.1186
OM*CaCO3	1	54.9	6.91	0.0111
Olsen_P	1	54.13	5.43	0.0236

Figure 26. Type III Tests of Fixed Effects on Profit for Experiment 1.

Saturated Paste pH

Figures 27 and 28 below show that pH for the Depositional, Highly Eroded, and Non-Eroded blocks of erosional severity were statistically significant from each other. The pH of the Slightly Eroded block is not significant from the other block of the catena with a confidence P-Value of 0.0037. Figure 30 conceptualizes the possibility of variation in the amount of calcium carbonate and possibly other salts in the top foot of soil in the southern edge of the experiment. Visually, it seems as if this variation in pH was caused by surface erosion at the south side of the Non-Eroded block with sediment runoff down the hillslope into the depositional area.

Scheffe's Test for pH

Note: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.046181
Critical Value of F	2.75808
Minimum Significant Difference	0.2185

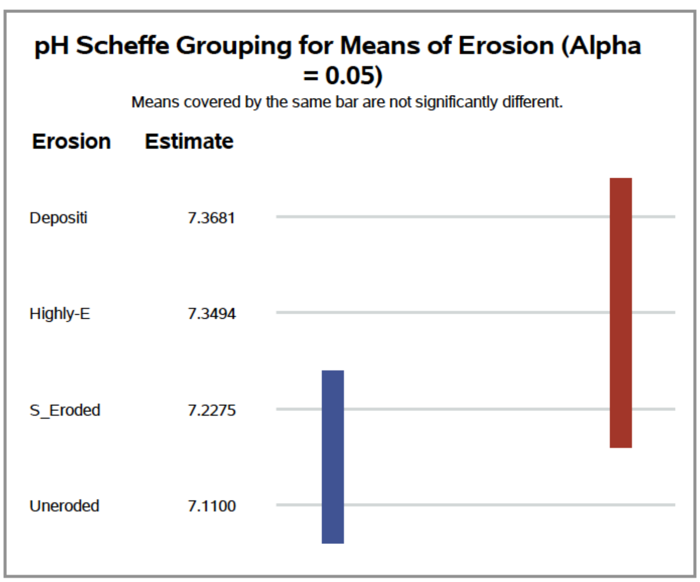


Figure 27. WE_17 test of pH for the four erosional severity blocks, with means.

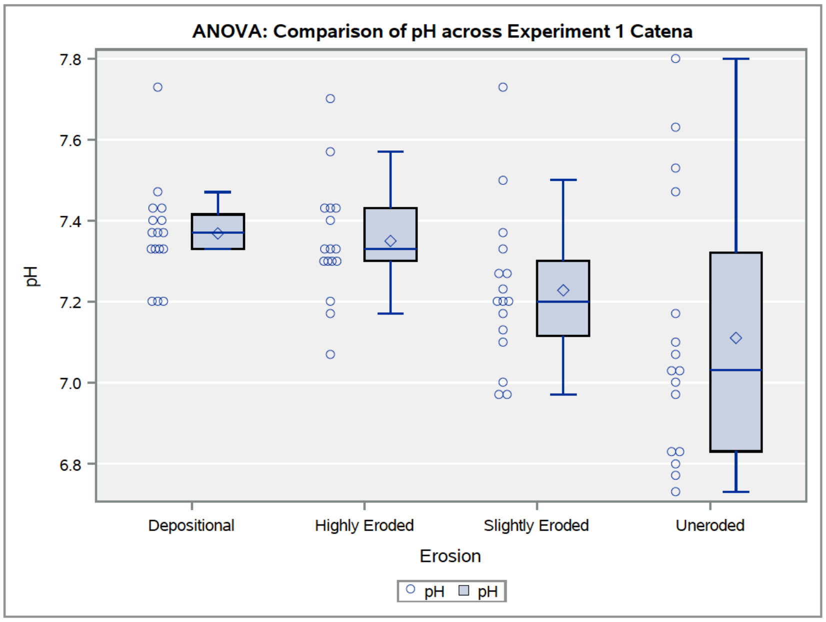


Figure 28. WE_17 box plot comparison of pH with point sample values of four erosional severity blocks.

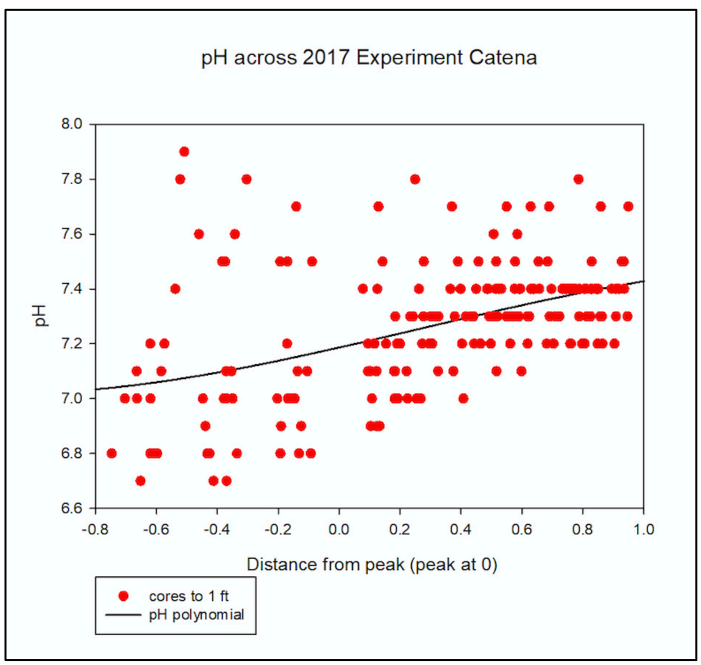


Figure 29. WE_17 pH samples are in red (1ft depth) with pH values on the y-axis. Points are plotted across the catena with 0.0 on the x-axis signifying the peak of the hill. On the x-axis, negative values are points east of the peak, in the Non-Eroded section, and positive values are points west of the peak, through the Slightly Eroded, Highly Eroded, and Depositional segments. The black line is the polynomial for the 192 soil core samples for pH content.

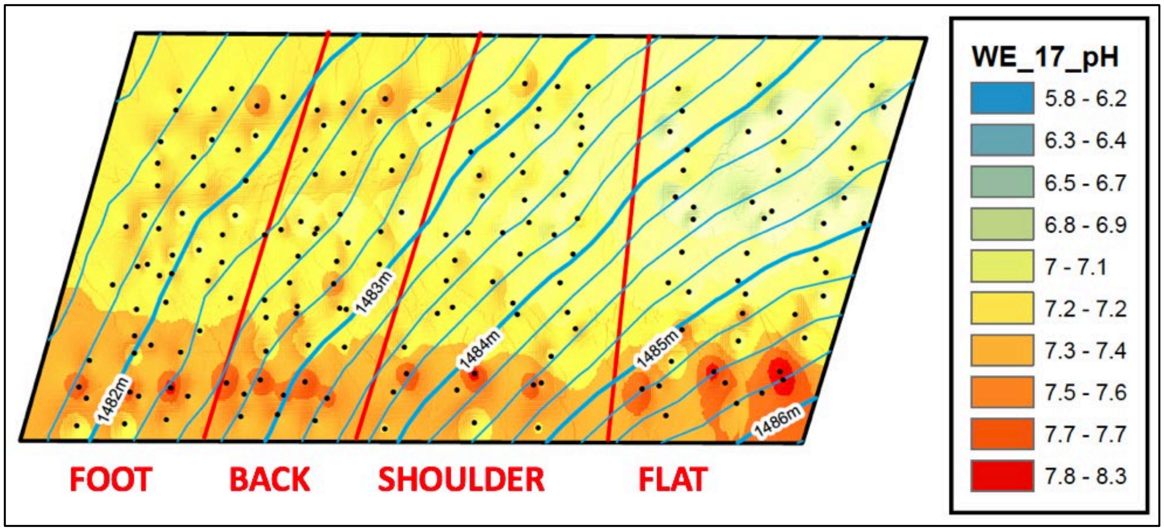
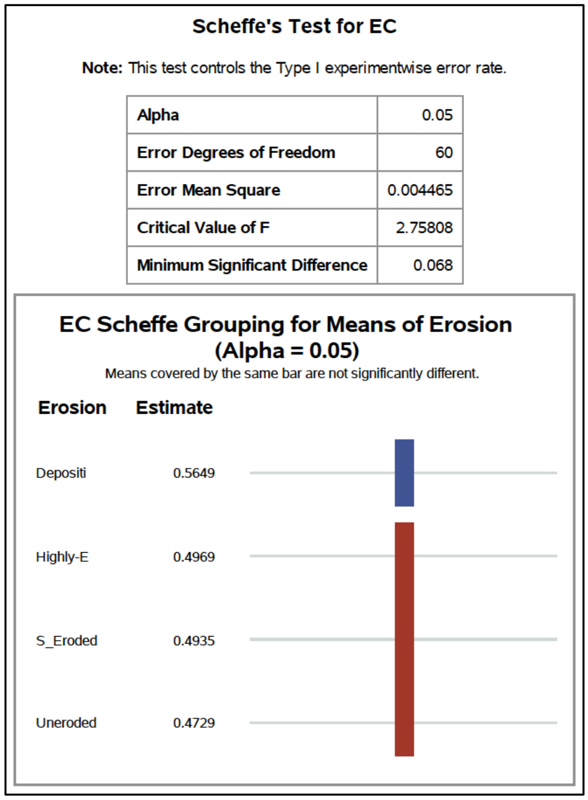


Figure 30. Spatial variation in pH across 192 samples of Experiment 1.

Saturated Paste Extractable Salinity

Using Scheffe's Test on Extractable Salinity (Figure 31) showed that the Depositional block was statistically significant from the other three blocks of erosional severity. All values were below 0.8 dS/m, and the Type III Test of Fixed Effects shown in Figure 47 show that it has a statistically significant effect on yield ($P<0.05$). It is good to note that the threshold value for salt tolerance of wheat is 4.7 dS/m (Kotuby-Amacher et al., 2000). Therefore, soil EC did not prove damaging to yield in Experiment 1.



Scheffe's Test for EC

Note: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.004465
Critical Value of F	2.75808
Minimum Significant Difference	0.068

Figure 31. WE_17 Scheffe test of EC for the four erosional severity blocks, with means.

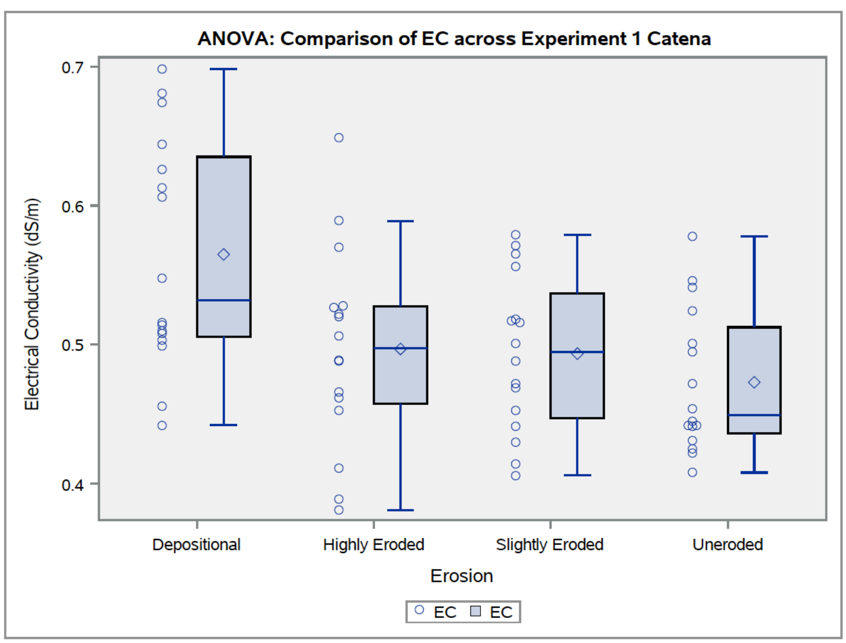


Figure 32. WE_17 box plot comparison of EC with point sample values of four erosional severity blocks.

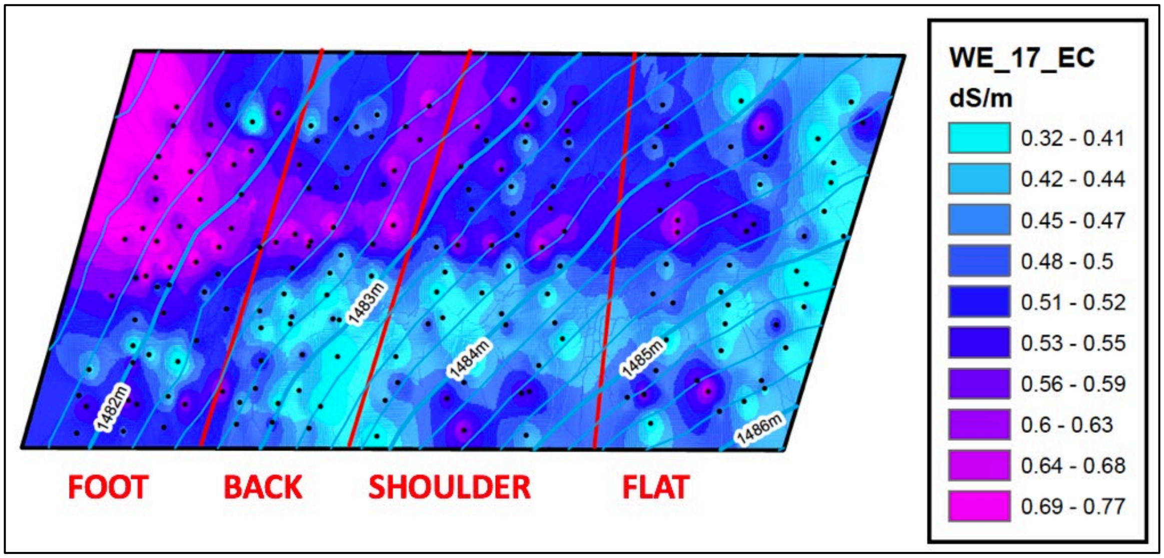


Figure 33. Spatial variation in EC (dS/m) across 192 samples of Experiment 1.

Extractable Soil Phosphorus (Olsen)

Plant available soil Phosphorus (Olsen P) was positively correlated to yield as seen in Figure 34 where its P-Value was 0.0236 with the proc GLIMMIX Type III test and in Figure 34 which demonstrates a "Loess" graph from the GLIMMIX procedure. Olsen P was not significantly correlated between the non-eroded and highly eroded blocks, as seen in Figure 35 with the proc ANOVA Scheffe test of Olsen P. Figure 37, which demonstrates the variation in Olsen P across the catena, shows where the box plot variation lies between the four erosion blocks of Figure 36. Figure 37 shows quite a spread in Olsen P content at the top of the catena (non-eroded block) and the bottom of the hill (depositional block). Between these two areas (0.0 to 05 of the x-axis, Figure 37), Olsen P values are lower and more densely spaced (area of high erosion). The non-eroded and depositional areas of the catena also showed higher levels of organic matter content, which explains the weak positive correlation between Organic Matter and Olsen

P in Figure 46. These variations and similarities can be further supported by the spatial distribution of Olsen P in Figure 38.

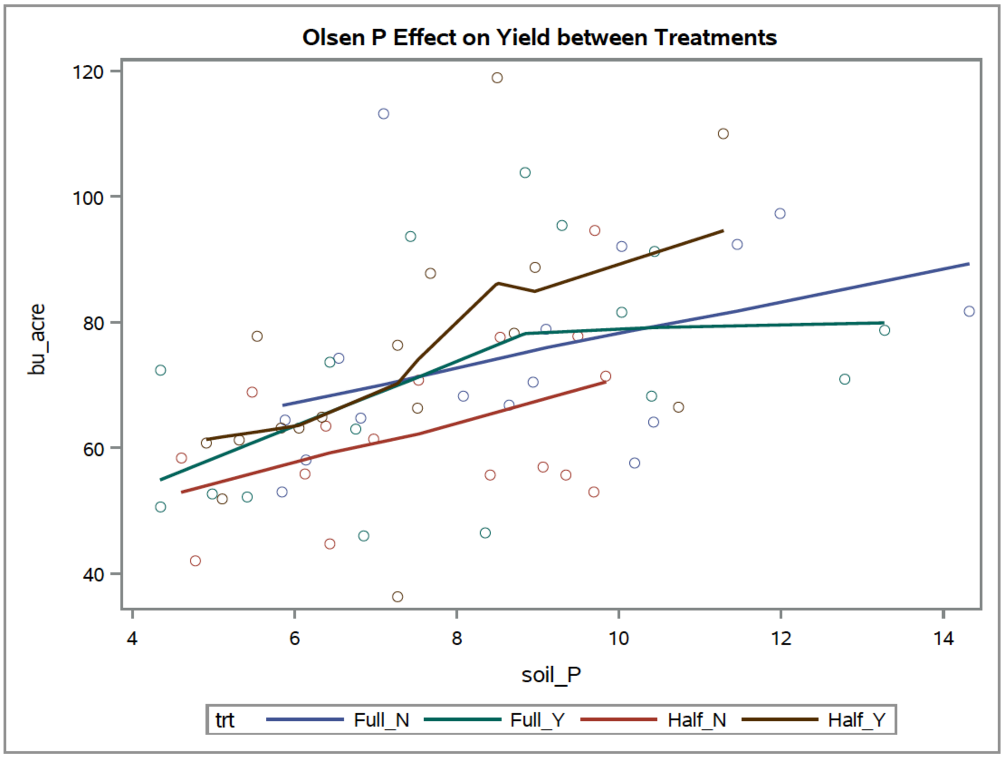


Figure 34. Olsen P effect on yield between fertilizer treatments across Experiment 1. Yield (bu/acre) on the y-axis and Olsen P (ppm; mg/kg) on the x-axis.

Scheffe's Test for soil_P

Note: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	3.984293
Critical Value of F	2.75808
Minimum Significant Difference	2.03

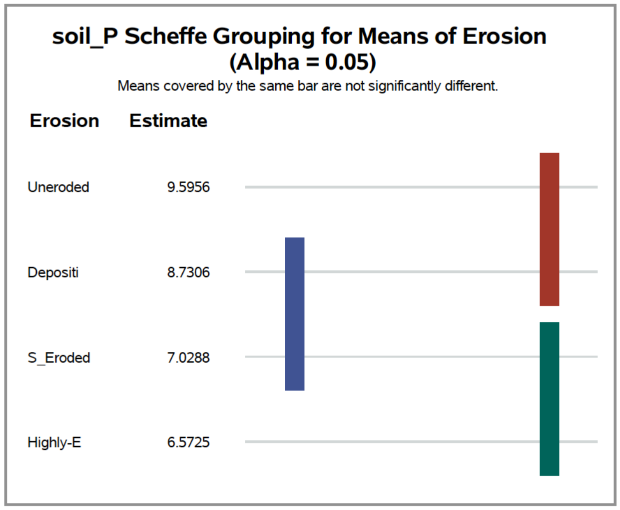


Figure 35. WE_17 Scheffe test of Olsen P for the four erosional severity blocks, with means. ‘Depositi’ = Depositional, ‘S_Eroded’ = Slightly Eroded, and ‘Highly-E’ = Highly Eroded.

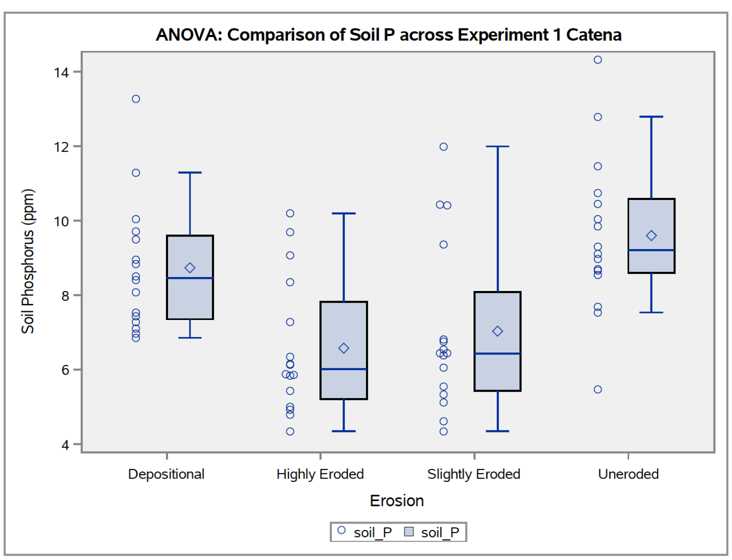


Figure 36. WE_17 box plot comparison of Olsen P with point sample values of four erosional severity blocks.

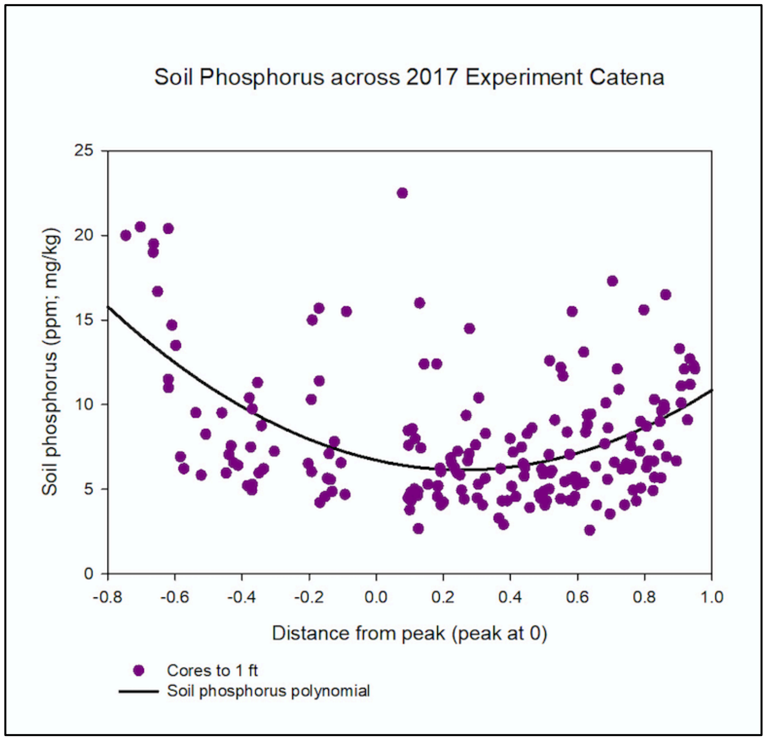


Figure 37. WE_17 Olsen P samples are in purple (1 ft depth) with P values on the y-axis. Points are plotted across the catena with 0.0 on the x-axis signifying the peak of the hill. On the x-axis, negative values are points east of the peak, in the Non-Eroded section, and positive values are points west of the peak, through the Slightly Eroded, Highly Eroded, and Depositional segments. The black line is the polynomial for the 192 soil core samples for P content.

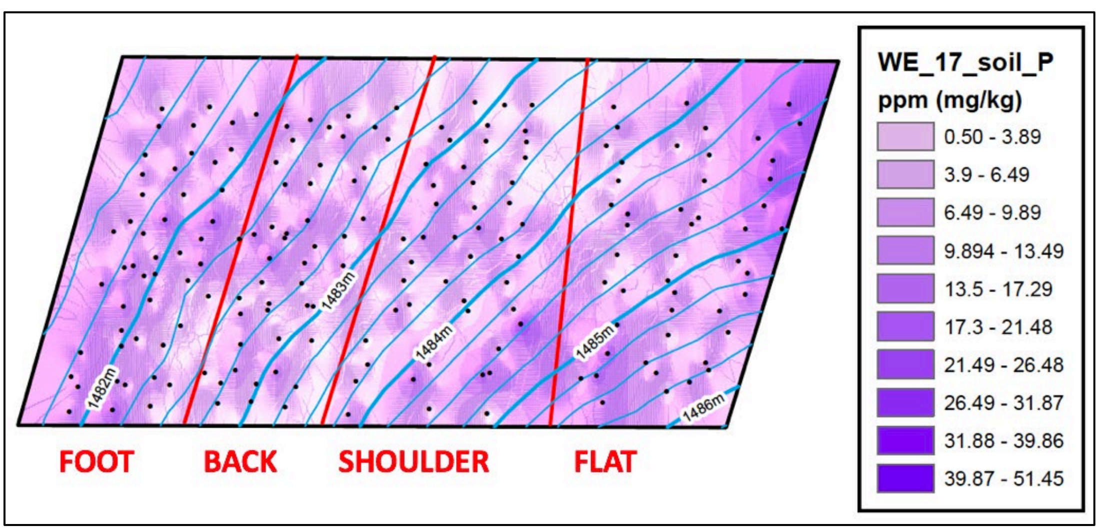


Figure 38. Spatial variation in Olsen P (ppm) across 192 samples of Experiment 1.

Total Soil P (EPA 3050A) and its difference from Olsen P

The high fixation capacity of phosphorus with calcium carbonate explain why plant available P is less than 5% of the phosphorus contained in the soil. Figure 39 shows that unavailable P is even high in the depositional areas of the catena (closer to 1.0) supporting the strong positive correlation between organic matter and unavailable P.

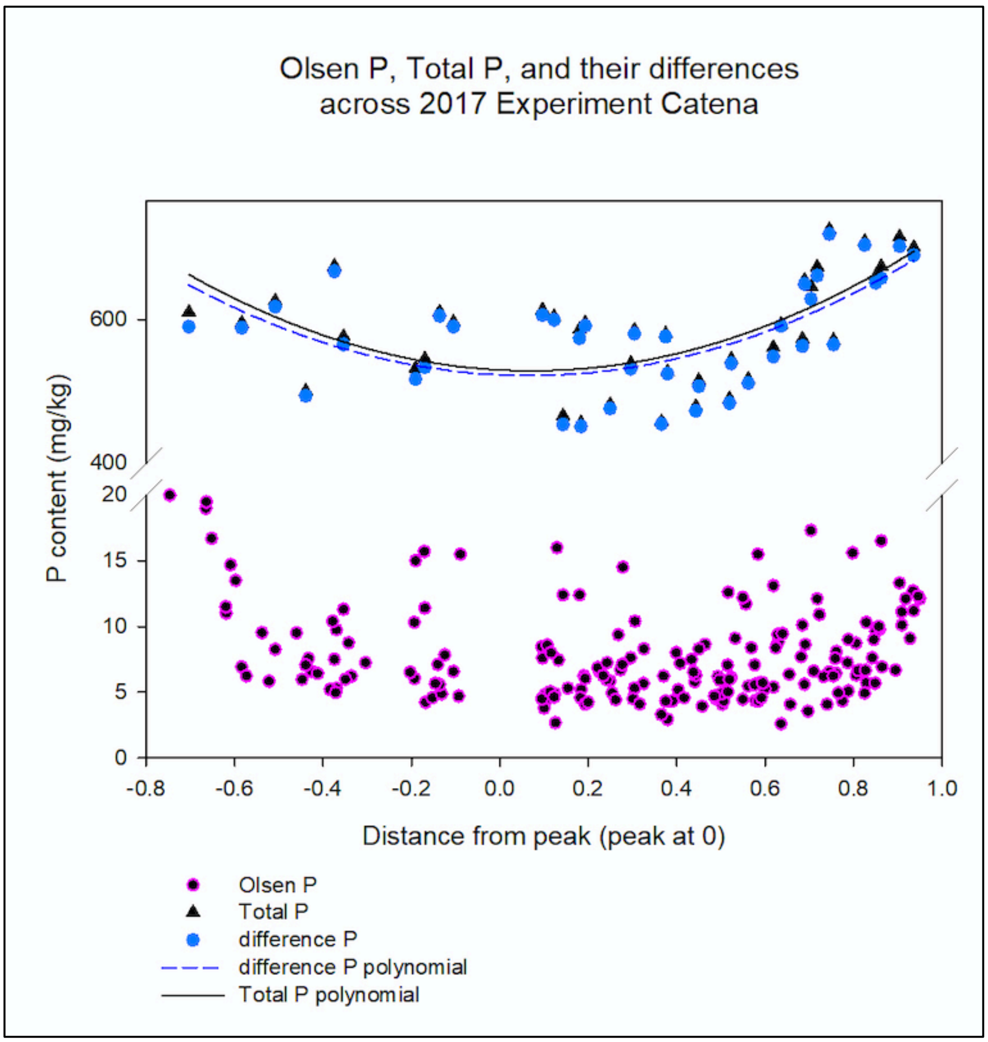


Figure 39. WE_17 Olsen P, Total P, and their difference. Values (mg/kg) are represented across the catena with the peak at point 0.0 and the bottom of the hill slope at point 1.0 of the x-axis. All point samples were taken to 1 ft depth.

Organic Matter and Calcium Carbonate Content

Organic Matter, soil phosphorus, EC, and the OM*$CaCO_3$ mixed effect treatments are all statistically significant with P-Values of 0.001, 0.0236, 0.0003, and 0.0112, respectively. It can be assumed that the level of erosion has a significant because it is dependent on the amounts of Organic Matter, soil phosphorus, and calcium carbonate, which all contribute in its severity, or classification, and thus, effect yield.

To determine how the contributing elements of erosion and morphology of the catena affected yield when crossed with the fertilizer treatments, Organic Matter and $CaCO_3$ results were used to first paint a picture of the catena, showing their relationship to each other and to yield between each block of erosional severity. Figure 40 below shows the $CaCO_3$ content across the catena for Experiment 1. Figure 41 shows the Organic Matter content across the catena. The trend lines from Figures 40 and 41 were combined in Figure 42 which also includes the total yield for each block of erosional severity, regardless of fertilizer treatment. For Figures 40 to 44, $CaCO_3$ and OM values are given as a percent and the peak of the hill in Figure 40 to 42 is point 0.0 of the x-axis. The more negative a value is on the x-axis, the further the sample was taken east of the peak of the experiment. All negative value samples of these Figures were taken east of the peak, which were of the non-eroded block of erosional severity. The more positive a sample is on the x-axis, the further west and down the hill the sample was taken from the peak of the experiment or catena. The value 1.0 on the x-axis is the furthest edge of Experiment 1 from the peak of the catena. Differences in yield are supported by the variations in $CaCO_3$ and OM values across the experiment in Figures 43 and 44. The

difference in organic matter content between the non-eroded and slightly eroded blocks supports the determination of the peak location separating the two blocks in Figure 44.

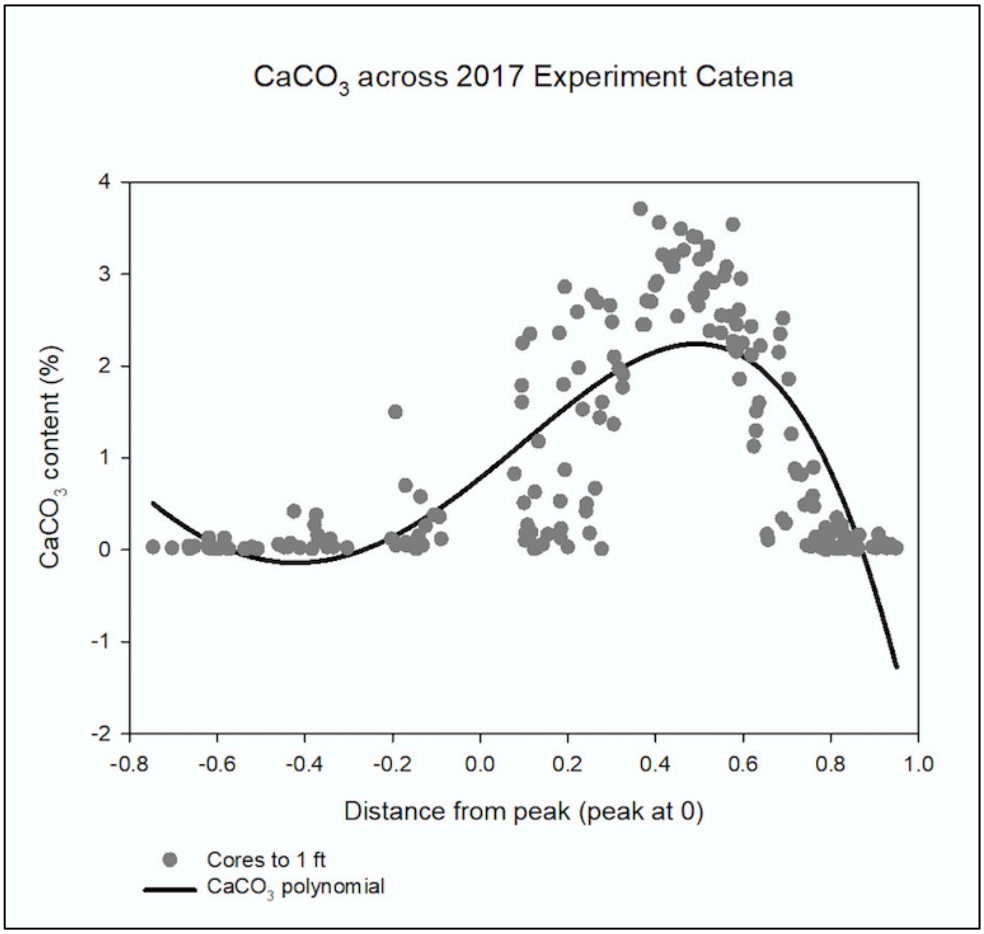


Figure 40. $CaCO_3$ across 2017 experiment catena. Samples are in grey (1 ft depth) with $CaCO_3$ values on the y-axis. Points are plotted across the catena with 0.0 on the x-axis signifying the peak of the hill. On the x-axis, negative values are points east of the peak, in the Non-Eroded section, and positive values are points west of the peak, through the Slightly Eroded, Highly Eroded, and Depositional segments. The black line is the polynomial for the 192 soil core samples for $CaCO_3$ content.

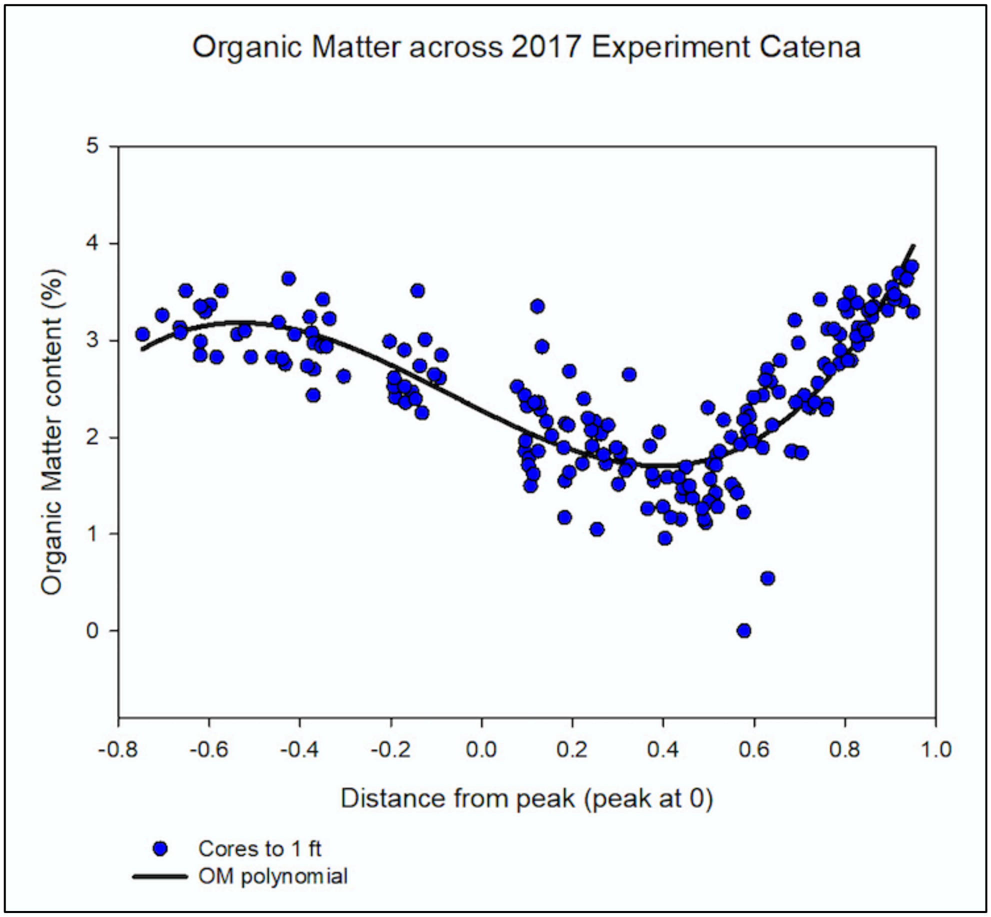


Figure 41. Organic Matter across 2017 experiment catena. Samples are in blue (1 ft depth) with OM values on the y-axis. Points are plotted across the catena with 0.0 on the x-axis signifying the peak of the hill. On the x-axis, negative values are points east of the peak, in the Non-Eroded section, and positive values are points west of the peak, through the Slightly Eroded, Highly Eroded, and Depositional segments. The black line is the polynomial for the 192 soil core samples for OM content. The black line is the polynomial for the 192 soil core samples for OM content.

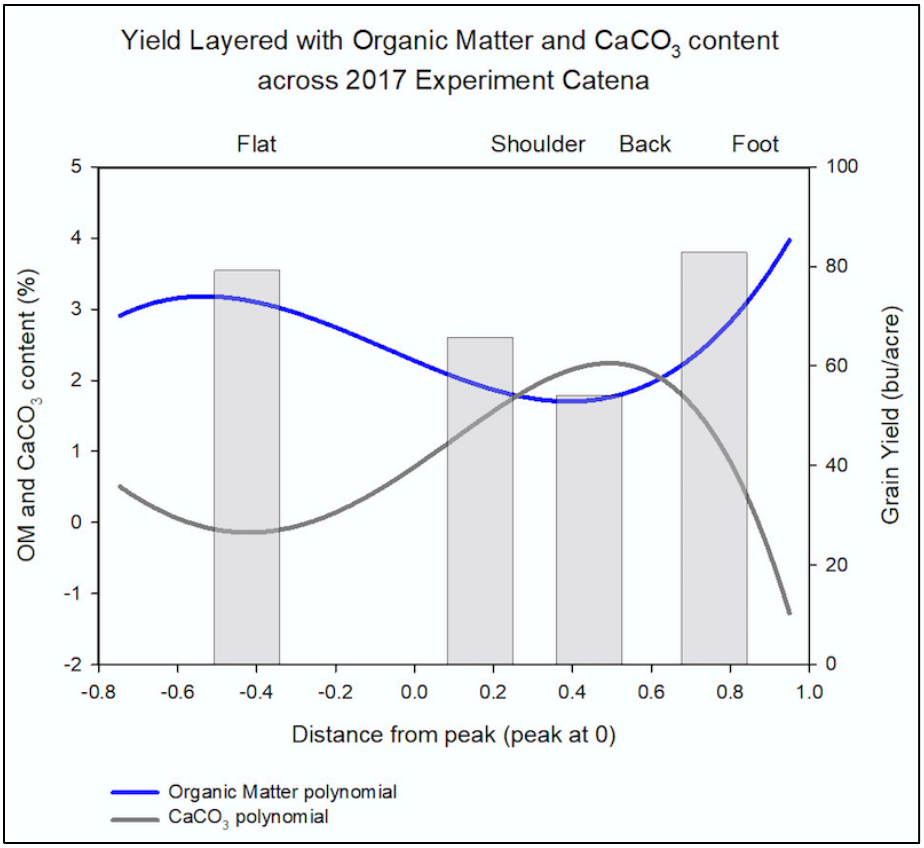


Figure 42. Yield layered with OM and $CaCO_3$ content across 2017 experiment catena. The blue and grey lines represent the polynomials for OM and $CaCO_3$ content across the catena, respectively. Each vertical grey bar represents yield (bu/acre) for each block of erosional severity. Each block yield bar on the x-axis is center to the level of coverage it has on the field.

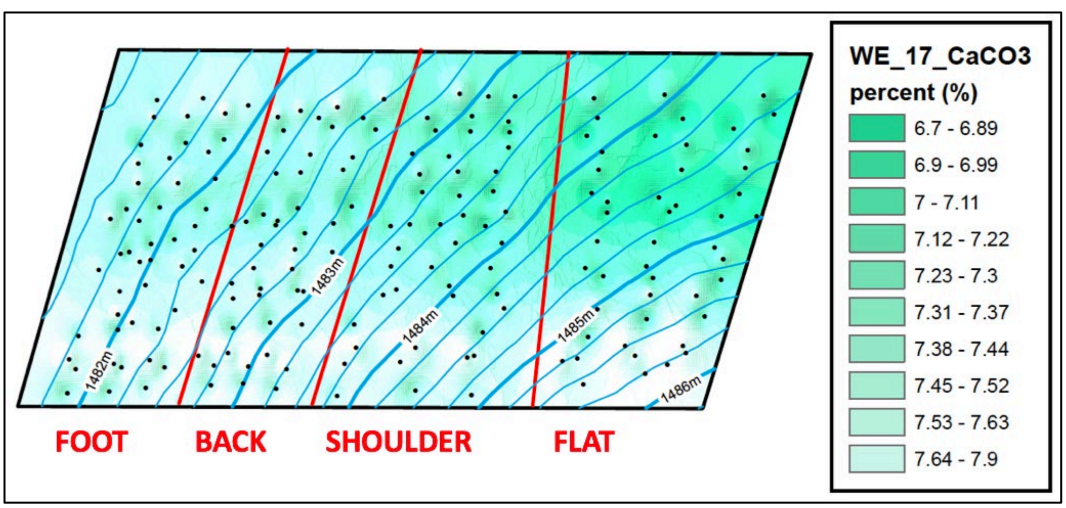


Figure 43. Spatial variation in $CaCO_3$ (%) across 192 samples of Experiment 1.

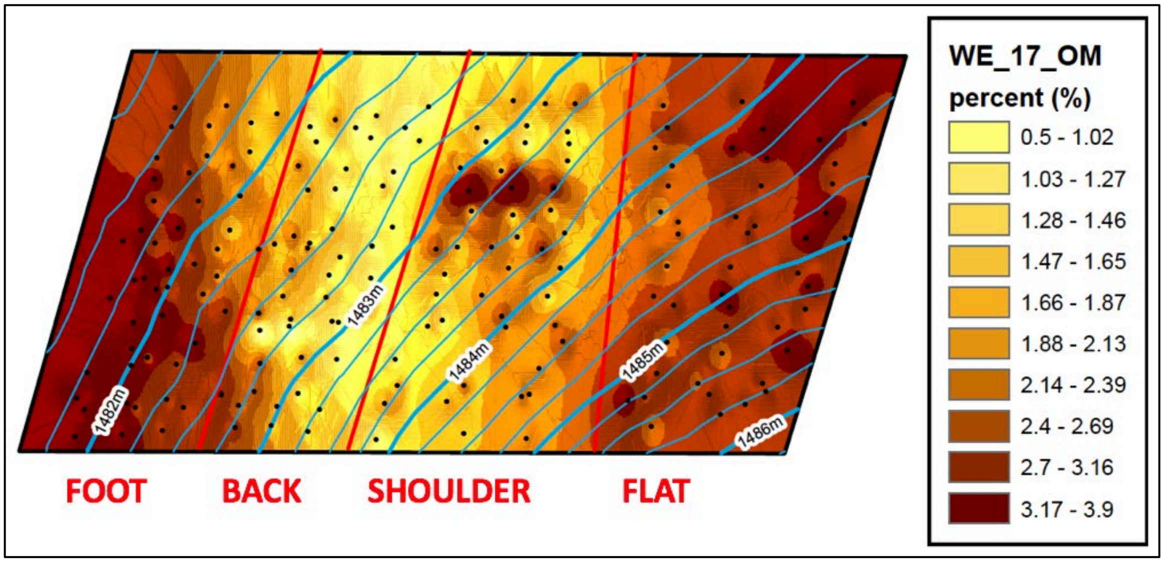


Figure 44. Spatial variation in OM (%) across 192 samples of Experiment 1.

A SAS Correlation procedure for OM and $CaCO_3$ with Olsen P and Unavailable P was performed and results are shown in Figures 45 and 46 below. Figure 45 shows that Organic Matter was positively correlated with Olsen P and Unavailable P with statistical P-values < 0.10, and $CaCO_3$ was negatively correlated with Olsen P and Unavailable P with statistical P-values also < 0.10.

Pearson Correlation Coefficients, N = 40 Prob > |r| under H0: Rho=0		
	Olsen_P	**unav_P**
OM	0.26926 0.0929	0.72308 <.0001
CaCO3	-0.28519 0.0745	-0.43248 0.0053

Figure 45. WE_17 SAS correlations OM and $CaCO_3$ with Olsen P and Unavailable P. The top value is between -1 and 1, and the bottom value is the correlation's P-Value.

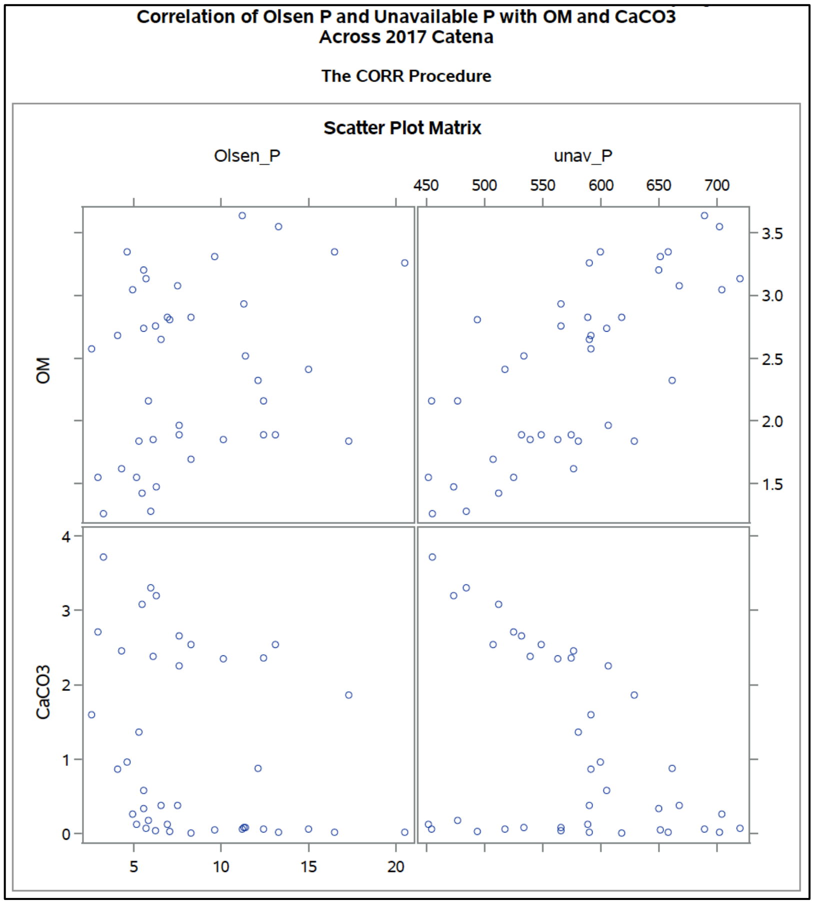


Figure 46. WE_17 Correlation procedure (SAS) for Olsen P and Unavailable P with OM and $CaCO_3$. Phosphorus values are in ppm (mg/kg). OM and $CaCO_3$ values are in percent.

Experiment 2: Band Applied Treatments

Blocked Pedon Descriptions

Figure 47 below represents the profiles of each block of erosional severity for Experiment 2 to a depth of 3 ft. In addition, each horizon color shown was referenced and is accurate to the Munsell Soil Color Book. The depositional block, unfortunately, is not truly an area of deposition. With respect to the other blocks of the experiment, it is the lower, and furthest from the catena peak. The experiment was limited to this are of the site, so to create a true block of deposition would place us in the runoff ditch on the

western half of the Godfrey Farm. Therefore, the “depositional” block resembles a second replication of the highly eroded block, but will be called the “depositional block” as a positional reference.

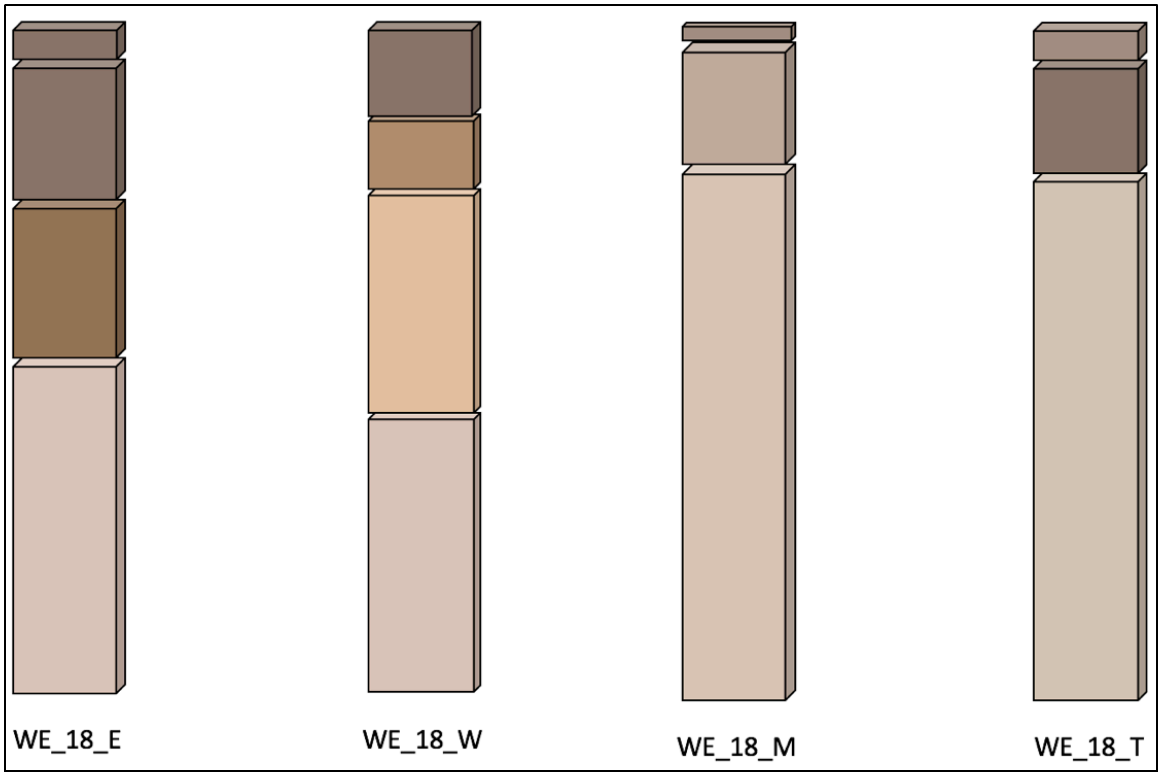


Figure 47. Soil profiles for WE_18 blocks of erosional severity. The following letter for each profile name delineates the block from the experiment: E- East of peak, Flat block; W- West of peak, Slightly eroded block (shoulder slope); M- Mid, Highly eroded block (back slope); and T- Toe, Toe block (toe slope). Each block pedon above represents a profile depth of 3 ft.

Treatment Effects on Yield

Results from the 2018 banded experiment show that there was statistically no significance between the four fertilizer treatments within any block of erosional severity. The Full rate without AVAIL produced the highest yield (114 bu/acre) in the non-eroded

block, and the Full rate with AVAIL produced the highest yield (95.3 bu/acre) in the slightly eroded bock. Correlating box plots of yield (bu/acre) content variation within levels of erosional severity are given in the Appendix (Figures 103 to 106). Comparative bar graphs of each associated block is given in Figures 49 to 52.

Like experiment 1, total yield for each fertilizer treatment in Figure 48 is given as an average of the treatment yields across the four blocks of erosional severity. The Full rate without AVAIL produced the highest yield (82.1 bu/acre) as well as the highest profit ($217.80) (Table 4). While the Half rate without AVAIL produced 3.5 bu/acre less than the full rate, it only yielded $1.73 less/acre in profit (Table 4).

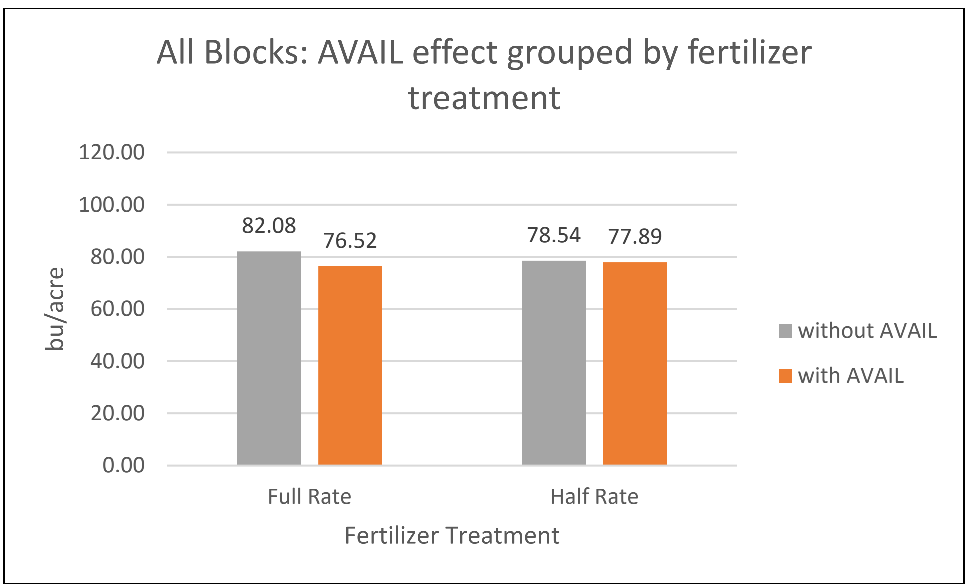


Figure 48. WE_18 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment across all levels of erosional severity.

Of the non-eroded block in Figure 49, the Full rate without AVAIL produced the highest yield (114 bu/acre) along with the highest profit of $359.33/acre. In the slightly eroded block (Figure 50), the Full rate with AVAIL produced the greatest yield of 95.25

bu/acre with the highest profit of $271.21/acre. In the highly eroded block (Figure 51), the Half rate with AVAIL produced the greatest yield and profit of 67.2 bu/acre and $163.49/acre, respectively. Because the Depositional block resembled the highly eroded block in many soil properties (OM, $CaCO_3$, and Olsen P content), it showed similar results to the highly eroded block across the four treatments. In the depositional block (Figure 52), the Half rate with AVAIL had the greatest yield (65 bu/acre) and profit ($153.46/acre).

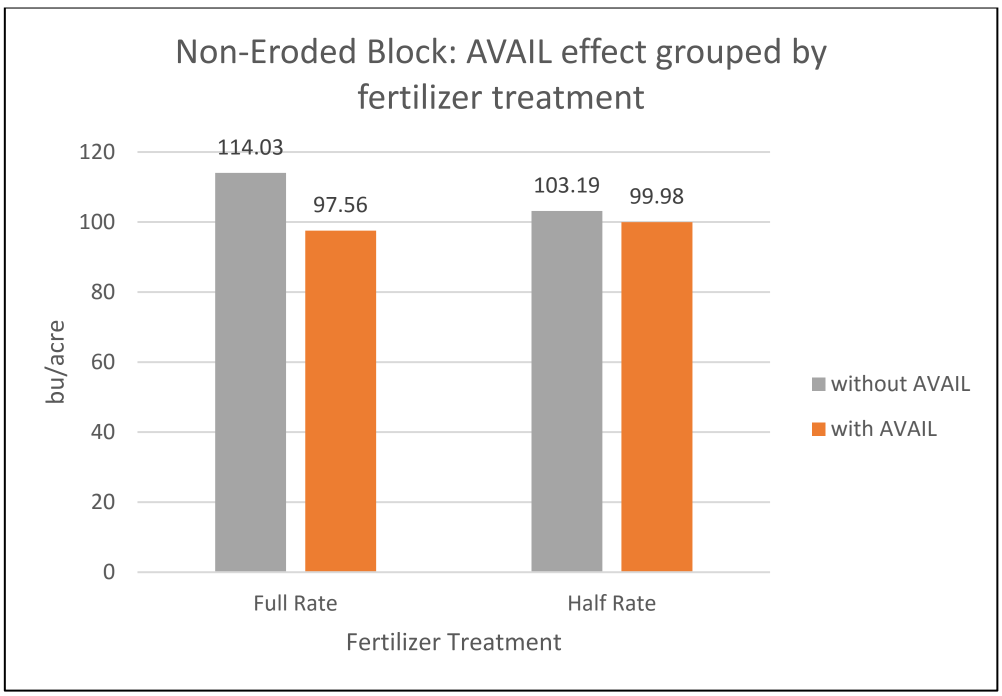


Figure 49. WE_18 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment for the Non-Eroded block. Mean $CaCO_3$ and OM contents are 0.26% and 2.48%, respectively.

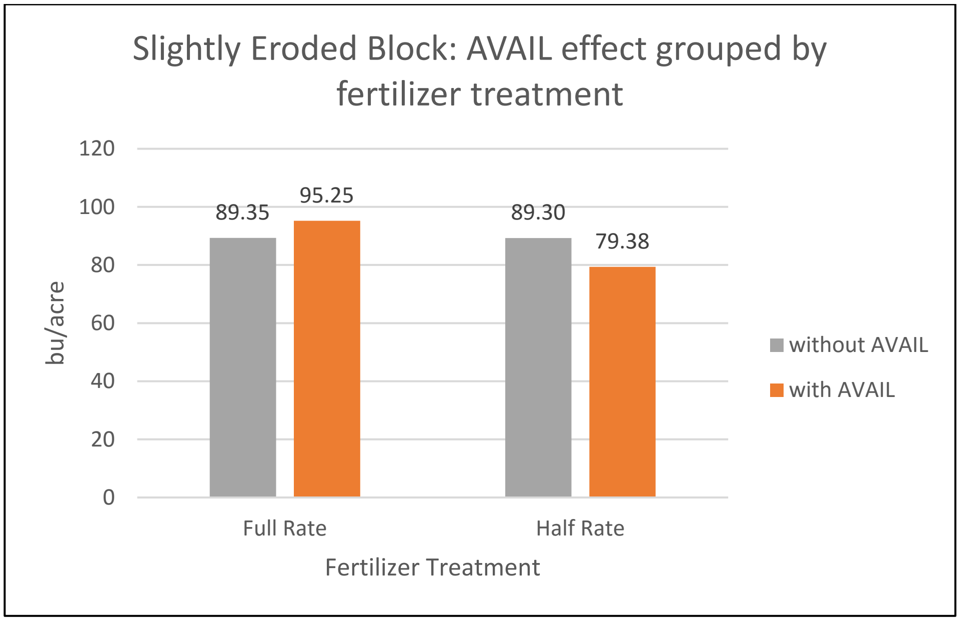


Figure 50. WE_18 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment for the Slightly Eroded block. Mean $CaCO_3$ and OM contents are 0.16% and 1.79%, respectively.

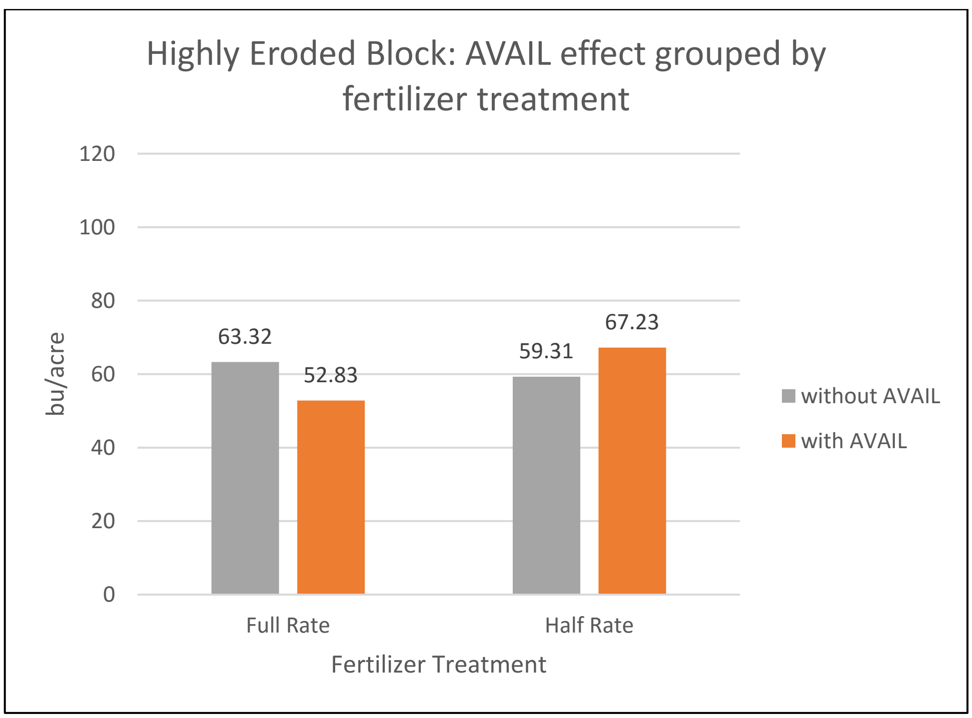


Figure 51. WE_18 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment for the Highly Eroded block. Mean $CaCO_3$ and OM contents are 2.75% and 1.02%, respectively.

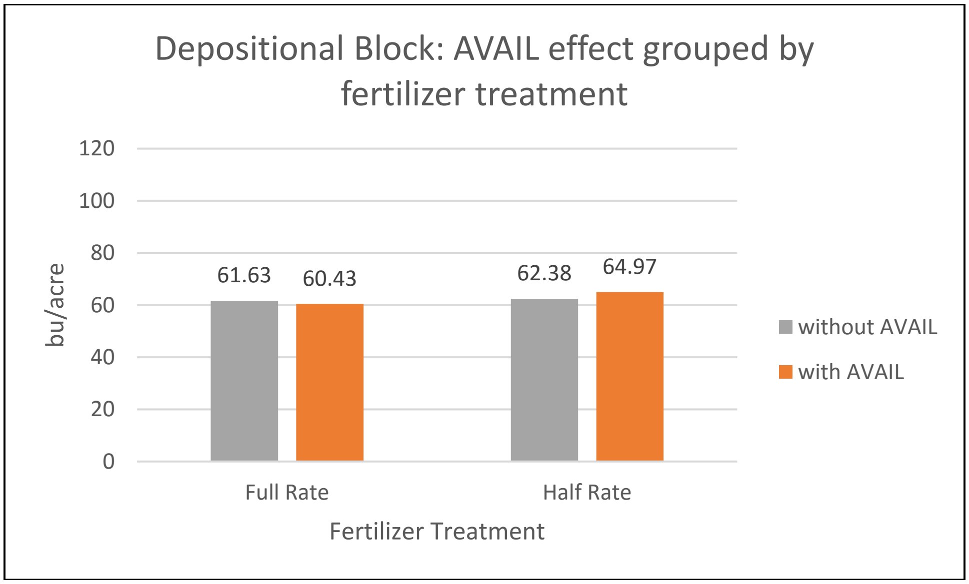


Figure 52. WE_18 yield (bu/acre) effect due to AVAIL® grouped by fertilizer treatment for the Depositional block. Mean $CaCO_3$ and OM contents are 3.17% and 0.62%, respectively.

As in experiment 1, we used the same costs and returns template created by USU Extension for dryland winter wheat (Holmgren and Pace, 2016). We were able to produce estimates of profit for each fertilizer treatment across the entire experiment and is presented in Table 4. The Full rate without AVAIL produced the greatest yield (82.1 bu/acre) by 3.5 bu/acre. It also returned with the greatest profit of $217.80/acre. The Half rate with AVAIL treatment produced nearly the same in profit at $216.07/acre, a difference of just $1.73/acre.

Table 4. Wheat Experiment 2018 (banded fertilizer) cost analysis. Yield values in bu/acre for each treatment are mean values across the four block of erosional severity. "Other costs/acre" include operating costs outlined in USU Extension's Costs and Returns template. Protein content is defaulted to 12% (no monetary benefit or deduction).

Treatment	bu/acre	Revenue at $4.83/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Total Profit $/acre
Full rate without AVAIL	82.08	$ 396.46	$ (28.18)	$ (150.49)	$ (178.67)	$ 217.80
1/2 rate without AVAIL	78.54	$ 379.37	$ (14.21)	$ (149.09)	$ (163.30)	$ 216.07
Full rate with AVAIL	76.52	$ 369.57	$ (33.06)	$ (148.28)	$ (181.34)	$ 188.23
1/2 rate with AVAIL	77.89	$ 376.22	$ (16.68)	$ (148.83)	$ (165.51)	$ 210.71

The same costs and returns template was applied to each level (block) of erosional severity in Table 6 of the Appendices (pp 83) also seen in Tables 5. Each block includes the average amount of calcium carbonate and Organic Matter. In the non-eroded block (OM= 2.48%, $CaCO_3$= 0.26%), the Full rate without AVAIL returned with the greatest yield and profit ($359.33/acre). In the slightly eroded block (OM= 1.79%, $CaCO_3$= 0.16%), the Full rate with AVAIL returned with the greatest yield and profit ($271.21). In the highly eroded block (OM= 1.02%, $CaCO_3$= 2.75%), the half rate with AVAIL produced the greatest yield and profit ($163.49/acre). The depositional block (OM= 0.62, $CaCO_3$= 3.17), the Half rate with AVAIL again produced the greatest yield and profit ($153.46).

Plant Measurement Correlations

A Correlation procedure was done in SAS between the different plant measurements made in Experiment 2 in order to see how much one plant measurement was associated with another. Correlations of plant measurements broken up by blocks of erosional severity or treatments was unnecessary, and finding correlations across the entire experiment provided a larger sample size (N=48). Figures 53 and 54 demonstrate the correlations below.

- Plant Height = plant_ht
- Stem Count (plant density) = Stem_Cnt
- Total Plant Weight (total biomass) = Total_PW
- protein content = protein
- Plant Phosphorus content = plant_P

All plant measurements made, with the exception of protein content (%), are highly and positively correlated with each other. All positively correlated plant measurements have P-values < .0001.

Pearson Correlation Coefficients, N = 48 Prob > |r| under H0: Rho=0					
	plant_ht	Stem_Cnt	Total_PW	protein	plant_P
plant_ht	1.00000	0.66734 <.0001	0.72923 <.0001	-0.03127 0.8329	0.30969 0.0322
Stem_Cnt	0.66734 <.0001	1.00000	0.93107 <.0001	0.17021 0.2474	0.59446 <.0001
Total_PW	0.72923 <.0001	0.93107 <.0001	1.00000	0.18958 0.1968	0.61940 <.0001
protein	-0.03127 0.8329	0.17021 0.2474	0.18958 0.1968	1.00000	0.09860 0.5049
plant_P	0.30969 0.0322	0.59446 <.0001	0.61940 <.0001	0.09860 0.5049	1.00000

Figure 53. WE_18 plant measurement Pearson correlations. Within each box, the top value is the correlation number (a) between the plant measurements in the top row and left column, where $-1 \leq a \geq 1$. The bottom value is its P-value.

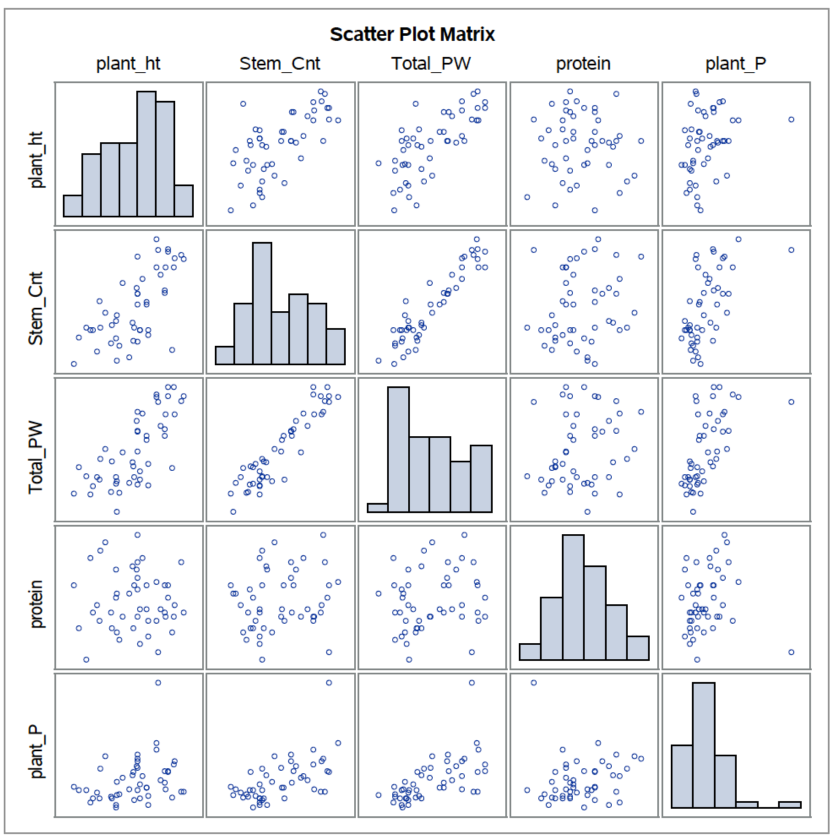


Figure 54. WE_18 plant measurement scatter plot correlations. A scatter plot matrix displaying correlations between different plant measurements shown in the top row and left column.

Plant Height at Harvest

Plant height across all blocks of erosional severity showed no significance between fertilizer treatments. P-Values were 0.3, 0.55, 0.14, and 0.51 for the non-eroded, slightly eroded, highly eroded, and depositional blocks, respectively. The half fertilizer rate did have the greatest plant height across all blocks. Correlating box plots of plant height (cm) variation within levels of erosional severity are shown in Figures 107 to 110 of the Appendix.

Total Biomass Dry Weight

Total plant biomass across all blocks of erosional severity showed no significance between fertilizer treatments. P-Values were 0.52, 0.68, 0.34, and 0.38 for the non-eroded, slightly eroded, highly eroded, and depositional blocks, respectively. Correlating box plots of total biomass dry weight variation within levels of erosional severity are shown in Figures 111 to 114 of the Appendix.

Plant Density

Plant density (stem count) across all blocks of erosional severity showed no significance between fertilizer treatments. P-Values were 0.41, 0.27, 0.48, and 0.14 for the non-eroded, slightly eroded, highly eroded, and depositional blocks, respectively. Correlating box plots of plant density variation within levels of erosional severity are shown in Figures 115 to 118 of the Appendix.

Grain Protein Content

Grain protein content (%) across all blocks of erosional severity showed no significance between fertilizer treatments. P-Values were 0.95, 0.27, 0.51, and 0.49 for the non-eroded, slightly eroded, highly eroded, and depositional blocks, respectively.

Correlating box plots of grain protein content variation within levels of erosional severity are shown in Figures 119 to 122 of the Appendix.

Plant Phosphorus Content

Plant phosphorus content (ppm) across all blocks of erosional severity showed no significance between fertilizer treatments. P-Values were 0.2, 0.48, 0.9, and 0.71 for the non-eroded, slightly eroded, highly eroded, and depositional blocks, respectively. Correlating box plots of plant P content (ppm) variation within levels of erosional severity are shown in Figures 123 to 126 of the Appendix.

Soil Characteristics and Effects on Yield

Results from the Type III Tests of Fixed Effects on yield produced from the SAS Proc GLIMMIX procedure is shown below in Figure 55. MAP rate had no effect on yield, whereas AVAIL was statistically significant. Electrical conductivity and pH were statistically significant, with OM, $CaCO_3$, and the mixed effect OM*$CaCO_3$ were extremely statistically significant with P-Values <0.0001. Unlike the first experiment, Olsen P was not statistically significant with yield for the banded treatments.

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
MAP_rate	1	30.14	1.58	0.2191
AVAIL	1	30.47	3.45	0.0728
EC	1	34.79	4.38	0.0437
pH	1	33.28	10.75	0.0024
OM	1	28.06	47.26	<.0001
CaCO3	1	34.57	20.47	<.0001
OM*CaCO3	1	37.53	48.90	<.0001
Olsen_P	1	35.55	1.27	0.2670

Figure 55. Type III Tests of Fixed Effects on Yield for Experiment 2.

Soil Characteristics and Effects on Profit

Results from the Type III Tests of Fixed Effects on profit produced from the SAS Proc GLIMMIX procedure is shown below in Figure 56. MAP rate had no effect on profit, whereas AVAIL was more statistically significant with profit than with yield. EC, pH, Olsen P and the mixed effect OM*$CaCO_3$ have nearly identical P-Values between profit and yield.

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
MAP_rate	1	30.13	0.14	0.7067
AVAIL	1	30.46	5.08	0.0316
EC	1	34.79	4.21	0.0478
pH	1	33.28	10.89	0.0023
OM	1	28.04	46.97	<.0001
CaCO3	1	34.55	20.35	<.0001
OM*CaCO3	1	37.52	49.03	<.0001
Olsen_P	1	35.55	1.27	0.2664

Figure 56. Type III Tests of Fixed Effects on Profit for Experiment 2.

Saturated Paste pH

Soil pH was not significantly correlated between the non-eroded and highly eroded blocks, as seen in Figure 57 with the proc ANOVA Scheffe test of pH with a P-Value of 0.0002. The lack of variability in soil pH across experiment 2 can be seen in Figure 60. Shown in Figure 58 and 59, the pH was between 7.0 and 7.2, which is ideal

for maximum soil phosphorus availability for plants. This brings more certainty to the effect of other soil parameters on yield for this experiment.

Scheffe's Test for pH

Note: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	44
Error Mean Square	0.001951
Critical Value of F	2.81647
Minimum Significant Difference	0.0524

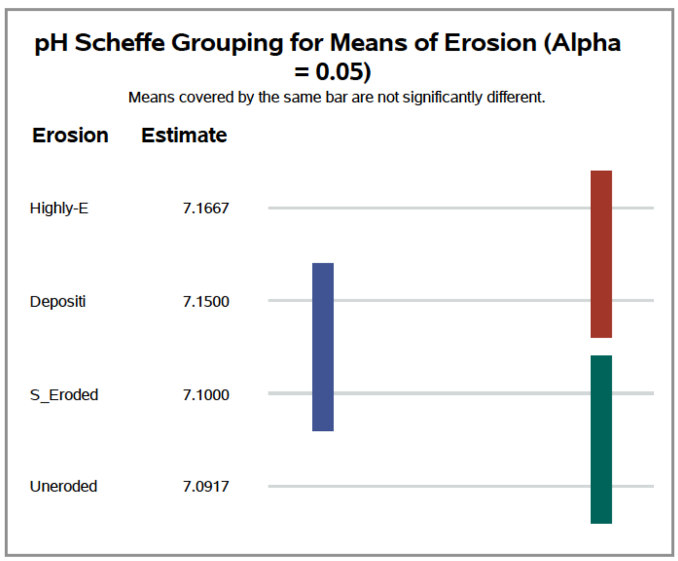


Figure 57. WE_18 Scheffe test of pH for the four erosional severity blocks, with means.

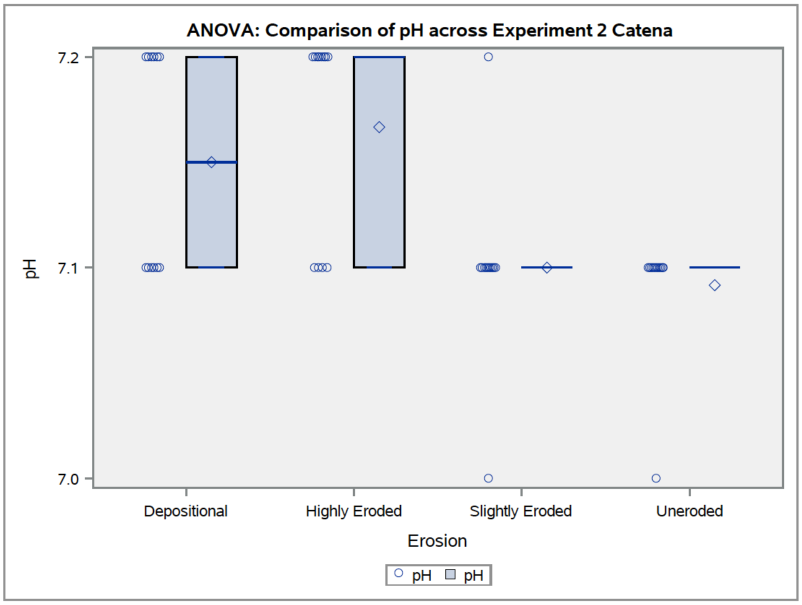


Figure 58. WE_18 box plot comparison of pH with point sample values of four erosional severity blocks.

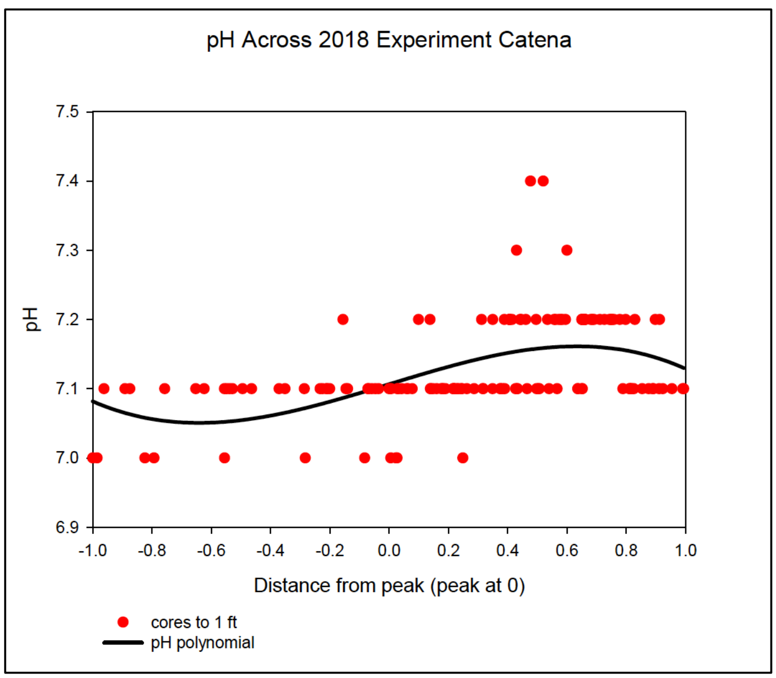


Figure 59. WE_18 pH samples are in red (1ft depth) with pH values on the y-axis. Points are plotted across the catena with 0.0 on the x-axis signifying the peak of the hill. On the x-axis, negative values are points east of the peak, in the Non-Eroded section, and positive values are points west of the peak, through the Slightly Eroded, Highly Eroded, and Depositional segments. The black line is the polynomial for the 144 soil core samples for pH content.

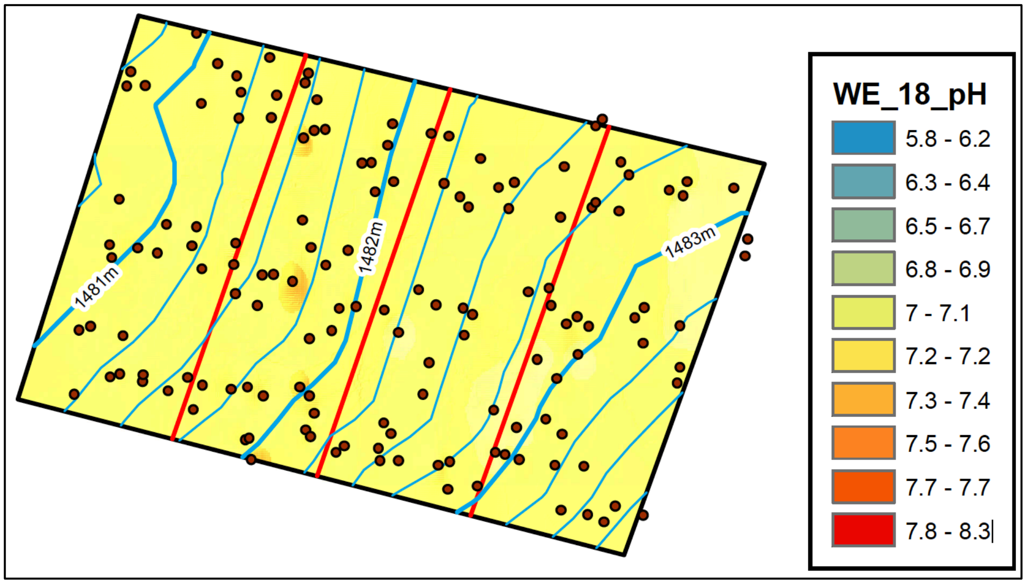


Figure 60. Spatial variation of pH across 144 samples in Experiment 2.

Saturated Paste Extractable Salinity

Electrical Conductivity (EC), like experiment 1, had a statistically significant effect on yield with a P-Value of 0.0437. The low presence of salts did not present a damaging effect on yield, but a beneficial one. Like pH, EC was relatively constant across the entire field of experiment 2 (Figures 62 and 63). Figure 61 shows that although EC varied little across the experiment 2, there was statistical significance between the non-eroded block and the slightly eroded and highly eroded blocks.

Scheffe's Test for EC

Note: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	44
Error Mean Square	0.004138
Critical Value of F	2.81647
Minimum Significant Difference	0.0763

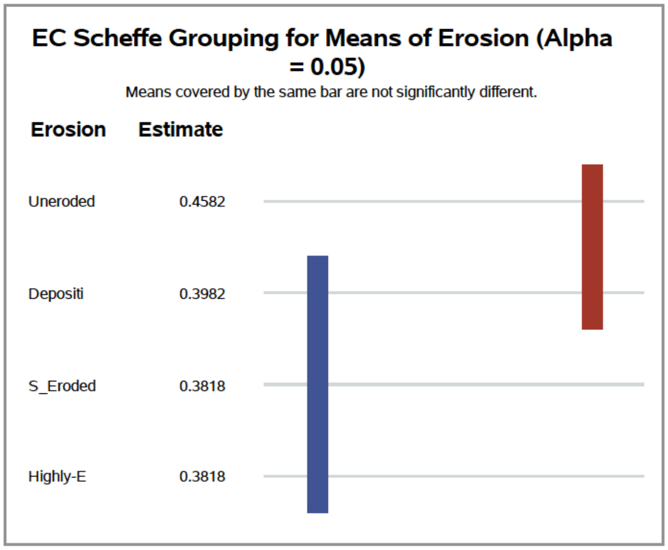


Figure 61. Scheffe test of pH for the four erosional severity blocks, with means.

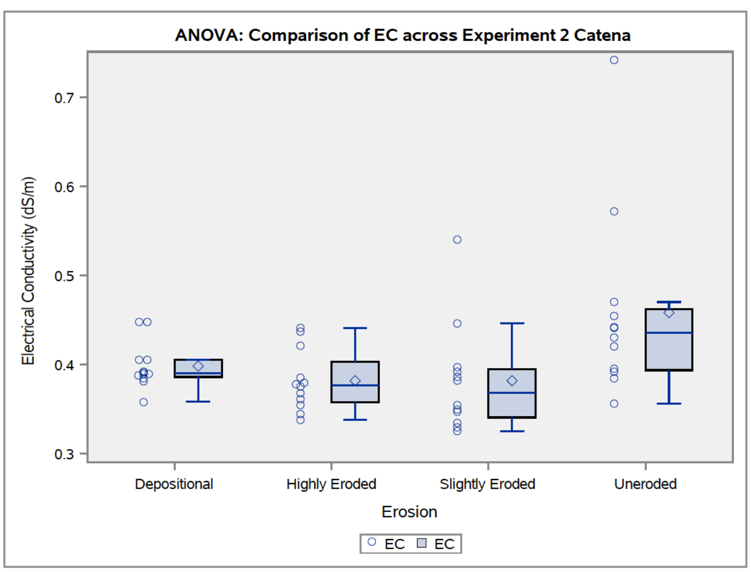


Figure 62. Box plot comparison of EC with point sample values of four erosional severity blocks.

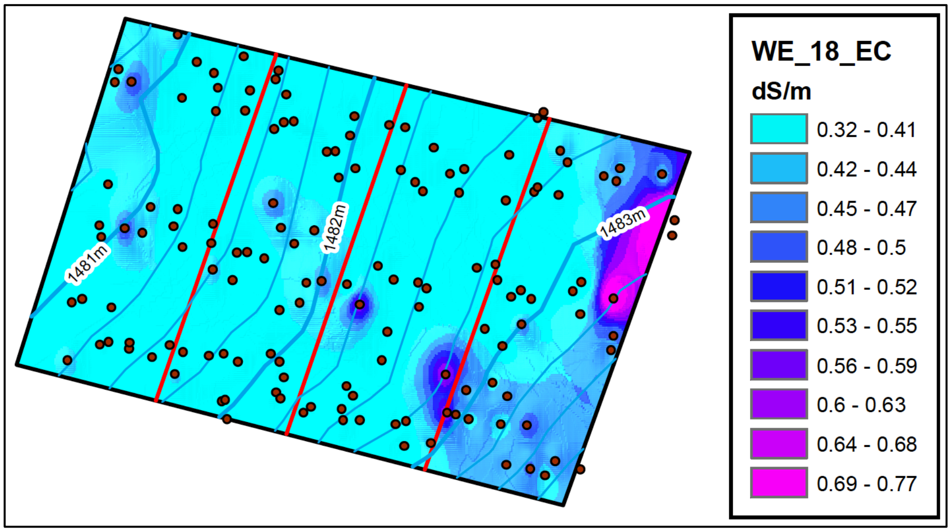


Figure 63. Spatial variation of EC (dS/m) across 144 samples in Experiment 2.

Extractable Soil Phosphorus (Olsen P)

Unlike plant available soil P from the broadcast applied experiment, the two treatments of experiment 2 which did not contain AVAIL displayed a negative correlation with yield and Olsen P increased (Figure 64). There was also a statistically significant difference between the highly eroded block and the non-eroded block from the SAS Sheffe Test of Olsen P (Figures 65 and 66). Figure 67 represents Olsen P across the catena of Experiment 2 as well as the points which seem linear relative to Total P in Figure 69. The polynomial line of Figure 67 shows that like experiment 1, Olsen P is higher at the non-eroded segment of the experiment and decreases into areas of high erosion. Because the “depositional” block of this experiment is more similar to an area of high erosion, we don’t see a sharp increase in Olsen P in this area, as in experiment 1. There are some points of increased Olsen P in the depositional block based on the box plot of Figure 66, and that can be seen as well in Figure 68. Like experiment 1, there are

varying amounts of Olsen P in the non-eroded and depositional blocks, but there is little variation in Olsen P at the back slope where most P values are quite low.

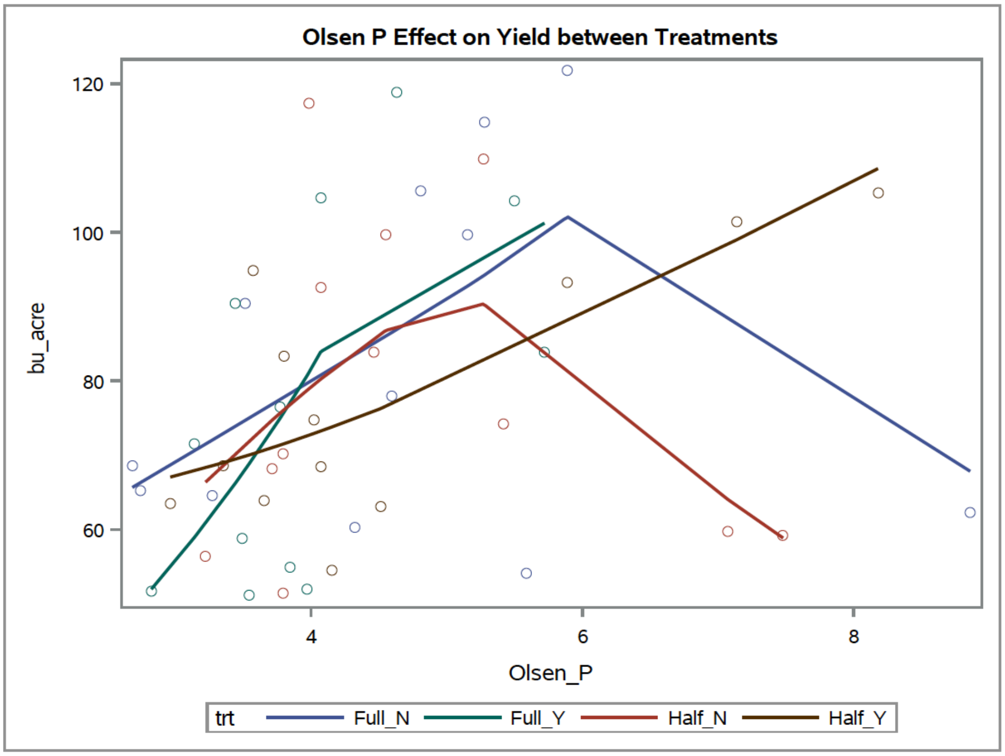


Figure 64. Olsen P effect on yield between fertilizer treatments across Experiment 2.

Scheffe's Test for Olsen_P

Note: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	44
Error Mean Square	1.639936
Critical Value of F	2.81647
Minimum Significant Difference	1.5197

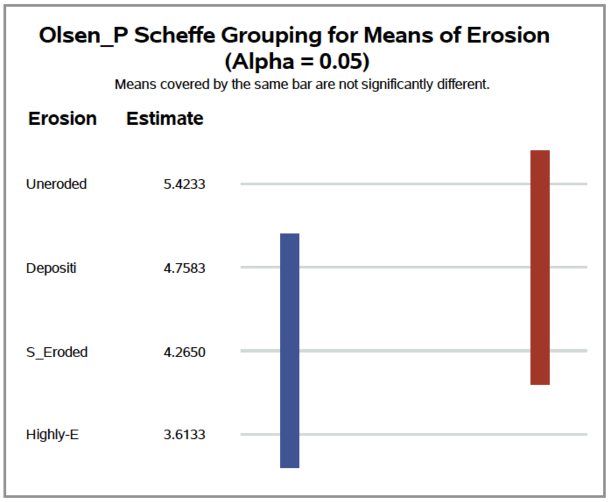


Figure 65. WE_18 Scheffe test of Olsen P for the four erosional severity blocks, with means.

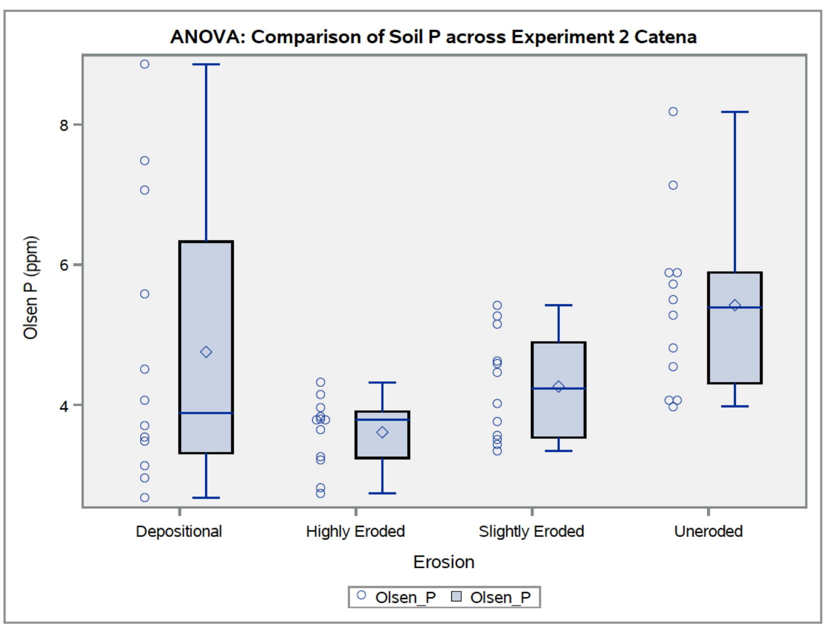


Figure 66. WE_18 box plot comparison of Olsen P with point sample values of four erosional severity blocks.

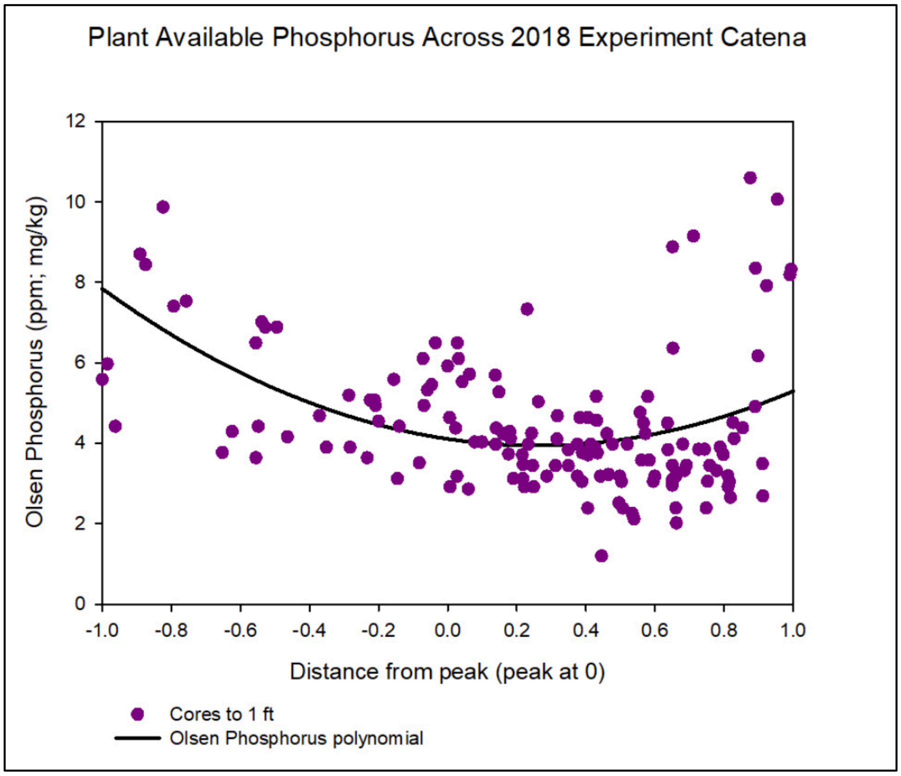


Figure 67. WE_18 Olsen P samples are in purple (1 ft depth) with P values on the y-axis. Points are plotted across the catena with 0.0 on the x-axis signifying the peak of the hill. On the x-axis, negative values are points east of the peak, in the Non-Eroded section, and positive values are points west of the peak, through the Slightly Eroded, Highly Eroded, and Depositional segments. The black line is the polynomial for the 144 soil core samples for P content.

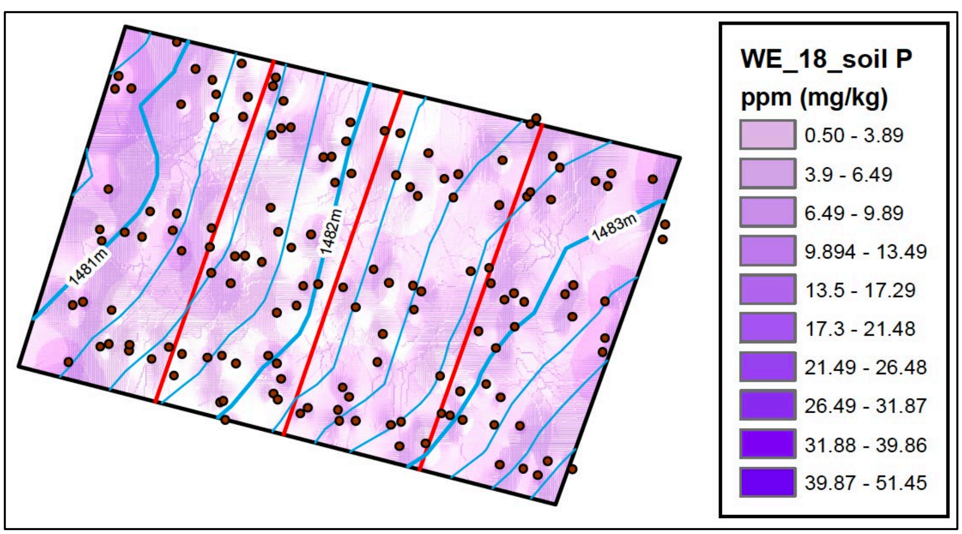


Figure 68. Spatial variation of Olsen P (ppm) across 144 samples in Experiment 2.

Total Soil P (EPA 3050A) and its difference from Olsen P

Like Experiment 1, unavailable P makes up a large percentage of the total p present in the soil of Experiment 2. This supports the high fixation capacity of phosphorus with calcium carbonate. Figure 69 shows that unavailable P is high in the depositional areas of the catena (closer to 1.0) supporting the strong positive correlation between organic matter and unavailable P.

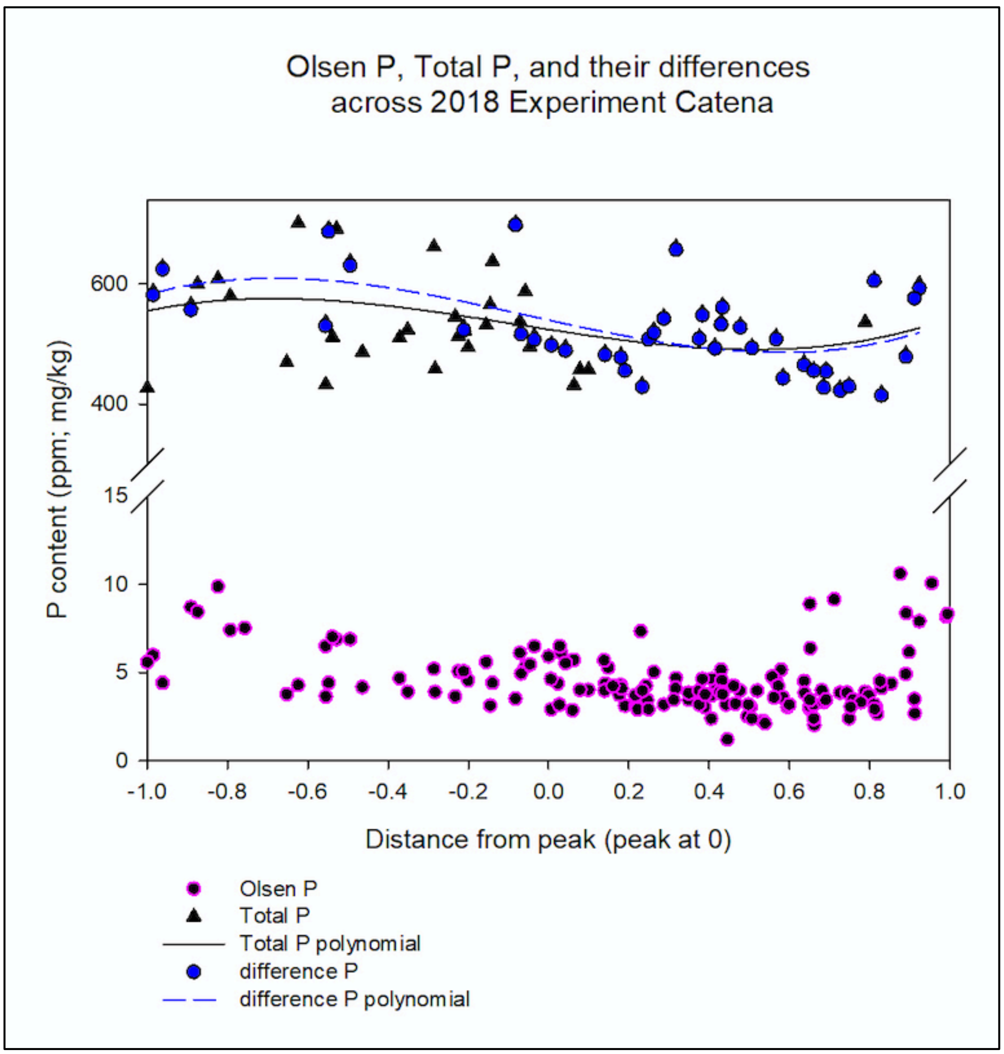


Figure 69. WE_18 Olsen P, Total P, and their difference. Values (mg/kg) are represented across the catena with the peak at point 0.0 and the bottom of the hill slope at point 1.0 of the x-axis. All point samples were taken to 1 ft depth.

Organic Matter and Calcium Carbonate Content

Like Experiment 1, soil samples were measured for $CaCO_3$ and Organic Matter. Here, 144 soil samples were taken (3 per treatment replication) and their distances were measure from the peak of the catena. Values east of the peak (non-eroded block) were given negative values to distinguish them from the slope effect of the catena (Figures 70 and 71). As the catena begins to steepen into the back slope, calcium carbonate content increases while organic matter decreases. Values remain high for calcium carbonate and low for organic matter due to the fact that the depositional block more resembles the back slope. Figure 72 layers the $CaCO_3$ and OM polynomials with grain yield (bu/acre) shown as a bar graph. The spatial variations in $CaCO_3$ and OM are evident in Figures 73 and 74. Organic Matter differences between the non-eroded and slightly eroded blocks support the subjective determination of the peak.

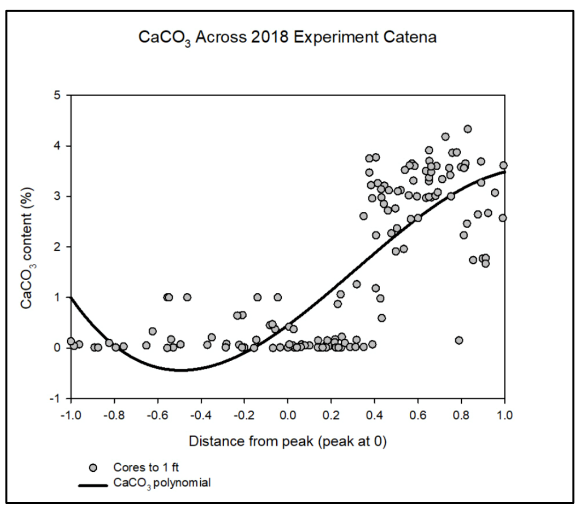


Figure 70. $CaCO_3$ across 2018 experiment catena. Samples are in grey (1 ft depth) with $CaCO_3$ values on the y-axis. Points are plotted across the catena with 0.0 on the x-axis signifying the peak of the hill. On the x-axis, negative values are points east of the peak, in the Non-Eroded section, and positive values are points west of the peak, through the Slightly Eroded, Highly Eroded, and Depositional segments. The black line is the polynomial for the 144 soil core samples for $CaCO_3$ content.

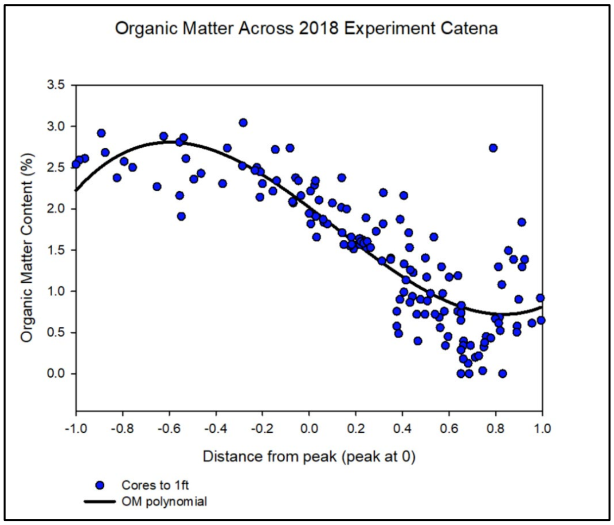


Figure 71. Organic Matter across 2018 experiment catena. Samples are in blue (1 ft depth) with OM values on the y-axis. Points are plotted across the catena with 0.0 on the x-axis signifying the peak of the hill. On the x-axis, negative values are points east of the peak, in the Non-Eroded section, and positive values are points west of the peak, through the Slightly Eroded, Highly Eroded, and Depositional segments. The black line is the polynomial for the 192 soil core samples for OM content. The black line is the polynomial for the 192 soil core samples for OM content.

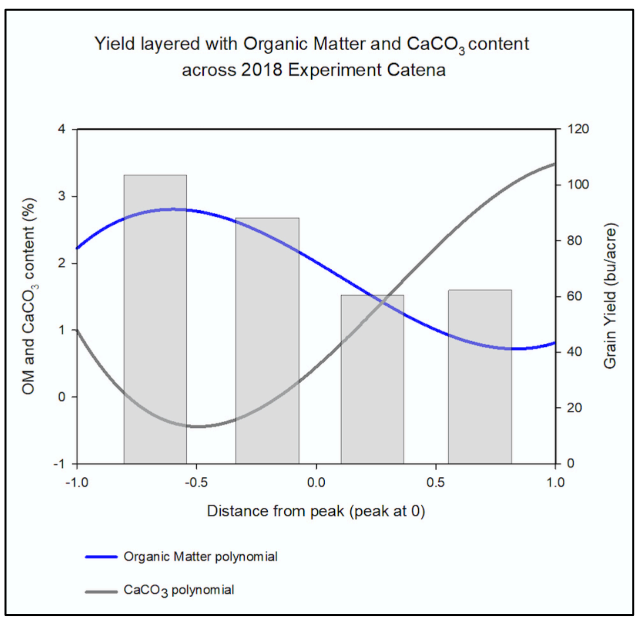


Figure 72. Yield layered with OM and $CaCO_3$ content across 2018 experiment catena. The blue and grey lines represent the polynomials for OM and $CaCO_3$ content across the catena, respectively. Each vertical grey bar represents yield (bu/acre) for each block of erosional severity. From left to right, they are the Flat, Shoulder, Back, and Foot slopes. Each block yield bar on the x-axis is center to the level of coverage it has on the field.

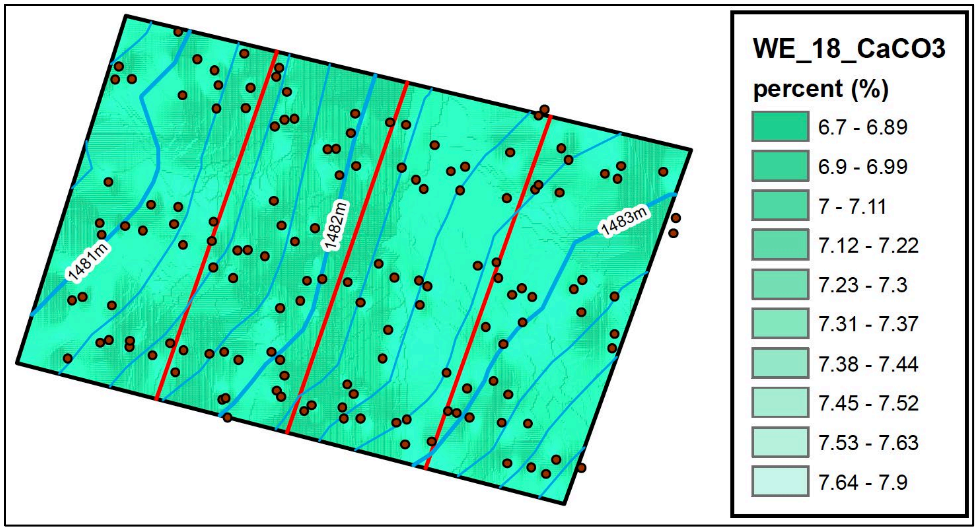


Figure 73. Spatial variation of $CaCO_3$ (%) across 144 samples in Experiment 2.

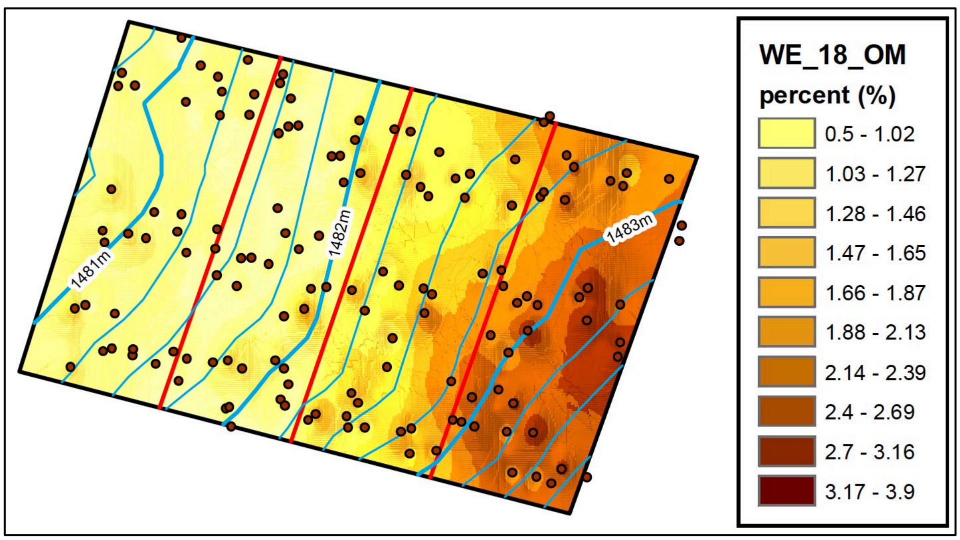


Figure 74. Spatial variation of OM (%) across 144 samples in Experiment 2.

The following Proc CORR results (SAS) support results from Experiment 2 (Figures 75 and 76). P-Values for all relationships between OM, $CaCO_3$, and Olsen P, and unavailable P are statistically significant (≤0.0388). OM has a strong, positive correlation with both forms of P, whereas $CaCO_3$ has a moderate, negative correlation with both forms of P.

Pearson Correlation Coefficients, N = 40 Prob > |r| under H0: Rho=0		
	Olsen_P	unavail_P
OM	0.53703 0.0004	0.65648 <.0001
CaCO3	-0.32802 0.0388	-0.40341 0.0098

Figure 75. SAS correlations OM and $CaCO_3$ with Olsen P and Unavailable P. The top value is between -1 and 1, and the bottom value is the correlation's P-Value.

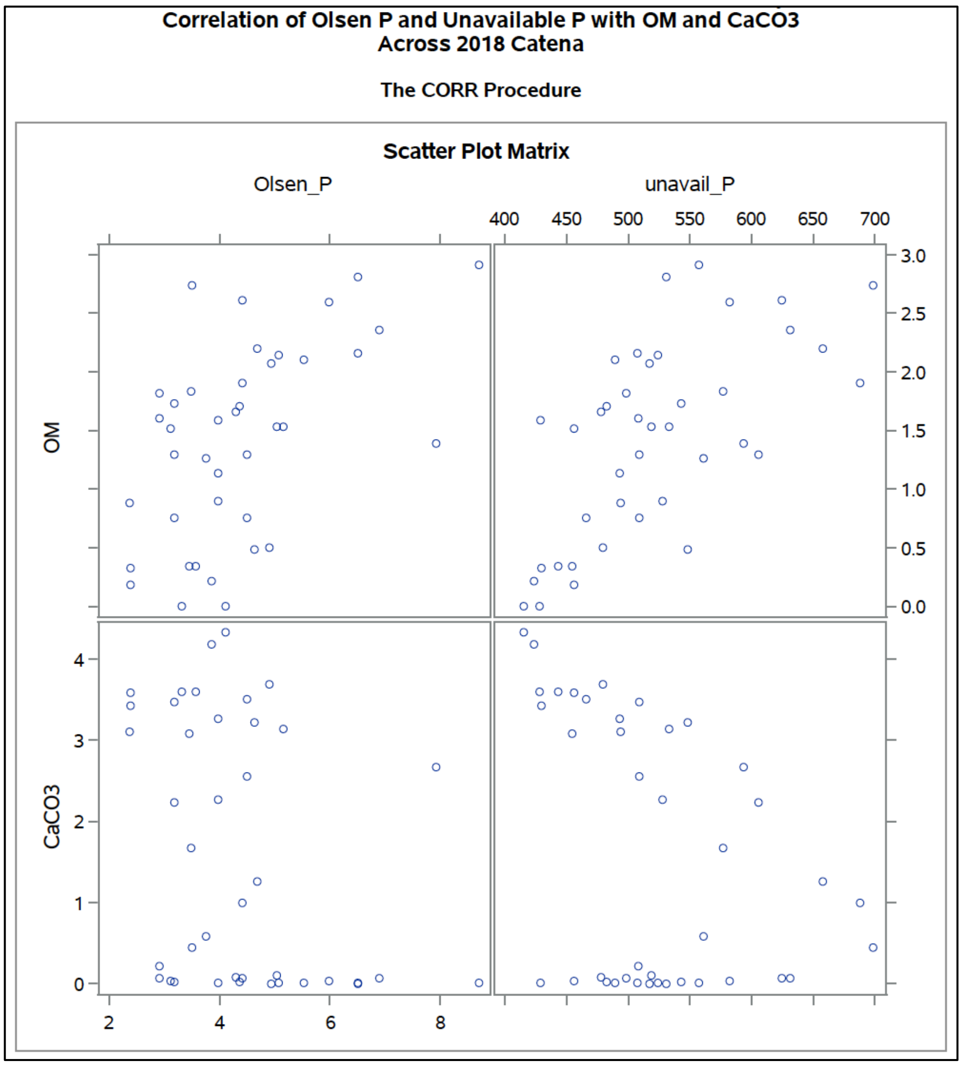


Figure 76. WE_18 Correlation procedure (SAS) for Olsen P and Unavailable P with OM and $CaCO_3$. Phosphorus values are in ppm (mg/kg). OM and $CaCO_3$ values are in percent.

DISCUSSION

To understand the effects of the fertilizer treatments used in this study, they need to be looked at in a particular block of erosional severity and the method of application. Blocks which include higher levels of phosphorus and organic matter, and lower levels of calcium carbonate include the non-eroded and depositional blocks of the 2017 experiment, and just the non-eroded block of the 2018 experiment. We must also look at blocks which include low levels of phosphorus and organic matter, with high levels of calcium carbonate. These parameters would include the slightly eroded and highly eroded blocks of the 2017 experiment, and all but the non-eroded block of the 2018 experiment.

In the broadcast applied experiment (WE_17), the non-eroded and depositional blocks had calcium carbonate and organic matter ranging from 0.15 to 0.43% and 1.9 to 3.8%, respectively. In both blocks, AVAIL had a positive effect on yield when applied with the half rate of MAP, and only in the non-eroded block did AVAIL have a positive effect on yield when applied with the full rate of MAP. AVAIL also had a positive effect on yield when applied with the half rate of MAP across all blocks of erosional severity when applied as a broadcast. These results support findings from Mooso *et al.* (2010), Dunn *et al.* (2008), and Shipp *et al.* (2017). What's also interesting to find is that AVAIL had a negative effect on yield when applied with the full rate of MAP as a broadcast for the slightly eroded, highly eroded, and depositional blocks.

While these findings are interesting, there is no statistically significant yield advantage of any fertilizer treatment at any level of erosional severity. Because there is

not significant difference in yield, a grower could broadcast apply just one-half the recommended rate of MAP and save $20.30/acre. Because there is indication that one-half the recommended rate of MAP with AVAIL® performed similarly in yield to the full recommended rate of MAP without AVAIL®, a grower could potentially save $6.42/acre by applying the under similar conditions.

In the banded experiment (WE_18), the highly eroded and depositional blocks contained calcium carbonate and organic matter ranging from 0.07 to 4.3% and 0 to 2.2%, respectively. These areas which would typically have lower levels of plant available phosphorus were the only areas where AVAIL® had a positive effect on yield when band applied with the Half rate of MAP. As calcium carbonate decreases and organic matter increases in the top foot of soil (non-eroded and slightly eroded blocks), AVAIL® had a negative impact on yield when band applied with the Half rate of AVAIL®.

Like experiment 1, there was no statistical significant difference in yield between treatments when fertilizer was band applied. Because of this, a grower could band apply one-half the recommended rate of MAP and save $15.37/acre. With the treatment yields averaged to view the effects of the treatments across the field (all blocks of erosional severity), neither treatments with AVAIL® actually had greater yield or profit than those without AVAIL®. Profit for the full recommended rate of MAP narrowly outperformed one-half the recommended rate of MAP by $1.73/acre when banded.

The non-eroded block, in general, proves useful in comparing treatment effects on yield not only within a mode of application, but also between modes of application. Results from the non-eroded block can provide insight to the effects of these treatments

on land of level ground. When comparing profit values from the non-eroded blocks between the two experiments of our study, the full rate of MAP without AVAIL® produced 1.94 times the profit when banded versus broadcasted, supporting findings where band-applied P was twice as effective (Hopkins *et al.*, 2018) or doubled profits (Lowry *et al.*, 1952) in low-P soils.

Correlating organic matter and $CaCO_3$ contents with unavailable and plant available phosphorus (Olsen P), for both experiments demonstrated the relationships of these two soil parameters on an essential macronutrient. Results from catenas of both experiments show that OM is positively correlated to total phosphorus, and more so with unavailable P. And interestingly, $CaCO_3$ was thought to be positively correlated with Unavailable and Inorganic phosphorus, but in fact, erosion, which carries with it Organic Matter and phosphorus, available or not, is the driving force behind this negative correlation. As topsoil runoff settles in an area of deposition, organic matter and surface applied fertilizer accumulate, while $CaCO_3$ continues to be buried. So, when phosphorus is at its highest in an area of deposition, $CaCO_3$ is at its lowest. A high amount of Unavailable P was thought to have been seen at the Back Slope, but as mentioned earlier, much of this material will find its way to the base of the catena, leaving behind a bare, calcium carbonate-rich, subsoil. If our areas of low OM and high $CaCO_3$ were located not on a back-slope, but in a flat area that could avoid effects of runoff, we may have seen a positive correlation between $CaCO_3$ and unavailable P.

What we see from this study is that the largest contributor to yield is Organic Matter content. It can counter-affect the negative impact that calcium carbonate has on the availability of phosphorus to plants, and based on our results, has an effect on yield.

Growing crops on eroded hillslopes will continue to require alternative solutions. As applied phosphorus is immobilized and fertilizer costs continually increase, utilizing the positive correlation between half the recommended rate of MAP with the copolymer AVAIL® on high $CaCO_3$, low OM soils, is a viable alternative for comparable yields if we are to conserve phosphorus as a non-renewable resource.

SUMMARY

While there were quantifiable differences in yield between treatments for both experiments, there was no statistical significance between treatments within any block of erosional severity. Therefore, a grower with similar field conditions could save \$20.30/acre by applying half the recommended rate of MAP (30 lbs/acre) as a spring broadcast or \$15.37/acre by incorporating the treatment with the seed at planting.

AVAIL® costs \$4.89/acre when used with the recommended rate of MAP and half that cost when used with half the recommended rate of MAP. Because there were comparable yield results when using 30 lbs/acre of MAP with AVAIL® to the full rate of MAP, especially on eroded hillslopes, a grower could benefit most in profit by supplementing the reduced rate of MAP with AVAIL® in similar field conditions. Further study of reduced rates of phosphorus fertilizers with enhanced efficiency products, such as AVAIL®, on larger scales would prove beneficial.

REFERENCES

Chien, S.H., D. Edmeades, R. McBride, and K.L. Sahrawat. 2014. Review of maleic-itaconic acid copolymer purported as urease inhibitor and phosphorus enhancer in soils. Agron. J. 106:423-430. doi: 10.2134/agronj2013.0214.

Collinston Series. 2003. Web Soil Survey. USDA-NRCS. https://soilseries.sc.egov.usda.gov/OSD_Docs/C/COLLINSTON.html (accessed 05 Jan. 2019).

Dunn, D.J., and G. Stevens. 2008. Response of Rice Yields to Phosphorus Fertilizer Rates and Polymer Coating. Crop Manag. 7. doi:10.1094/CM-2008-0610-01-RS.

Fiedler, R.J., D.H. Sander, and G.A. Peterson. 1989. Fertilizer phosphorus recommendations for winter wheat in terms of method of phosphorus application, soil pH, and yield goal. Soil Sci. Soc. Am. J. 53:1282-1287.

Gordon, W.B. 2005. Improving the efficiency of phosphorus fertilizers. *In* Kansas fertilizer research 2008 report of progress 1012 [CD]. Kansas State University, Manhattan, KS.

Gordon, W.B. 2007. Management of enhanced efficiency fertilizers. Proceedings of the North Central Extension-Industry Soil Fertility Conference. Des Moines, IA., International Plant Nutrient Institute, Brookings, SD. p. 19-23.

Gavlak, R, D. Horneck, and R.O. Miller. 2005. Soil, Plant and Water Reference Methods for the Western Region. 3rd ed. WREP-125.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.R. Nelson. 2005. Soil Fertility and Fertilizers. 7th ed. Prentice Hall, New Jersey.

Hodges, R.H., G.E. Cardon, and R. Clawson. 2017. Soil Series: Elevation and Agricultural Soil Test Survey of the Godfrey Dryland Experimental Farm, Clarkston, Utah. Utah State University Extension. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=2813&context=extension_curall (accessed 05 Jan. 2019).

Holmgren, L, and M. Pace. 2016. 2016 Costs and Returns for Non-Irrigated Hard Red Winter Wheat, Northern Utah. Utah State University Cooperative Extension. https://extension.usu.edu/boxelder/ou-files/DrylandWheat16.pdf (accessed 05 Jan. 2019).

Hopkins B.G., J.W. Ellsworth, A.K. Shiffler, T.R. Bowen, and A.G. Cook. 2010. Pre-Plant verus in-season application of phosphorus fertilizer for russet Burbank

potato grown in calcareous soil. Journal of Plant Nutrition. 33(7):1026-1039. doi: 10.1080/01904161003728693.

Hopkins, B.G., K.J. Fernelius, N.C. Hansen, and D.L. Eggett. 2018. AVAIL Phosphorus Fertilizer Enhancer: Meta-Analysis of 503 Field Evaluations. Agron. J. 110:389-398.

J.R. Simplot Company. 2015. Tech sheets: AVAIL® Phosphorus Fertilizer Enhancer. http://techsheets.simplot.com/Plant_Nutrients/Avail_Base.pdf (accessed 05 Jan. 2019).

Karamanos, R.E., and D. Puurveen. 2011. Evaluation of a polymer treatment as enhancer of phosphorus fertilizer efficiency in wheat. Canadian Journal of Soil Science. 91:123-125. doi: 10.4141/cjss10071.

Kotuby-Amacher, J., R. Koenig, and B. Kitchen. 2000. Salinity and Plant Tolerance. Utah State University Extension. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1042&context=extension_histall (accessed 05 Jan. 2019).

Larson, K.J., and L. Herron. 2003. N and P Placement and Timing of Dryland Winter Wheat Varieties. Agricultural Experiment Station, Colorado State University. http://webdoc.agsci.colostate.edu/aes/prc/pubs/NandPPlacementandTimingofDrylandWinterWheatVarieties.pdf (accessed 05 Jan. 2019).

Lowrey, G.W., R.A. Olson, A.F. Dreier, and P.L. Ehlers. 1952. Commercial fertilizer results with winter wheat and rye. OST Circular 23. Agric. Exp. Stn., University of Nebraska-Lincoln.

Lucin CL Wheat. 2009. Technology Publisher, Utah State University. http://utahstate.technologypublisher.com/technology/20625 (accessed 05 Jan. 2019).

Mooso, G., T.A. Tindall, and G. Hettiarachchi. 2013. Phosphorus use efficiency in crop production. Western Nutrient Management Conference, Reno, NV. 7-8 Mar. 2013. Int. Plant Nutrition Institute, Peachtree Corners, GA. p. 87-91.

Murphy, L., and L. Sanders. 2007. Improving N and P Use Efficiency with Polymer Technology. Proceedings for the Indiana CCA Conference. 18-19 Dec. 2007. Indianapolis, IN. p. 1-12.

National Agricultural Statistics Service. June 30, 2017. Washington, D.C.: USDA.

SAS Institute Inc. 2018. SAS user’s guide. SAS Inst., Cary, NC.

Shipp, E., T.J. Hopkins, and B.G. Hopkins. 2017. Improving phosphorus use efficiency: right rate, timing, and placement and enhanced efficiency fertilizer sources: research summary. Proceedings of the Western Nutrient Management Conference. 2-3 Mar. 2017. Reno, NV. p. 164-171.

Stark, J.C., and B.G. Hopkins. 2015. Fall and Spring Phosphorus Fertilization of Potato Using a Dicarboxylic Acid Polymer (AVAIL®). Journal of Plant Nutrition. 38:1595-1610.

Tindall, T.A. and J.R. Simplot Co. 2007. Recent Advances in P Fertilizer Technologies- Polymer Coatings and AVAIL Technology. Proceedings of the Idaho Alfalfa and Forage Conference. 26-27 Feb. 2007. Twin Falls, ID. p. 107-110.

UI Magic CL+. 2010. Limagrain Cereal Seeds, LLC. http://limagraincerealseeds.com/products/soft-white-winter-wheat/ui-magic-cl (accessed 05 Jan. 2019).

USUAL. 2017. Plant Analysis Information Sheet. http://www.usual.usu.edu/forms/plantform.pdf (accessed 05 Jan. 2019).

Utah Climate Center. 2018. Cutler Dam Weather Station (GHCN), report period: 01APR1980 to 30JUN2018. Utah State University. Available at https://climate.usu.edu/mapGUI/mapGUI.php (accessed 05 Jan. 2019).

Utah Fertilizer Guide. 2010. Utah State University Cooperative Extension. https://extension.usu.edu/waterquality/files-ou/Agriculture-and-Water-Quality/Fertilizer/AG-431.pdf (accessed 05 Jan. 2019).

Verity, G.E., and D.W. Anderson. 1990. Soil Erosion Effects on Soil Quality and Yield. Canadian Journal of Soil Science. 70:471-484. https://doi.org/10.4141/cjss90-046 (accessed 05 Jan. 2019)..

Ward, N.C. 2010. Nicholas Ward. Impact of AVAIL® and JUMSTART® on yield and phosphorus response of corn and winter wheat in Kansas. M.S. thesis, Department of Agronomy, College of Agriculture, Kansas State University, Manhattan. http://hdl.handle.net/2097/3519 (accessed 05 Jan. 2019).

APPENDICES

Table 5. Wheat Experiment 2017 (broadcast fertilizer) cost analysis. Results are broken up by erosional severity. Yield values in bu/acre for each treatment are mean values of replications within its respective block. Mean Calcium Carbonate and Organic Matter content values (%) are provided for each block.

Noneroded

	mean (%)
CaCO3	0.15
OM	2.93

Treatment	yield bu/acre	at $4.55/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Profit $/acre
Full rate without AVAIL	$ 79.94	$ 363.53	$ (28.18)	$ (149.65)	$ (177.83)	$ 185.70
1/2 rate without AVAIL	$ 72.13	$ 328.01	$ (14.21)	$ (146.52)	$ (160.73)	$ 167.28
Full rate with AVAIL	$ 84.78	$ 385.54	$ (33.06)	$ (151.58)	$ (184.64)	$ 200.89
1/2 rate with AVAIL	$ 80.28	$ 365.07	$ (16.68)	$ (149.78)	$ (166.46)	$ 198.62

Slightly Eroded

	mean (%)
CaCO3	1.3
OM	2.17

Treatment	yield bu/acre	at $4.55/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Profit $/acre
Full rate without AVAIL	$ 75.10	$ 341.52	$ (28.18)	$ (147.71)	$ (175.89)	$ 165.63
1/2 rate without AVAIL	$ 55.53	$ 252.52	$ (14.21)	$ (139.88)	$ (154.09)	$ 98.43
Full rate with AVAIL	$ 69.29	$ 315.10	$ (33.06)	$ (145.38)	$ (178.44)	$ 136.65
1/2 rate with AVAIL	$ 63.45	$ 288.54	$ (16.68)	$ (143.05)	$ (159.73)	$ 128.81

Highly Eroded

	mean (%)
CaCO3	2.56
OM	1.74

Treatment	yield bu/acre	at $4.55/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Profit $/acre
Full rate without AVAIL	$ 58.29	$ 265.07	$ (28.18)	$ (140.99)	$ (169.17)	$ 95.91
1/2 rate without AVAIL	$ 51.94	$ 236.20	$ (14.21)	$ (138.45)	$ (152.66)	$ 83.54
Full rate with AVAIL	$ 50.42	$ 229.28	$ (33.06)	$ (137.84)	$ (170.90)	$ 58.38
1/2 rate with AVAIL	$ 56.25	$ 255.80	$ (16.68)	$ (140.17)	$ (156.85)	$ 98.95

Depositional

	mean (%)
CaCO3	0.43
OM	2.98

Treatment	yield bu/acre	at $4.55/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Profit $/acre
Full rate without AVAIL	$ 85.96	$ 390.90	$ (28.18)	$ (152.05)	$ (180.23)	$ 210.68
1/2 rate without AVAIL	$ 72.35	$ 329.01	$ (14.21)	$ (146.61)	$ (160.82)	$ 168.19
Full rate with AVAIL	$ 80.47	$ 365.94	$ (33.06)	$ (149.86)	$ (182.92)	$ 183.01
1/2 rate with AVAIL	$ 92.87	$ 422.33	$ (16.68)	$ (154.82)	$ (171.50)	$ 250.83

Table 6. Wheat Experiment 2018 (banded fertilizer) cost analysis. Results are broken up by erosional severity. Yield values in bu/acre for each treatment are mean values of replications within its respective block. Mean Calcium Carbonate and Organic Matter content values (%) are provided for each block.

Noneroded

	mean (%)
CaCO3	0.26
OM	2.48

Treatment	yield bu/acre	at $4.83/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Profit $/acre
Full rate without AVAIL	114.03	$ 550.78	$ (28.18)	$ (163.28)	$ (191.45)	$ 359.33
1/2 rate without AVAIL	103.19	$ 498.39	$ (14.21)	$ (158.94)	$ (173.15)	$ 325.24
Full rate with AVAIL	97.56	$ 471.21	$ (33.06)	$ (156.69)	$ (189.76)	$ 281.46
1/2 rate with AVAIL	99.98	$ 482.92	$ (16.68)	$ (157.66)	$ (174.34)	$ 308.59

Slightly Eroded

	mean (%)
CaCO3	0.16
OM	1.79

Treatment	yield bu/acre	at $4.83/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Profit $/acre
Full rate without AVAIL	89.35	$ 431.57	$ (28.18)	$ (153.41)	$ (181.59)	$ 249.98
1/2 rate without AVAIL	89.30	$ 431.32	$ (14.21)	$ (153.39)	$ (167.60)	$ 263.72
Full rate with AVAIL	95.25	$ 460.04	$ (33.06)	$ (155.77)	$ (188.83)	$ 271.21
1/2 rate with AVAIL	79.38	$ 383.42	$ (16.68)	$ (149.42)	$ (166.10)	$ 217.32

Highly Eroded

	mean (%)
CaCO3	2.75
OM	1.02

Treatment	yield bu/acre	at $4.83/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Profit $/acre
Full rate without AVAIL	63.32	$ 305.82	$ (28.18)	$ (143.00)	$ (171.17)	$ 134.65
1/2 rate without AVAIL	59.31	$ 286.48	$ (14.21)	$ (141.39)	$ (155.60)	$ 130.87
Full rate with AVAIL	52.83	$ 255.14	$ (33.06)	$ (138.80)	$ (171.86)	$ 83.28
1/2 rate with AVAIL	67.23	$ 324.72	$ (16.68)	$ (144.56)	$ (161.24)	$ 163.49

Depositional

	mean (%)
CaCO3	3.17
OM	0.62

Treatment	yield bu/acre	at $4.83/bu	fertilizer cost/acre	other costs/acre	Total costs/acre	Profit $/acre
Full rate without AVAIL	61.63	$ 297.69	$ (28.18)	$ (142.32)	$ (170.50)	$ 127.19
1/2 rate without AVAIL	62.38	$ 301.28	$ (14.21)	$ (142.62)	$ (156.83)	$ 144.45
Full rate with AVAIL	60.43	$ 291.90	$ (33.06)	$ (141.84)	$ (174.91)	$ 116.99
1/2 rate with AVAIL	64.97	$ 313.80	$ (16.68)	$ (143.66)	$ (160.33)	$ 153.46

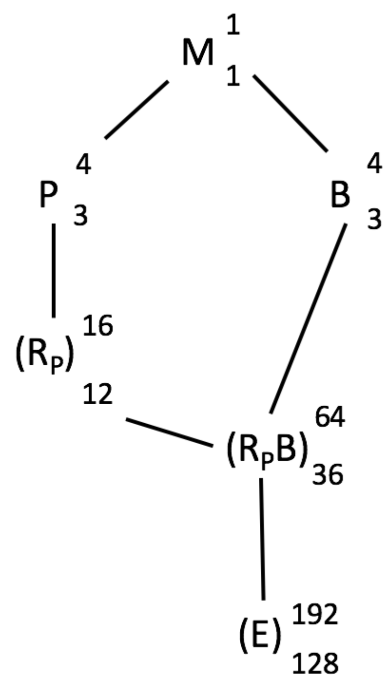


Figure 77. Hasse Diagram of Experiment 1 design.

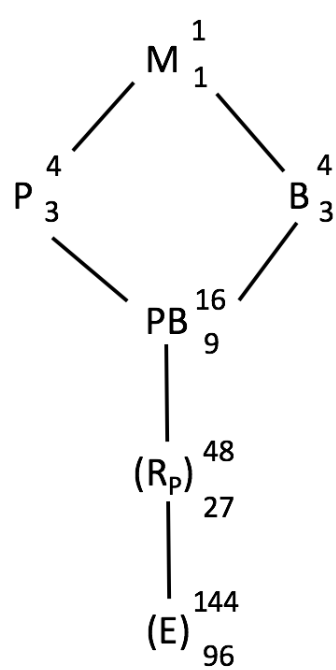


Figure 78. Hasse Diagram of Experiment 2 design.

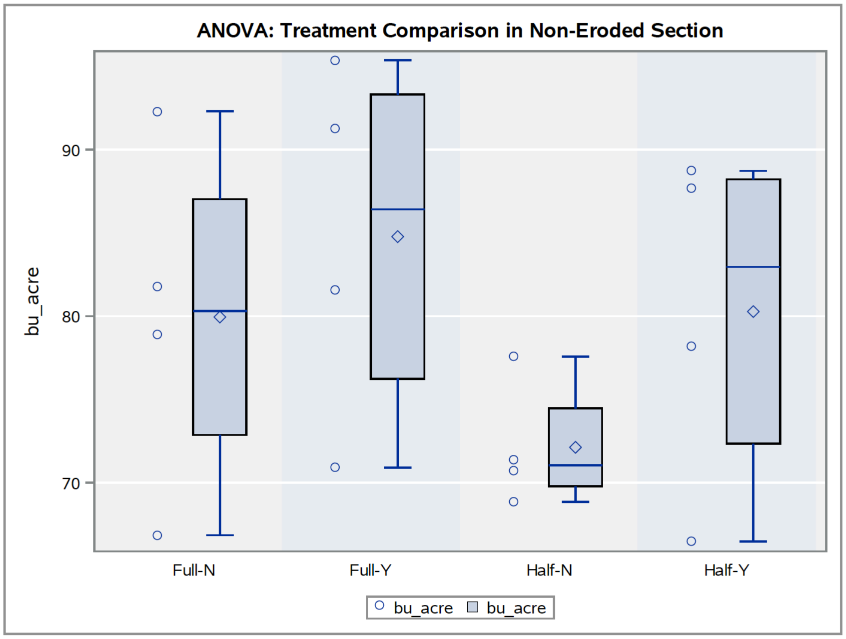


Figure 79. ANOVA box plot and value comparison of yield (bu/acre) between the four fertilizer treatments within the Non-eroded block of Experiment 1.

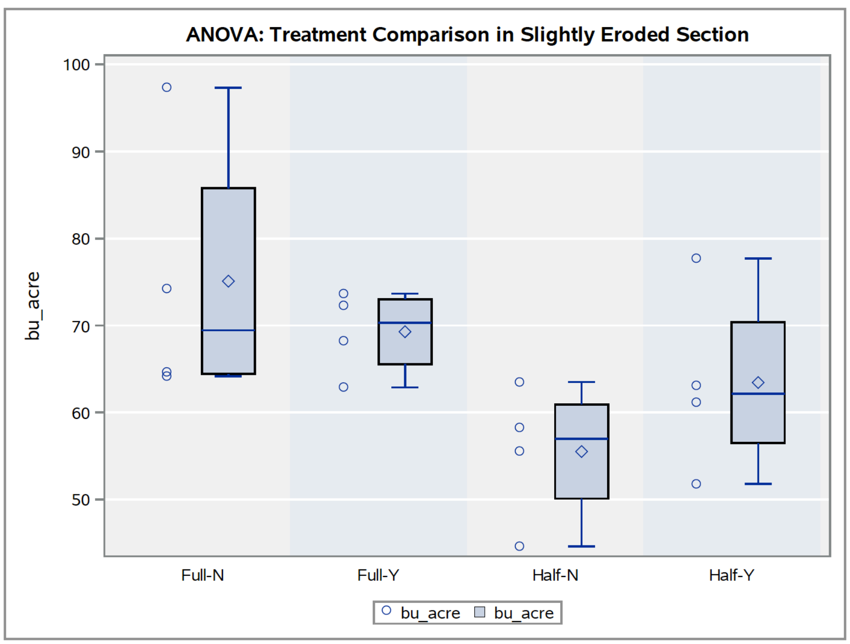


Figure 80. ANOVA box plot and value comparison of yield (bu/acre) between the four fertilizer treatments within the Slightly-eroded block of Experiment 1.

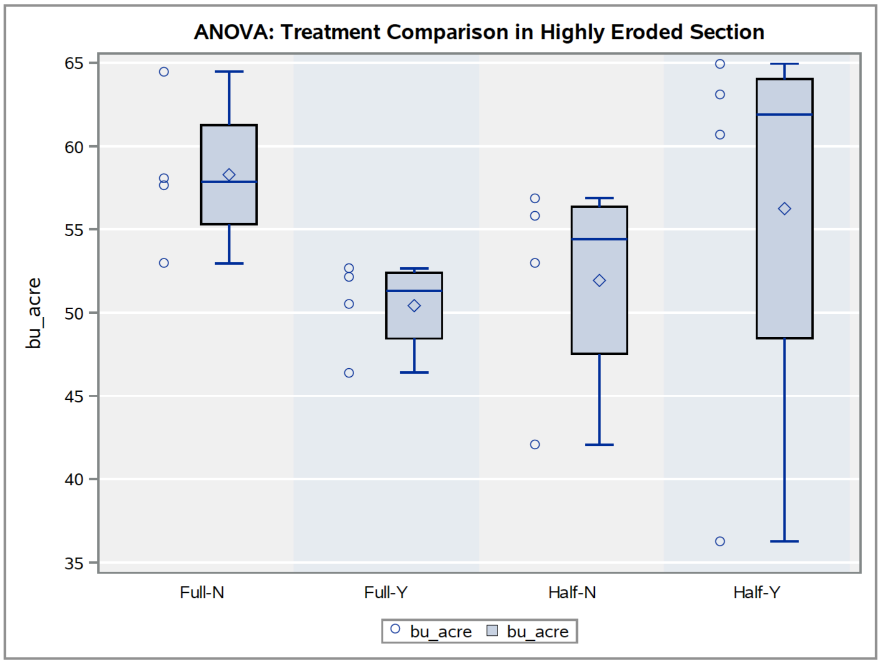


Figure 81. ANOVA box plot and value comparison of yield (bu/acre) between the four fertilizer treatments within the Highly-eroded block of Experiment 1.

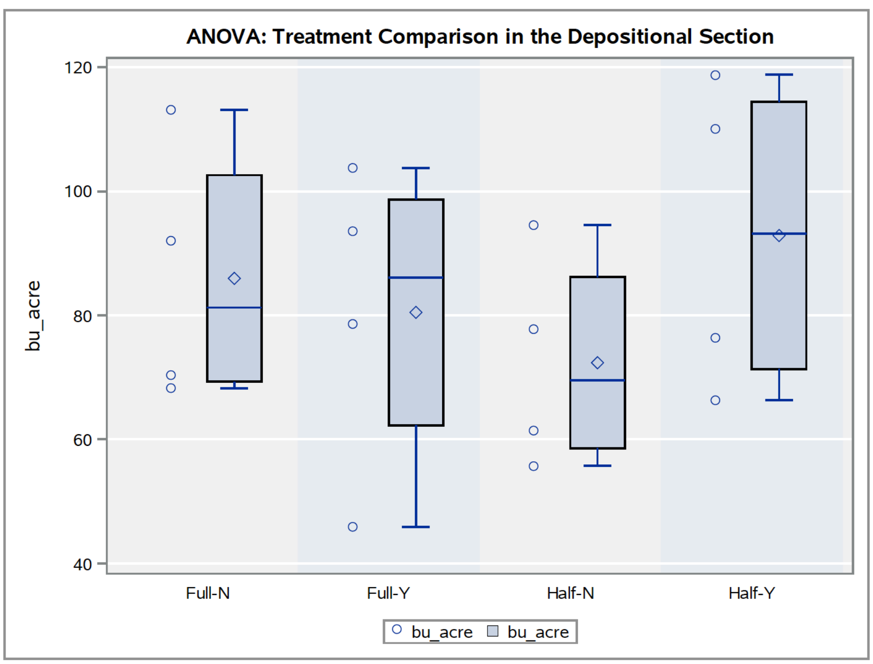


Figure 82. ANOVA box plot and value comparison of yield (bu/acre) between the four fertilizer treatments within the Depositional block of Experiment 1.

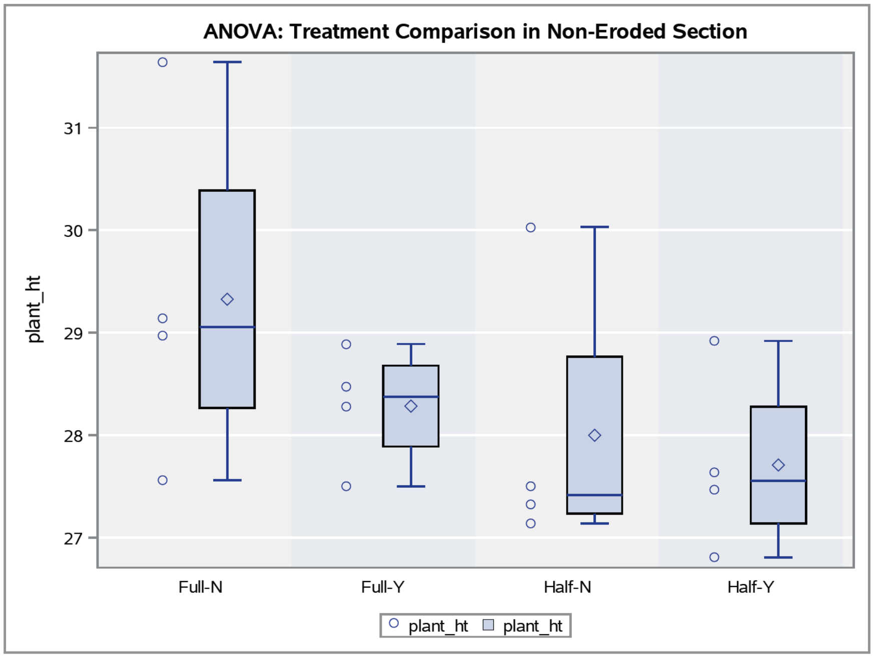


Figure 83. ANOVA box plot and value comparison of plant height (in) between the four fertilizer treatments within the Non-eroded block of Experiment 1.

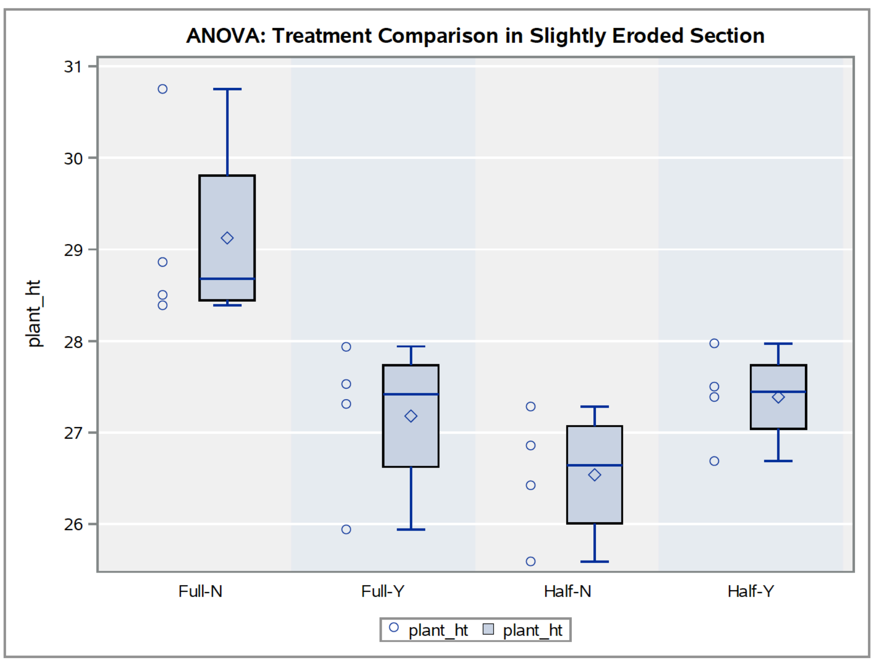


Figure 84. ANOVA box plot and value comparison of plant height (in) between the four fertilizer treatments within the Slightly-eroded block of Experiment 1.

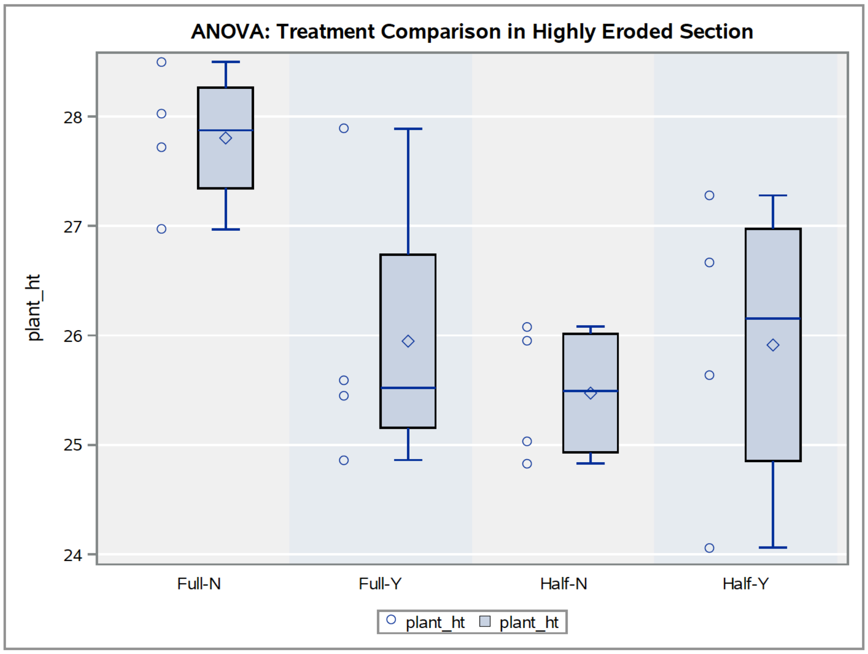


Figure 85. ANOVA box plot and value comparison of plant height (in) between the four fertilizer treatments within the Highly-eroded block of Experiment 1.

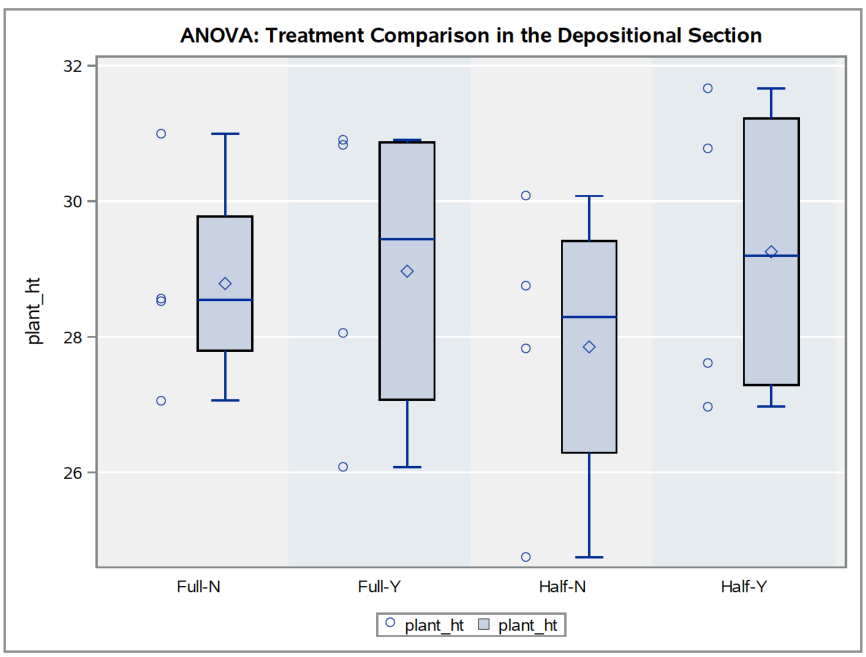


Figure 86. ANOVA box plot and value comparison of plant height (in) between the four fertilizer treatments within the Depositional block of Experiment 1.

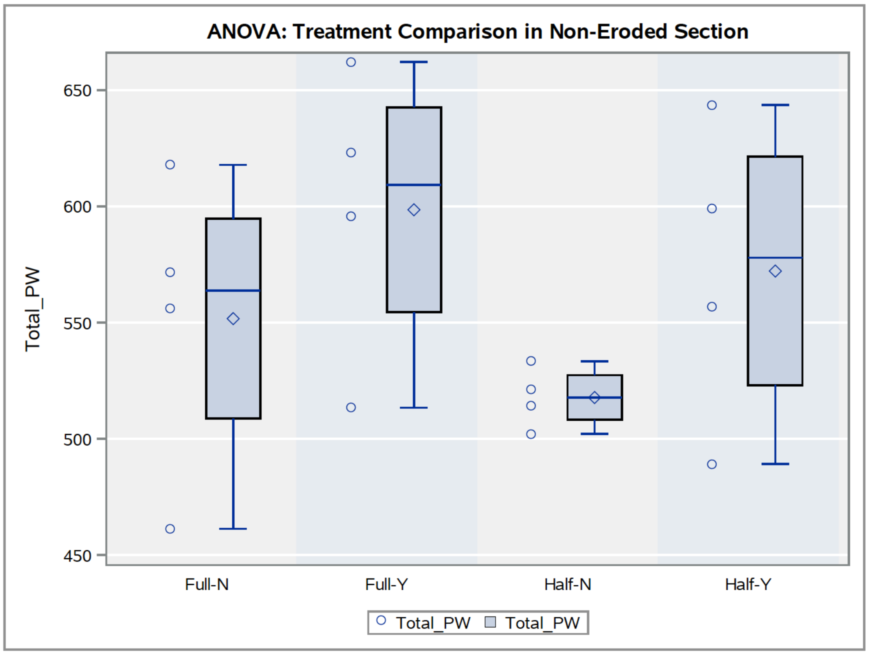


Figure 87. ANOVA box plot and value comparison of total plant biomass (grams) between the four fertilizer treatments within the Non-eroded block of Experiment 1.

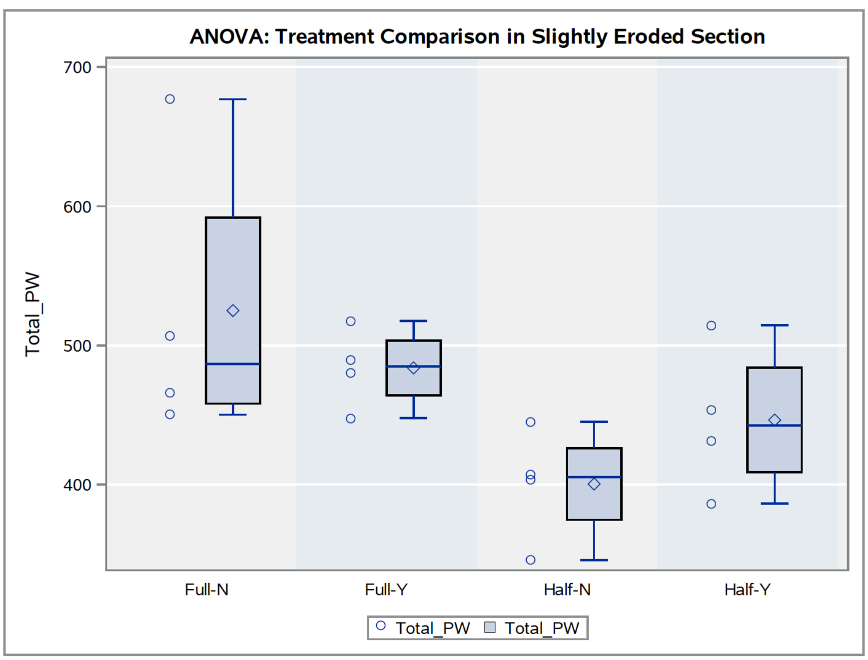


Figure 88. ANOVA box plot and value comparison of total plant biomass (grams) between the four fertilizer treatments within the Slightly-eroded block of Experiment 1.

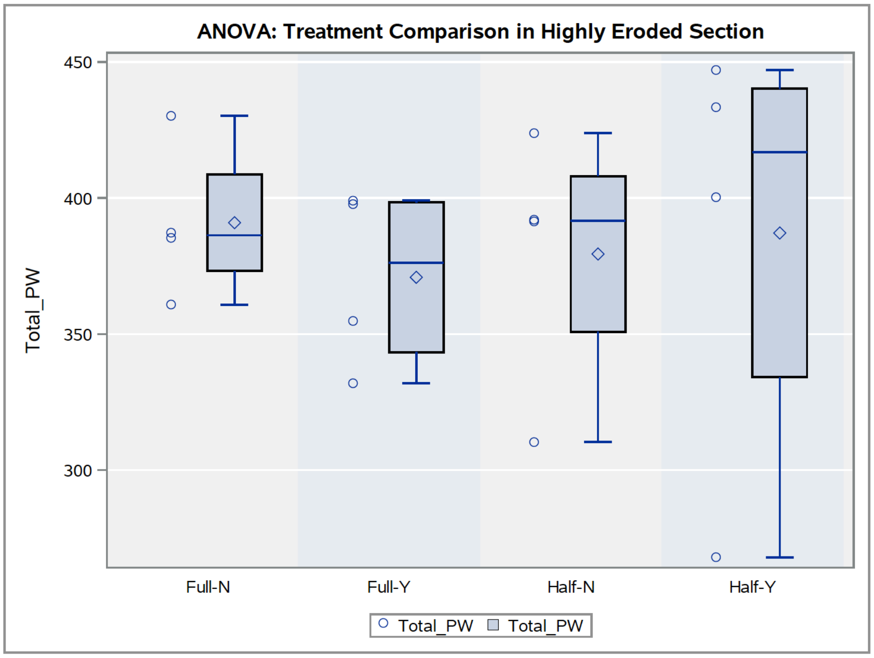


Figure 89. ANOVA box plot and value comparison of total plant biomass (grams) between the four fertilizer treatments within the Highly-eroded block of Experiment 1.

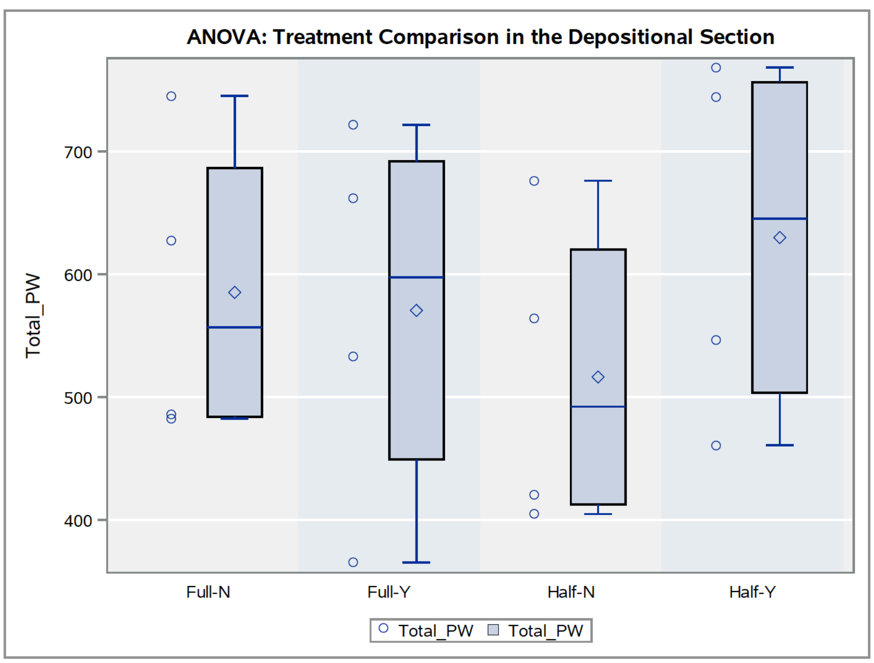


Figure 90. ANOVA box plot and value comparison of total plant biomass (grams) between the four fertilizer treatments within the Depositional block of Experiment 1.

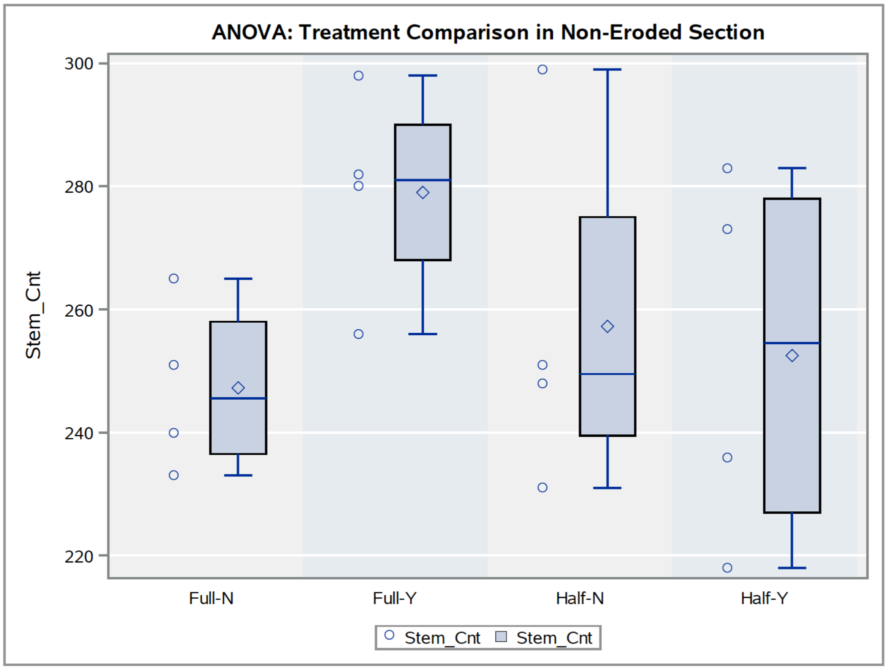


Figure 91. ANOVA box plot and value comparison of plant density (stem count) between the four fertilizer treatments within the Non-eroded block of Experiment 1.

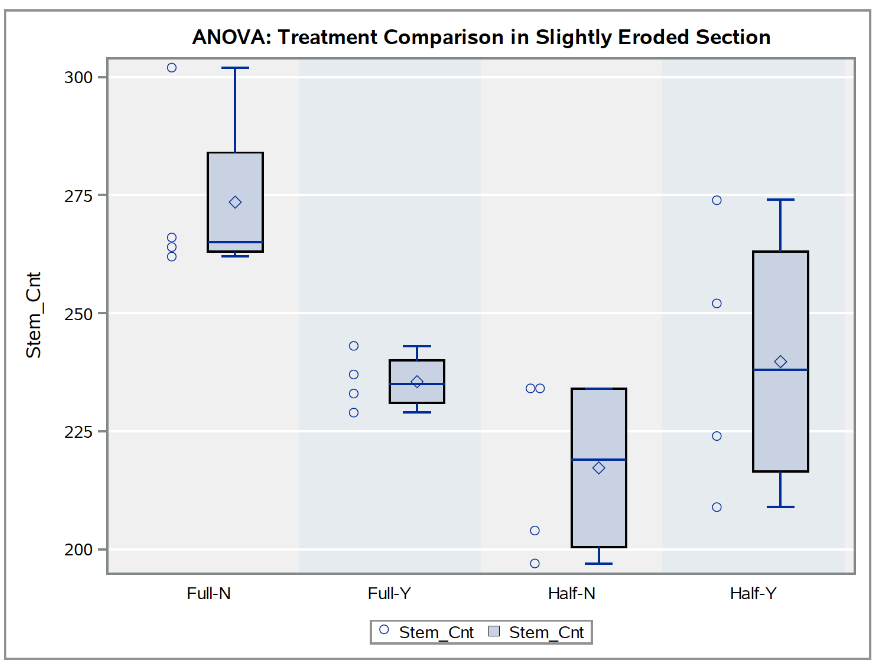


Figure 92. ANOVA box plot and value comparison of plant density (stem count) between the four fertilizer treatments within the Slightly Eroded block of Experiment 1.

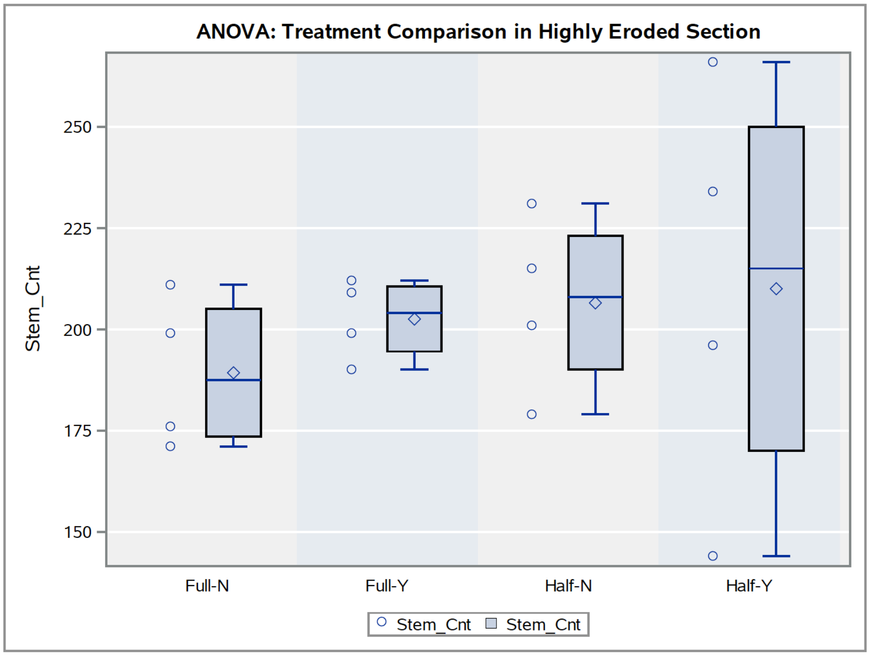


Figure 93. ANOVA box plot and value comparison of plant density (stem count) between the four fertilizer treatments within the Highly Eroded block of Experiment 1.

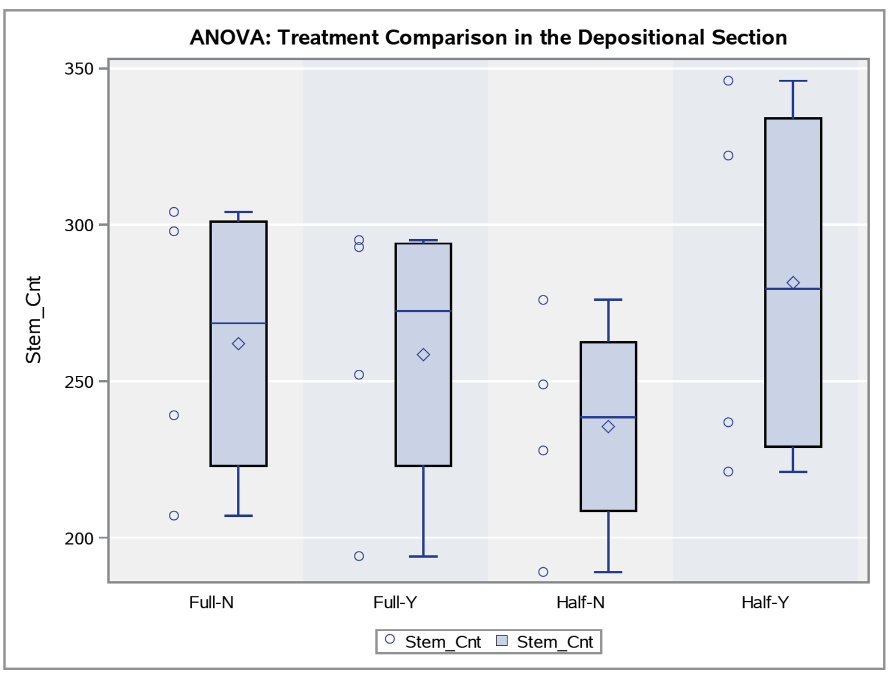


Figure 94. ANOVA box plot and value comparison of plant density (stem count) between the four fertilizer treatments within the Depositional block of Experiment 1.

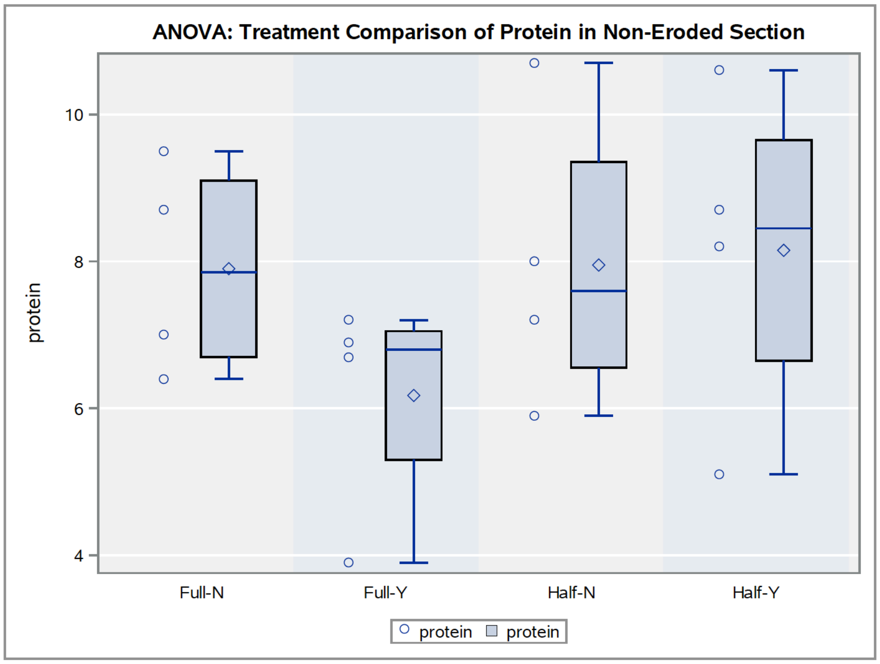


Figure 95. ANOVA box plot and value comparison of protein content (%) between the four fertilizer treatments within the Non-eroded block of Experiment 1.

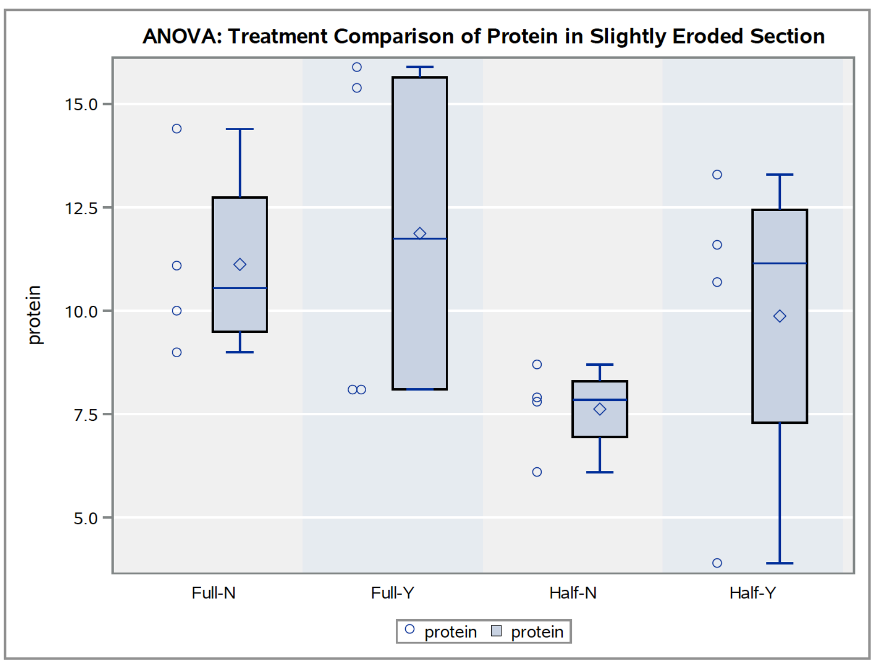


Figure 96. ANOVA box plot and value comparison of protein content (%) between the four fertilizer treatments within the Slightly-eroded block of Experiment 1.

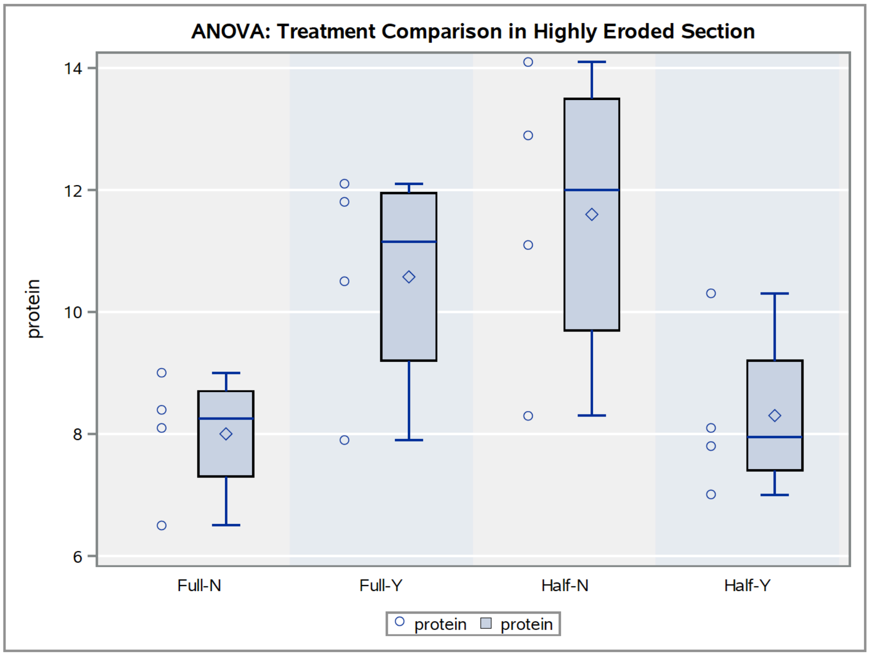


Figure 97. ANOVA box plot and value comparison of protein content (%) between the four fertilizer treatments within the Highly-eroded block of Experiment 1.

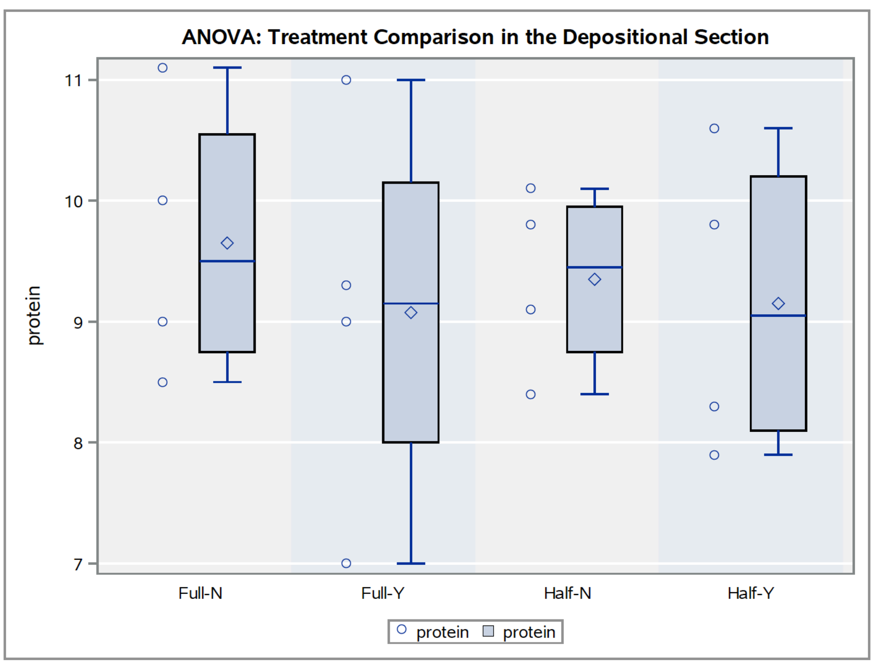


Figure 98. ANOVA box plot and value comparison of protein content (%) between the four fertilizer treatments within the Depositional block of Experiment 1.

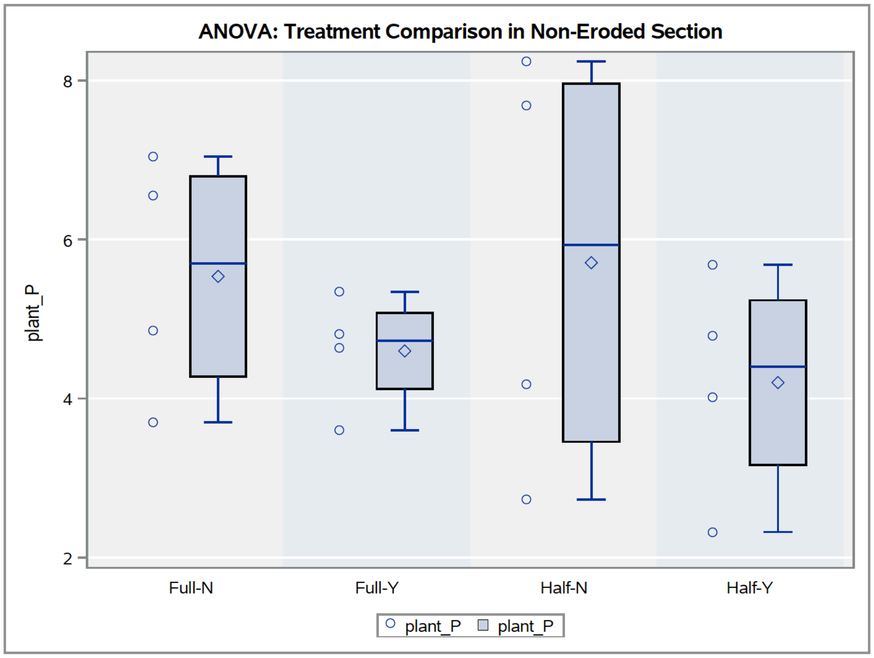


Figure 99. ANOVA box plot and value comparison of plant phosphorus (ppm) between the four fertilizer treatments within the Non-eroded block of Experiment 1 at harvest.

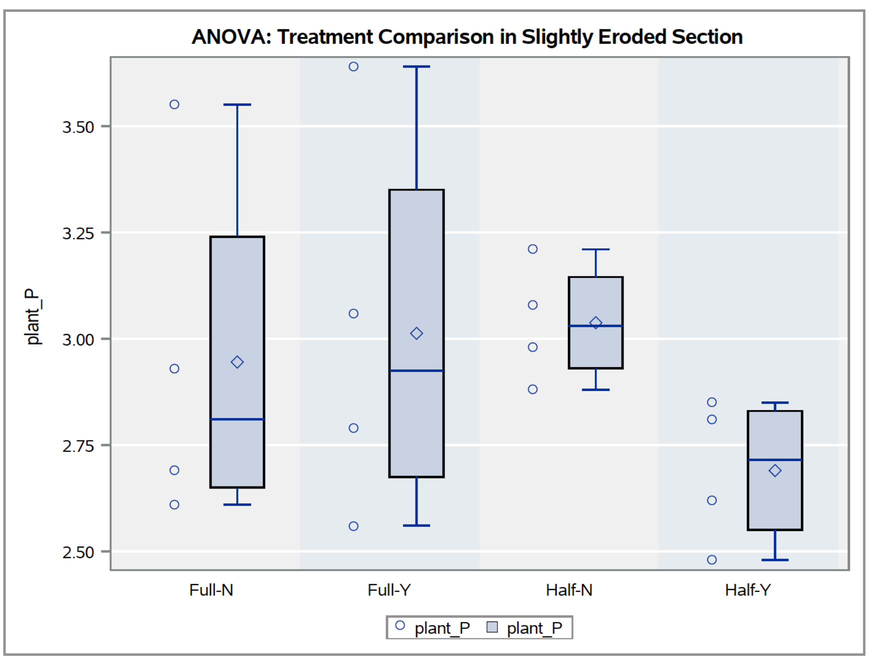


Figure 100. ANOVA box plot and value comparison of plant phosphorus (ppm) between the four fertilizer treatments within the Slightly-eroded block of Experiment 1 at harvest.

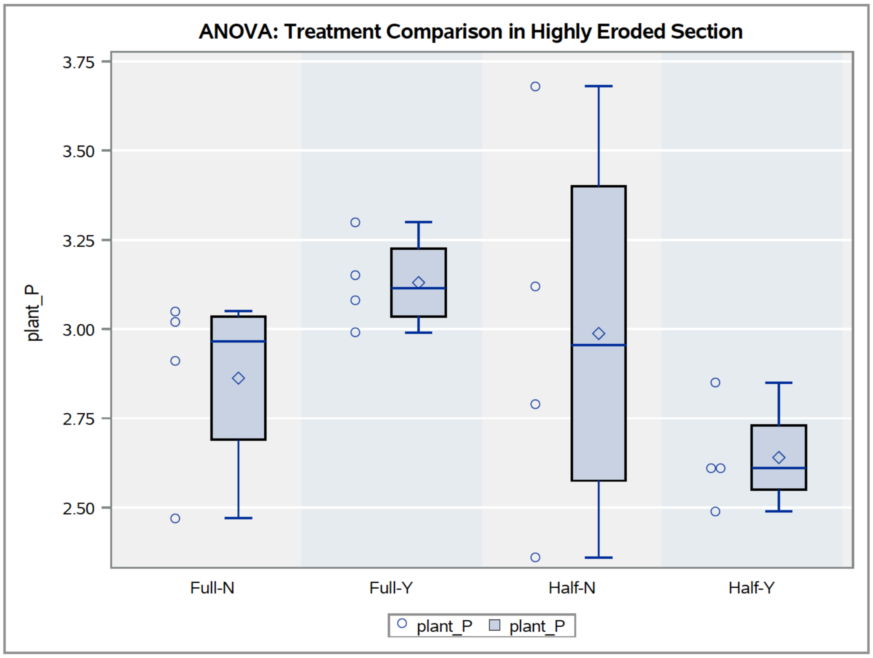


Figure 101. ANOVA box plot and value comparison of plant phosphorus (ppm) between the four fertilizer treatments within the Highly-eroded block of Experiment 1 at harvest.

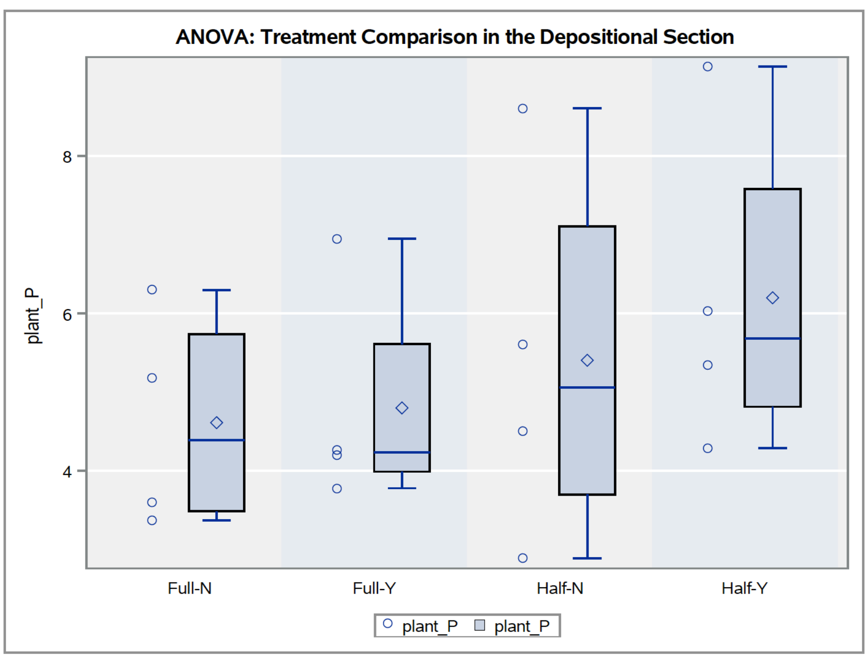


Figure 102. ANOVA box plot and value comparison of plant phosphorus (ppm) between the four fertilizer treatments within the Depositional block of Experiment 1 at harvest.

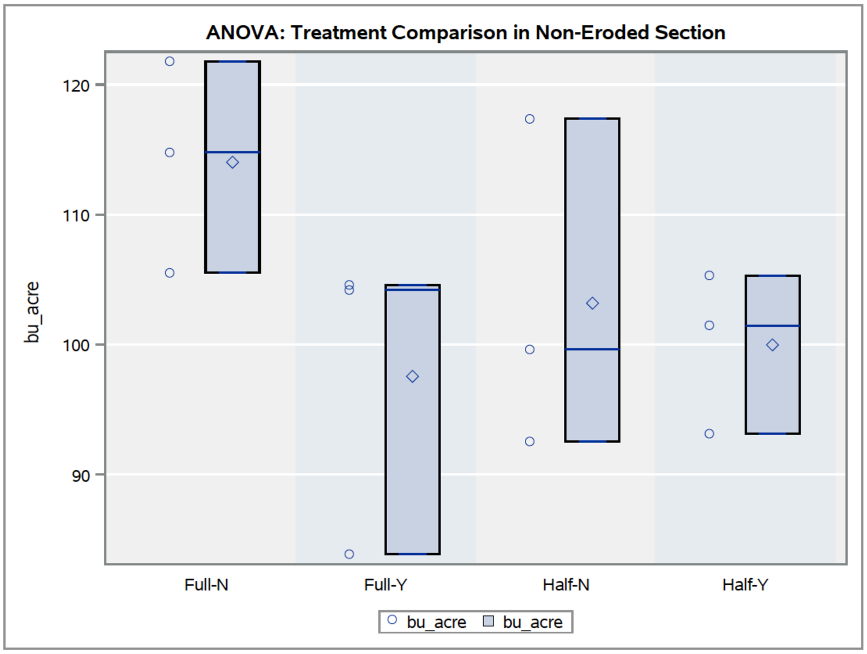


Figure 103. ANOVA box plot and value comparison of yield (bu/acre) between the four fertilizer treatments within the Non-eroded block of Experiment 2.

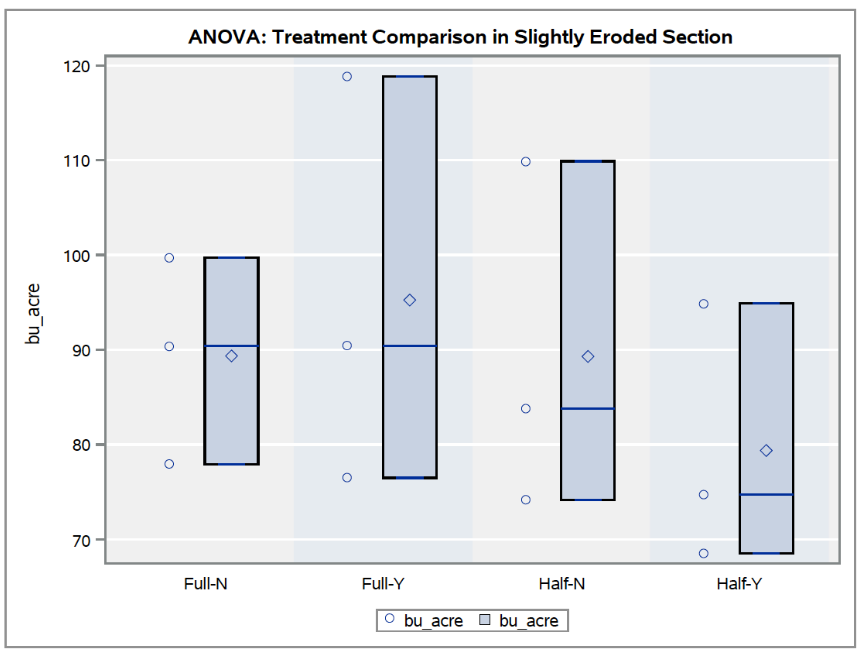


Figure 104. ANOVA box plot and value comparison of yield (bu/acre) between the four fertilizer treatments within the Slightly Eroded block of Experiment 2.

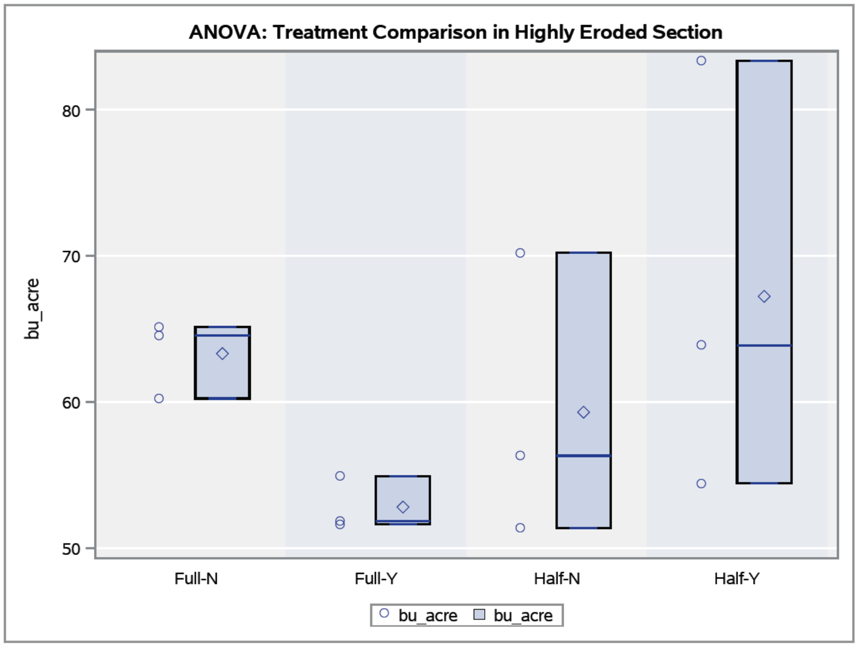


Figure 105. ANOVA box plot and value comparison of yield (bu/acre) between the four fertilizer treatments within the Highly Eroded block of Experiment 2.

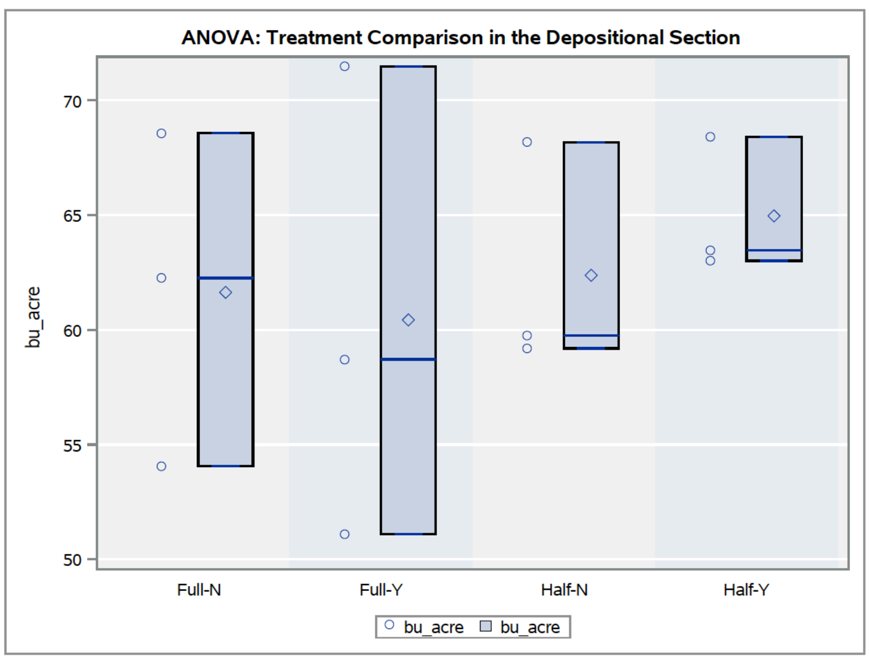


Figure 106. ANOVA box plot and value comparison of yield (bu/acre) between the four fertilizer treatments within the Depostional block of Experiment 2.

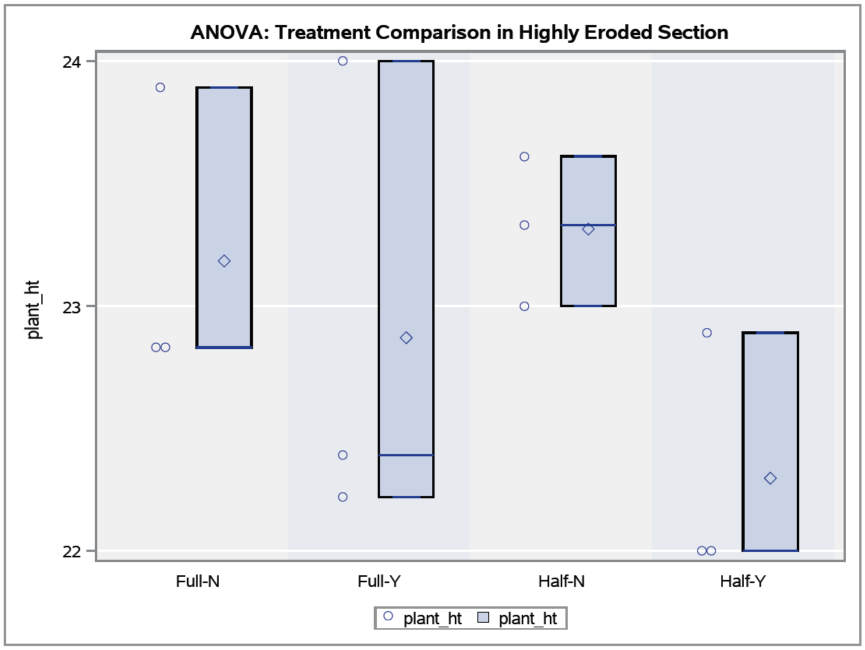


Figure 107. ANOVA box plot and value comparison of plant height (in) between the four fertilizer treatments within the Non-eroded block of Experiment 2.

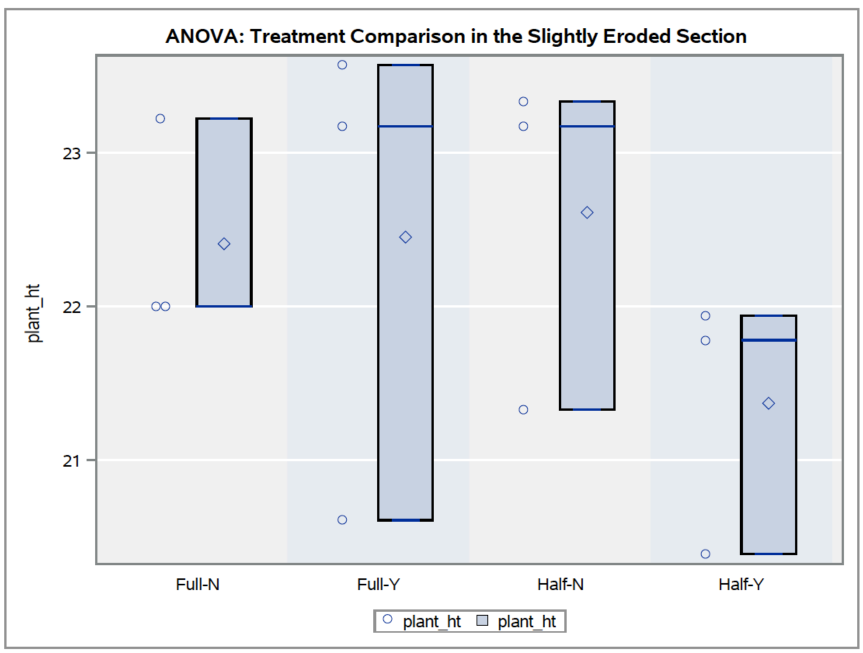


Figure 108. ANOVA box plot and value comparison of plant height (in) between the four fertilizer treatments within the Slightly Eroded block of Experiment 2.

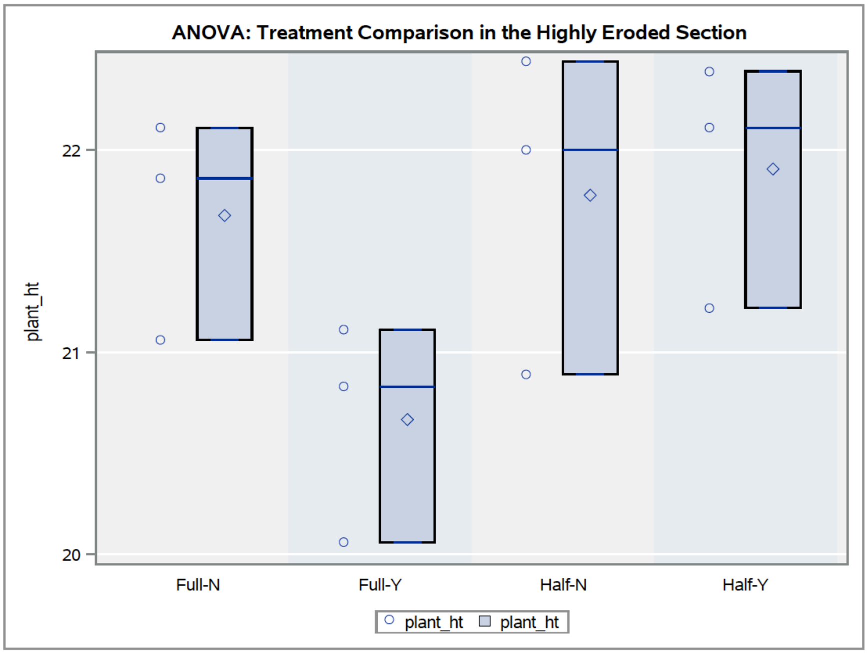


Figure 109. ANOVA box plot and value comparison of plant height (in) between the four fertilizer treatments within the Highly Eroded block of Experiment 2.

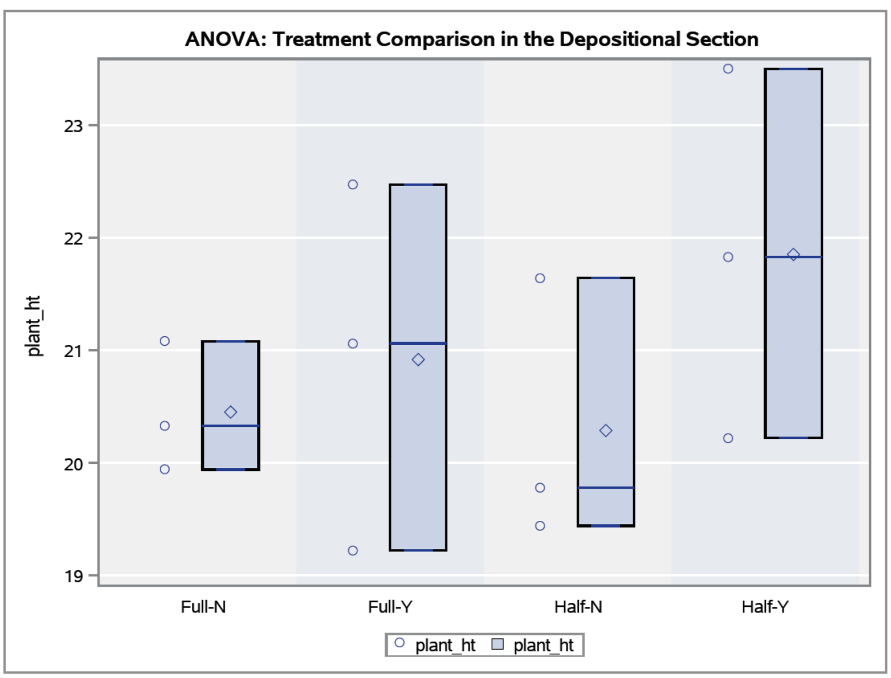


Figure 110. ANOVA box plot and value comparison of plant height (in) between the four fertilizer treatments within the Depositional block of Experiment 2.

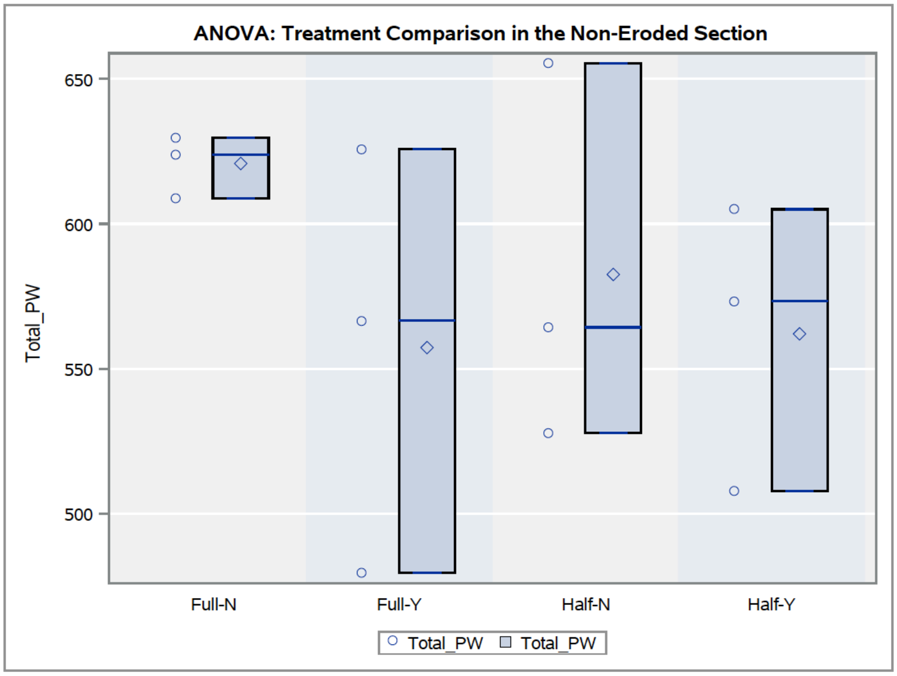


Figure 111. ANOVA box plot and value comparison of total plant biomass (grams) between the four fertilizer treatments within the Non-eroded block of Experiment 2.

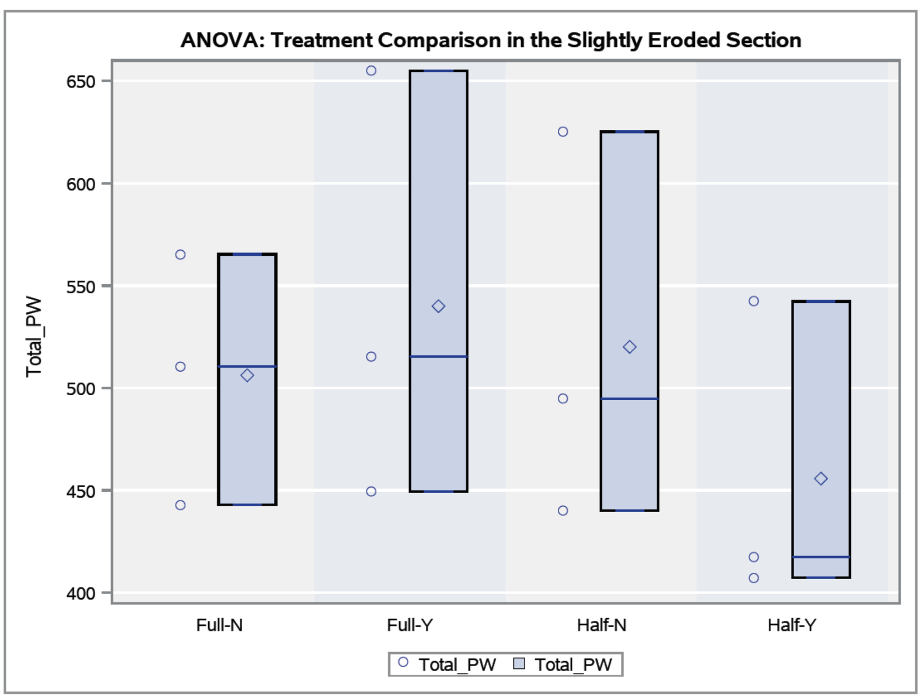


Figure 112. ANOVA box plot and value comparison of total plant biomass (grams) between the four fertilizer treatments within the Slightly Eroded block of Experiment 2.

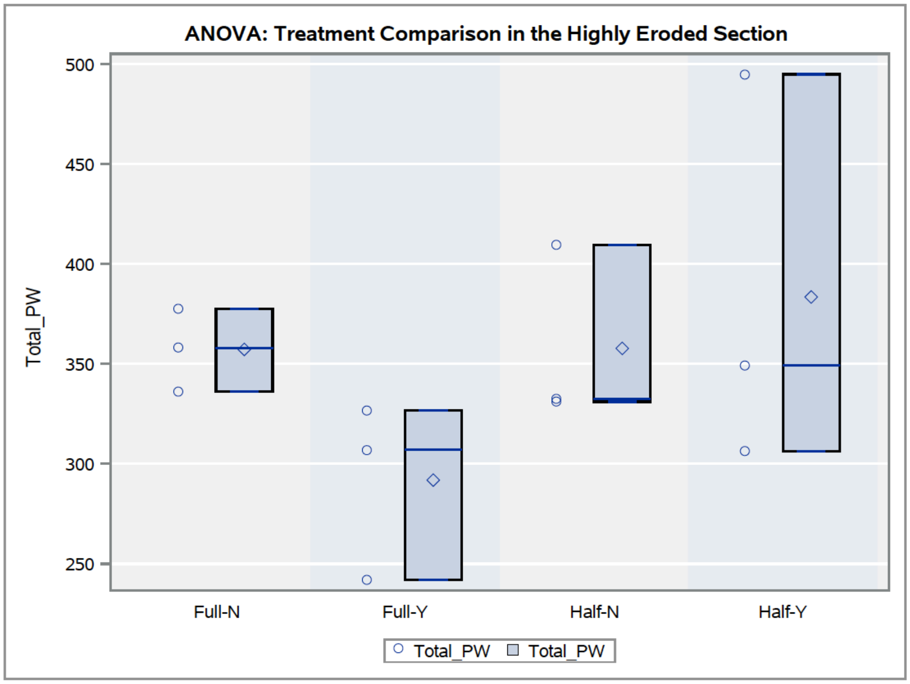


Figure 113. ANOVA box plot and value comparison of total plant biomass (grams) between the four fertilizer treatments within the Highly Eroded block of Experiment 2.

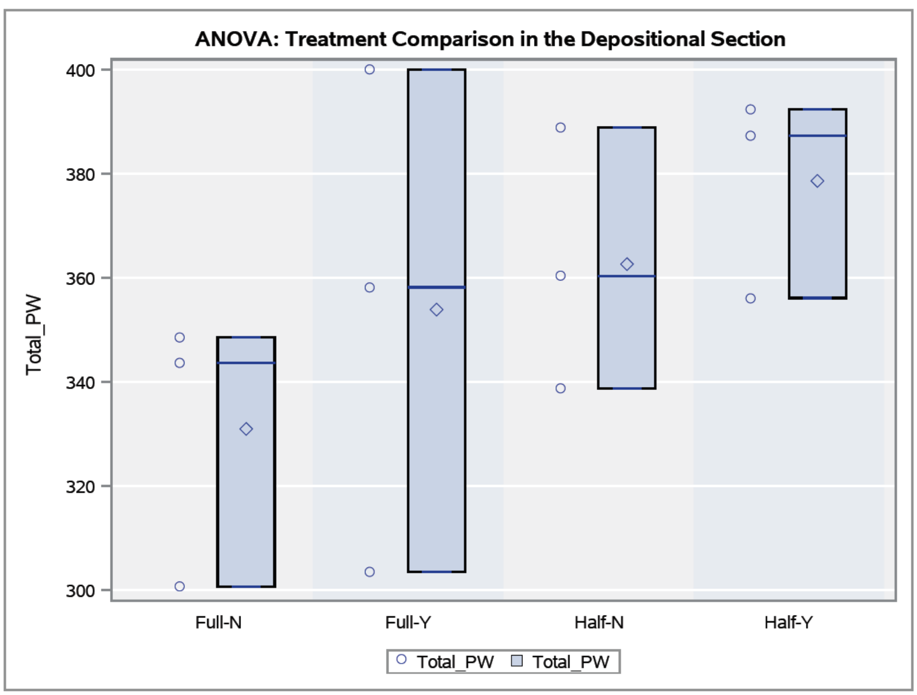


Figure 114. ANOVA box plot and value comparison of total plant biomass (grams) between the four fertilizer treatments within the Depositional block of Experiment 2.

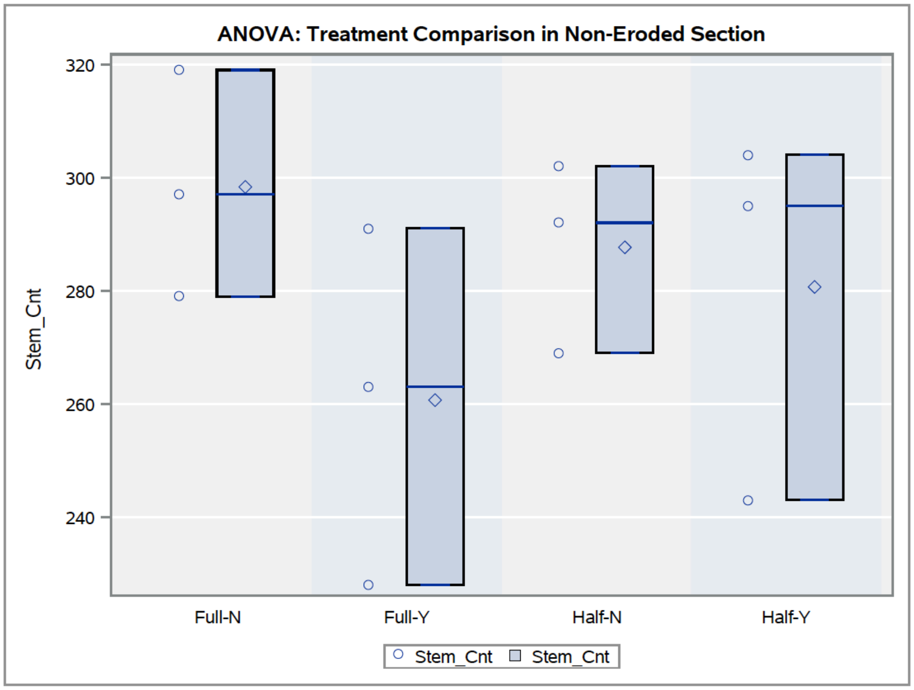


Figure 115. ANOVA box plot and value comparison of plant density (stem count) between the four fertilizer treatments within the Non-eroded block of Experiment 2.

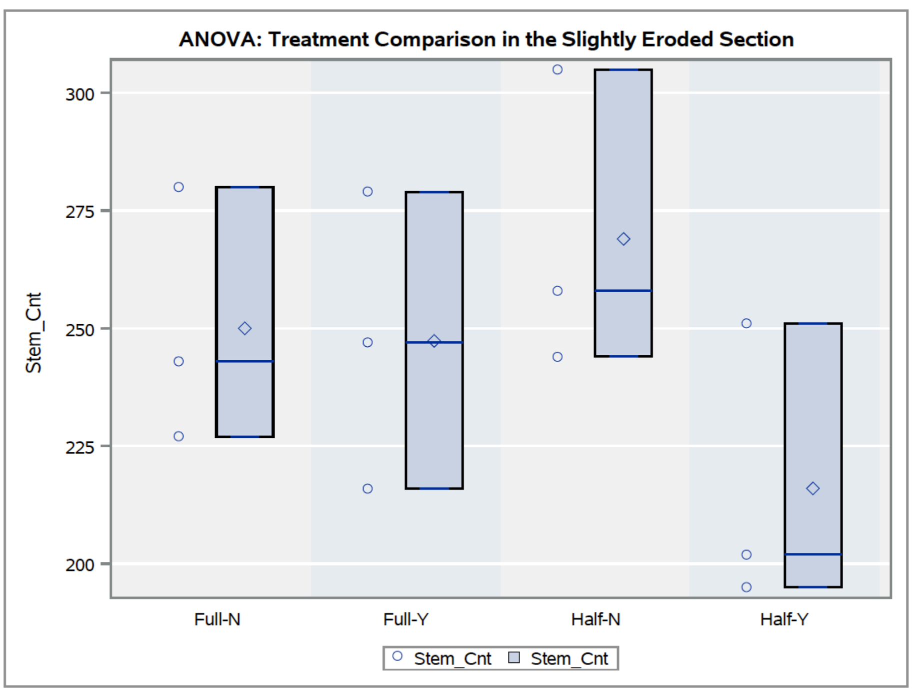


Figure 116. ANOVA box plot and value comparison of plant density (stem count) between the four fertilizer treatments within the Slightly Eroded block of Experiment 2.

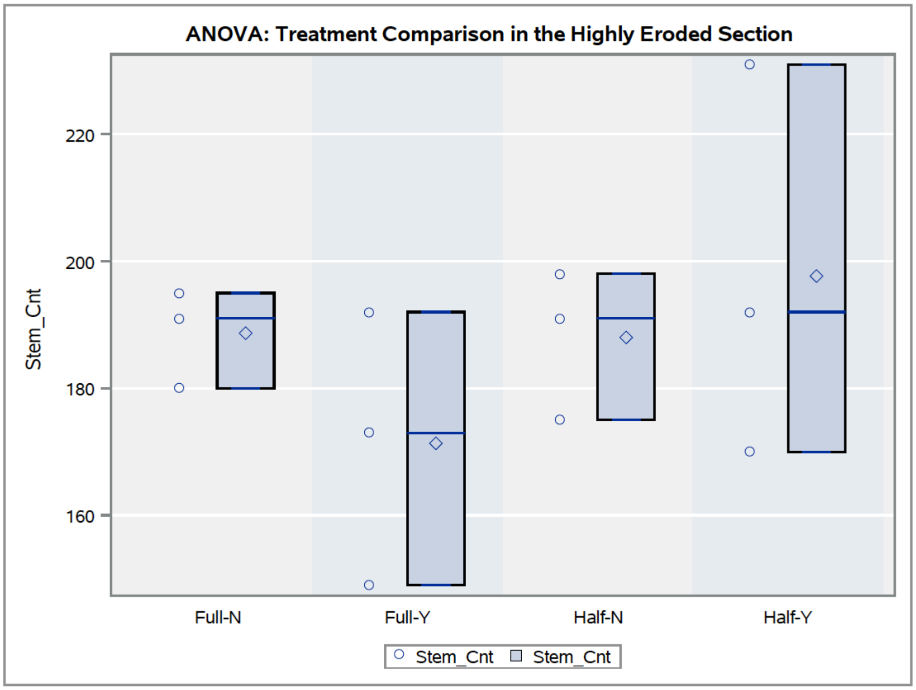


Figure 117. ANOVA box plot and value comparison of plant density (stem count) between the four fertilizer treatments within the Highly Eroded block of Experiment 2.

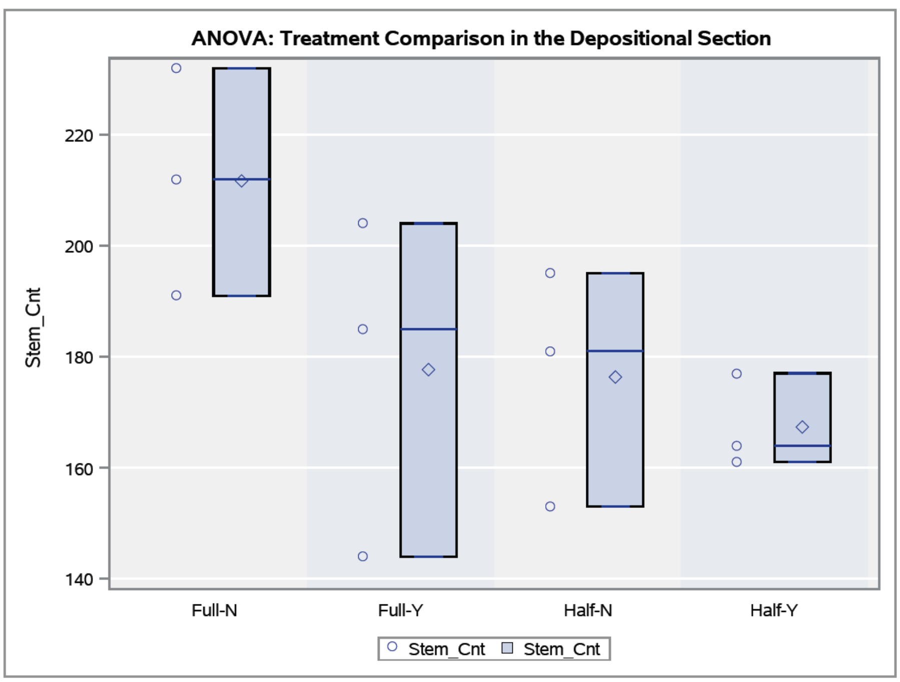


Figure 118. ANOVA box plot and value comparison of plant density (stem count) between the four fertilizer treatments within the Depositional block of Experiment 2.

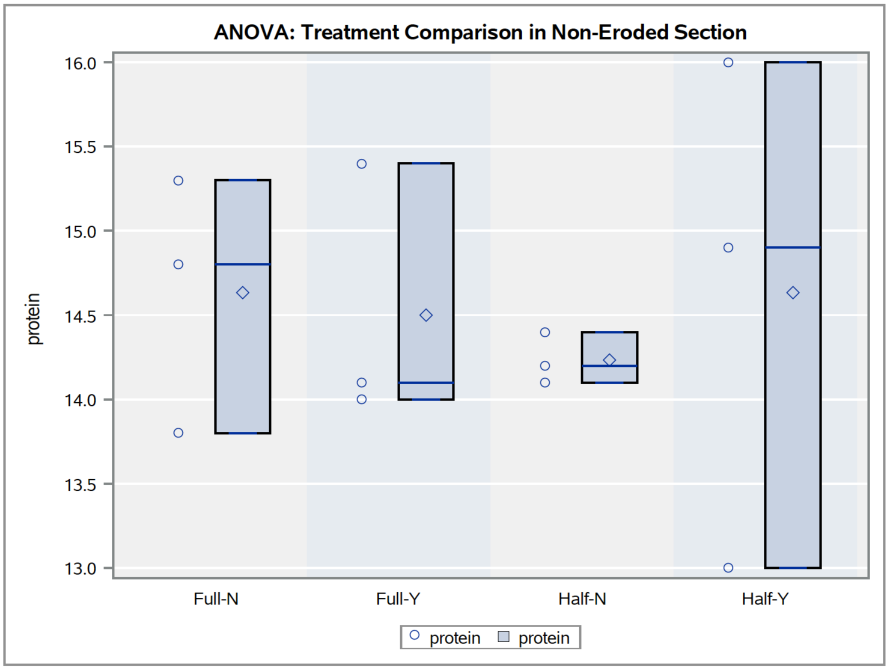


Figure 119. ANOVA box plot and value comparison of protein content (%) between the four fertilizer treatments within the Non-eroded block of Experiment 2.

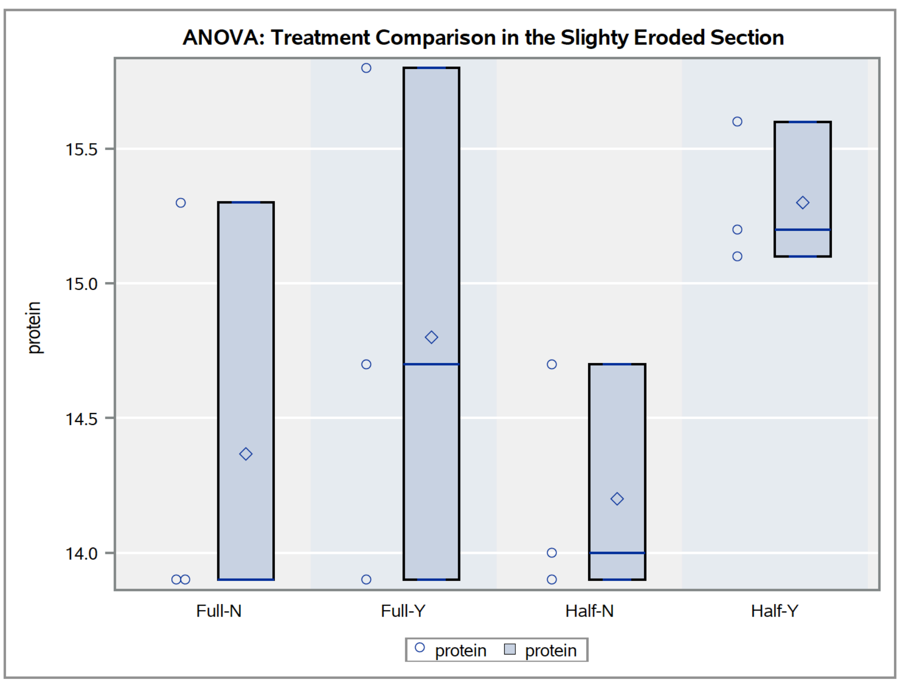


Figure 120. ANOVA box plot and value comparison of protein content (%) between the four fertilizer treatments within the Slightly Eroded block of Experiment 2.

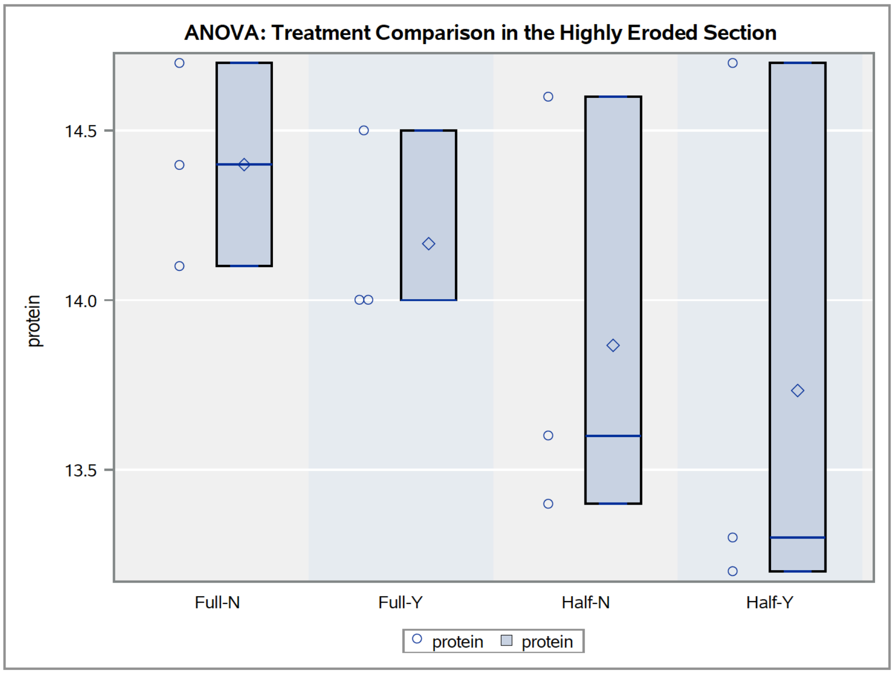


Figure 121. ANOVA box plot and value comparison of protein content (%) between the four fertilizer treatments within the Highly Eroded block of Experiment 2.

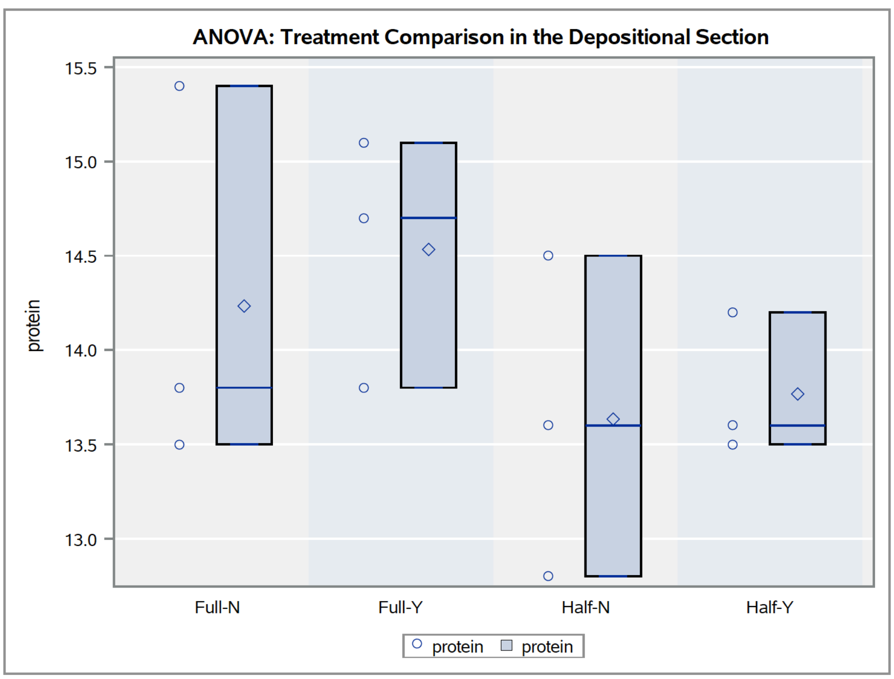


Figure 122. ANOVA box plot and value comparison of protein content (%) between the four fertilizer treatments within the Depositional block of Experiment 2.

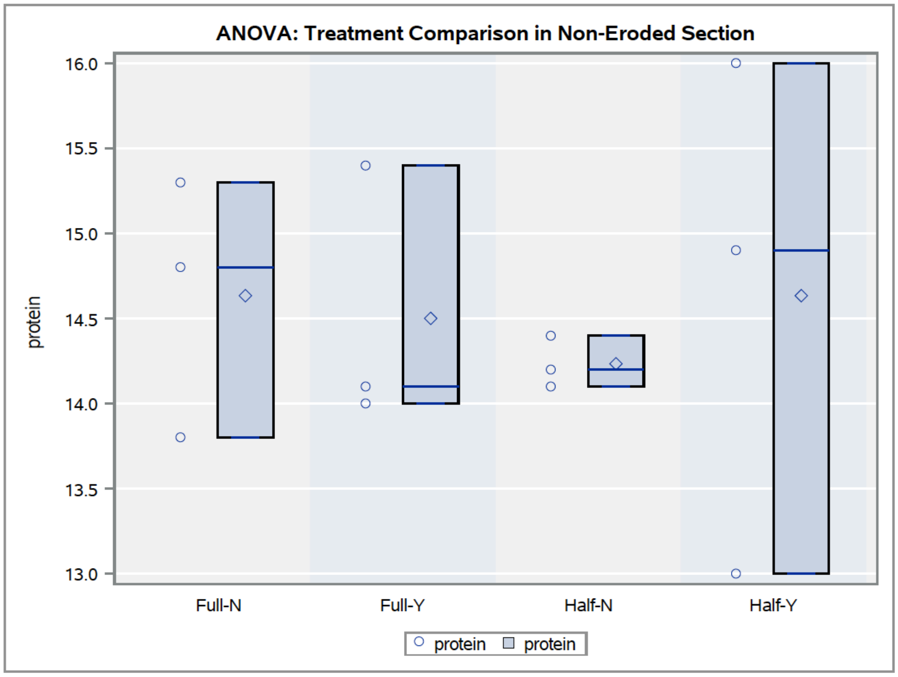


Figure 123. ANOVA box plot and value comparison of plant phosphorus (ppm) between the four fertilizer treatments within the Non-eroded block of Experiment 2 at harvest.

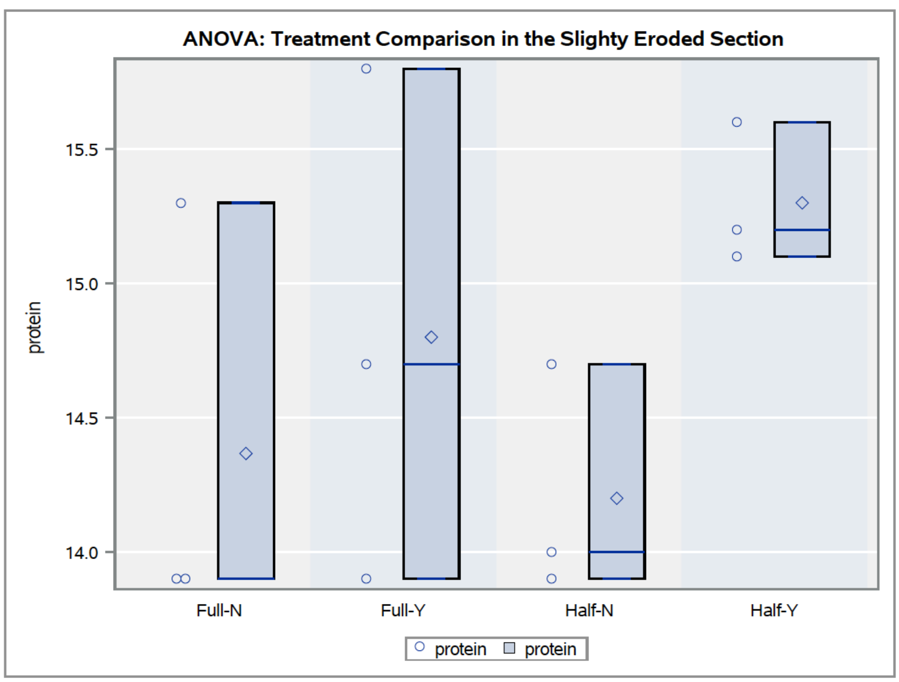


Figure 124. ANOVA box plot and value comparison of plant phosphorus (ppm) between the four fertilizer treatments within the Slightly Eroded block of Experiment 2 at harvest.

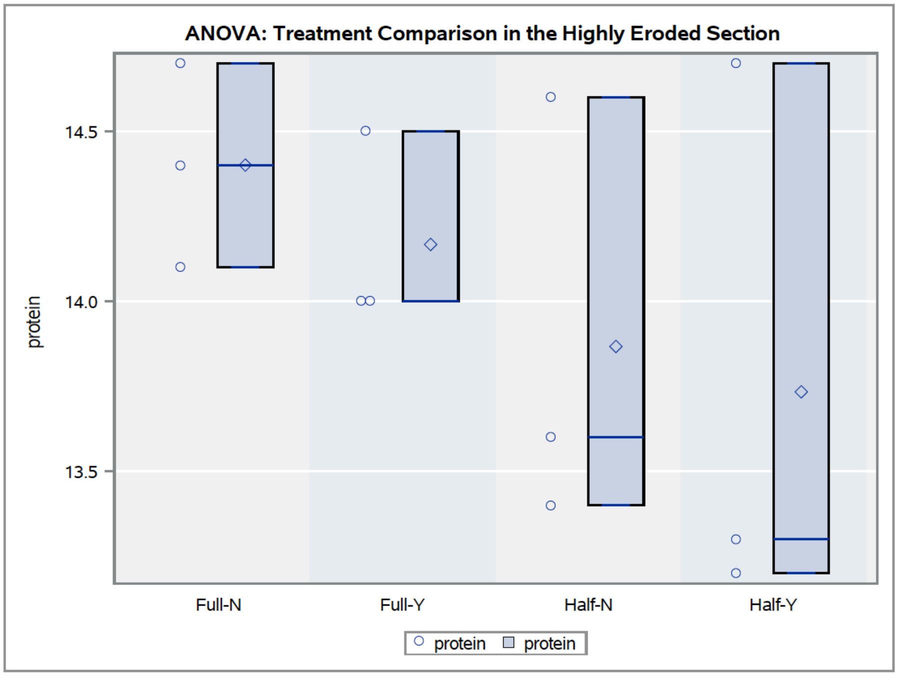


Figure 125. ANOVA box plot and value comparison of plant phosphorus (ppm) between the four fertilizer treatments within the Highly Eroded block of Experiment 2 at harvest.

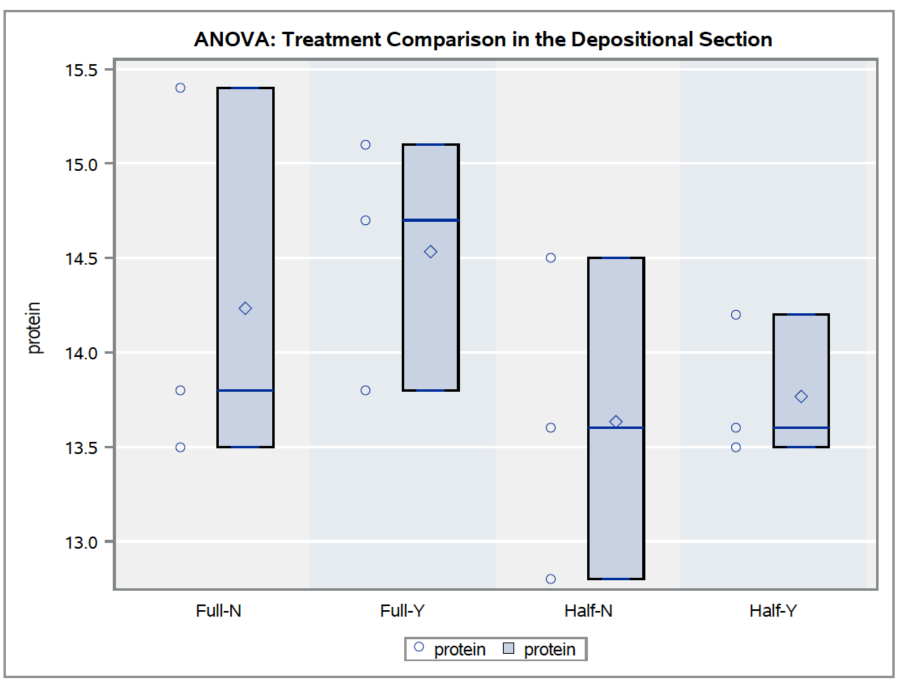


Figure 126. ANOVA box plot and value comparison of plant phosphorus (ppm) between the four fertilizer treatments within the Depositional block of Experiment 2 at harvest.

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Soil Series: Elevation and Agricultural Soil Test Survey of the Godfrey Dryland Experimental Farm, Clarkston, Utah

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(Graduate student, research technician and professor, respectively, PSC Department)

The Godfrey Dryland Experimental Farm (approximately 29 acres situated 1.5 miles south of Clarkston, Utah, on State Route 142) is the most recent addition to the research farm resources of the Utah Agricultural Experiment Station. Because it is the most recent experimental farm, there is no previous survey of the topographical and agricultural properties of the site and soil from which to make decisions on experimental study layout, equipment loading and access-way siting, suitability of soil physical and chemical conditions for specific study planning, etc. This survey details the areal distribution of soil type, topographical variation across the site and key agricultural soil test results to serve as baseline guidance information to potential researchers and farm managers.

Data for surficial features (topographic iso-lines, soil sampling site locations, and soil series distribution, respectively) are shown in Figures 1-3.

Agricultural soil test analyses were performed on 50 soil cores that were taken to a depth of 3 feet and divided into foot increments from the locations noted in Figure 2. The soil tests results were then mapped with each foot increment represented by a separate map. The analyses performed on these soils were as follows:

- Ammonium Bicarbonate (Olsen) extractable Phosphorus (P) – Figs. 4-6.
- Ammonium Acetate extractable Potassium (K) – Figs. 7-9.
- Saturated Paste extractable Sulfur as Sulfate (S) – Figs. 10-12.
- DTPA extractable Copper (Cu), Iron (Fe), Manganese (Mn) and Zinc (Zn) – Figs. 13-24.
- Saturated Paste extractable salinity – Figs. 25-27.
- Organic Matter (OM) by Loss on Ignition – Figs. 28-30.
- Saturated Paste pH – Figs 31-33.

The soil at the site is highly eroded Mendon series soil (with various slope sub-classes), with the exception of a small area in the northwest corner that is mapped as the Avon series. Both soils are lake terrace deposits of ancient Lake Bonneville and are derived from sandstone and limestone. The Avon series is closely related to the Mendon series with Mendon having a slightly higher lime content in the lower reaches of the argillic (high clay content) horizon, making it a calcic horizon at about 60 cm below the surface.

The fact that much of the topsoil on the steep side-slopes on the farm has been eroded exposing the highly calcareous subsoil horizons, the native fertility of these eroded regions is quite low. This is especially true for P, which is as low as 0.5 mg/kg in the most eroded areas. Organic matter (OM) levels are illustrative of the erosional and depositional areas within the farm. Native OM levels for the Mendon series are 2-3% in the upper horizons. Depositional areas have surface soil OM levels > 3% while erosional areas are < 2%. To help reduce further erosion at the site, a permanently vegetated waterway was established in the large channel running south to north in the west half of the farm.

DATA MAPS

Figure 1. Godfrey Farm topographic iso-lines (meters).

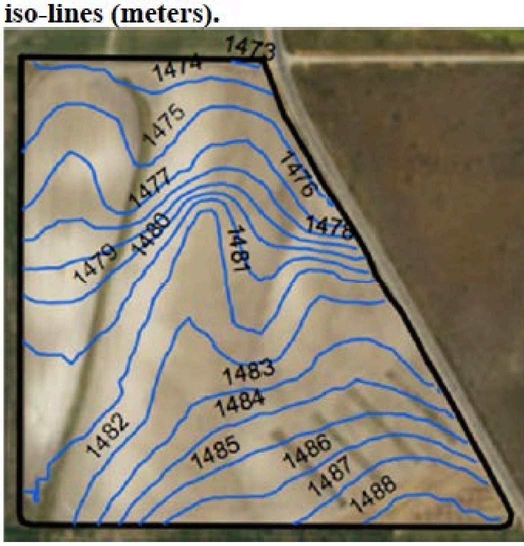


Figure 2. Sample site locations.

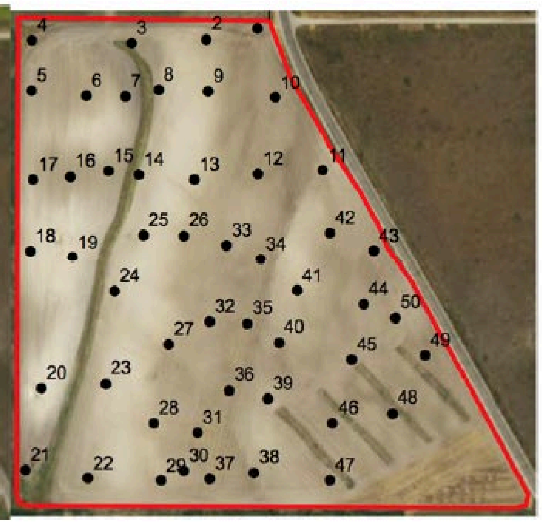
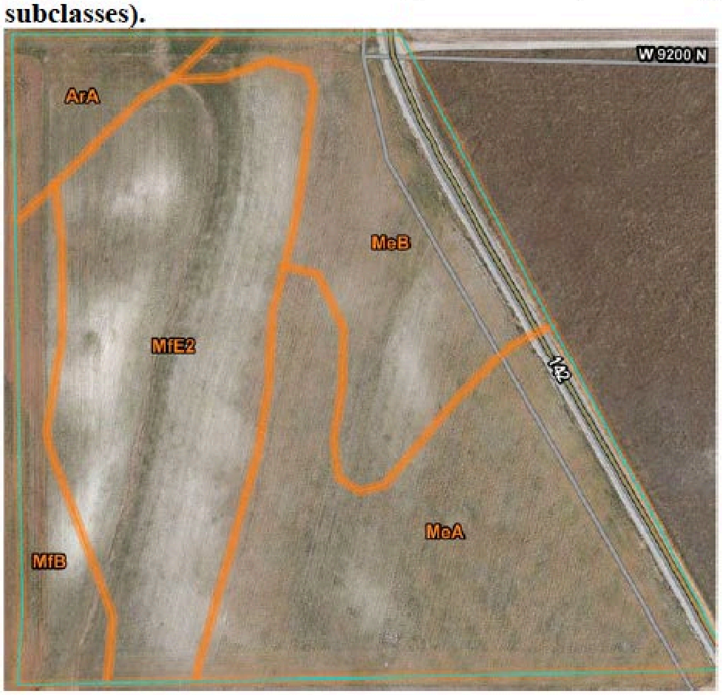
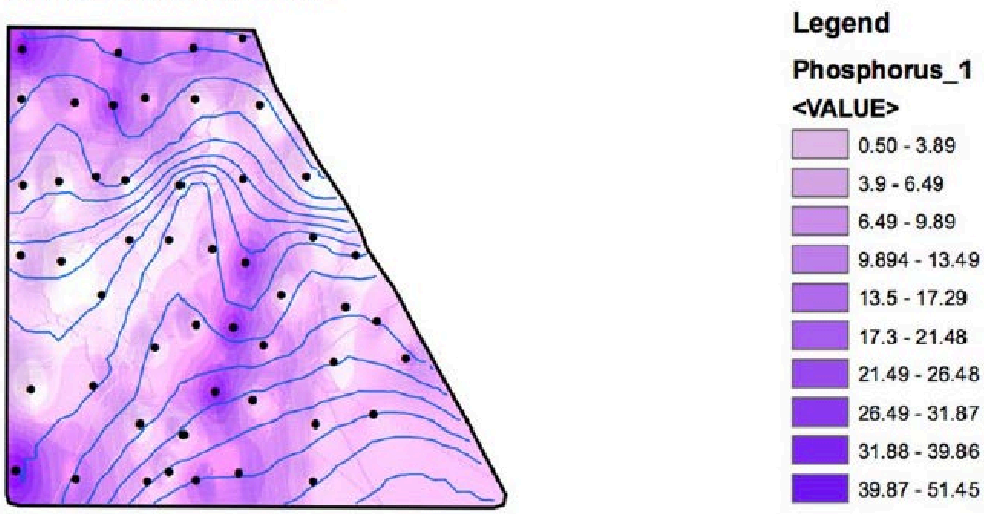


Figure 3. Soil series distribution (M = Mendon, A = Avon, other letters indicate slope subclasses).



PHOSPHORUS (Ammonium Bicarbonate Extractable; mg/kg)

Figure 4. P levels at 1 foot.



NOTE: For context, the sufficiency level for dryland small grain production is 12 mg/kg.

Figure 5. Phosphorus at 2 feet.

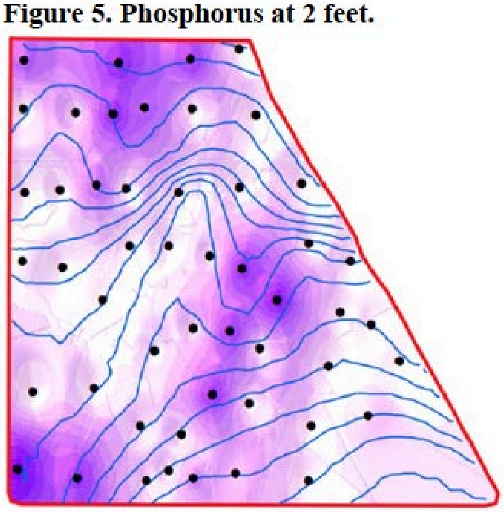
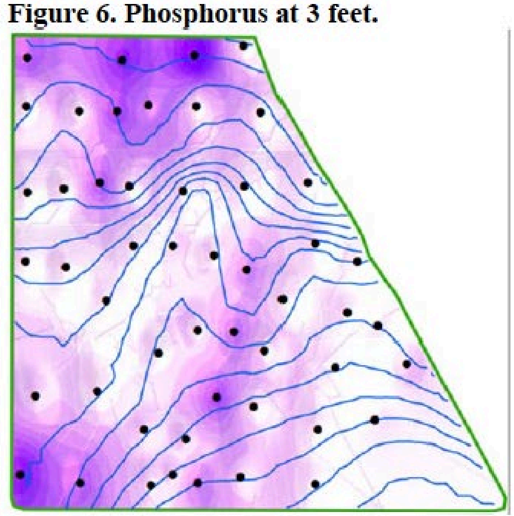
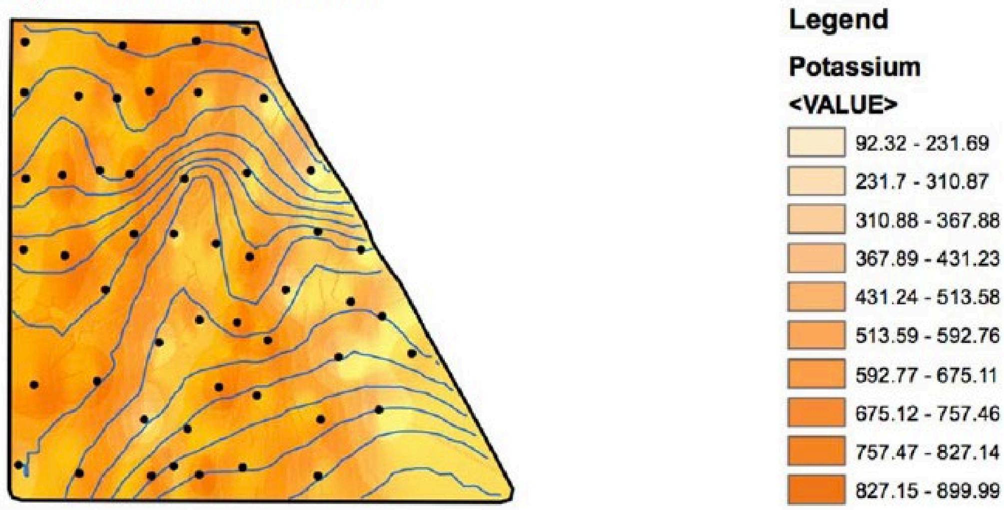


Figure 6. Phosphorus at 3 feet.



POTASSIUM (Ammonium Acetate Extractable; mg/kg)

Figure 7. Potassium at 1 foot.



NOTE: For context, the sufficiency level for dryland small grain production is 100 mg/kg.

Figure 8. Potassium at 2 feet.

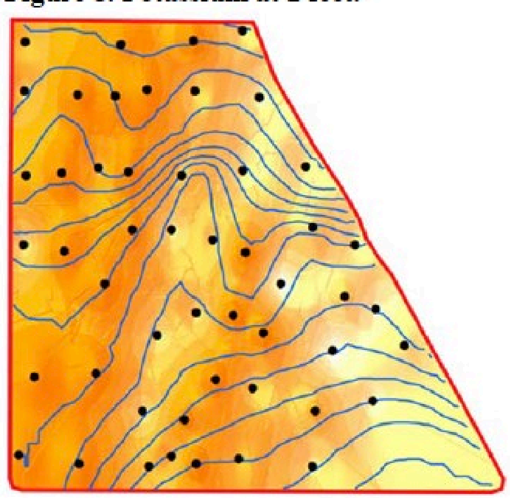
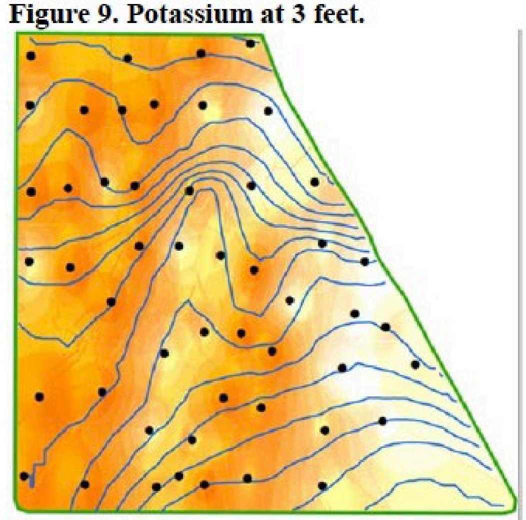
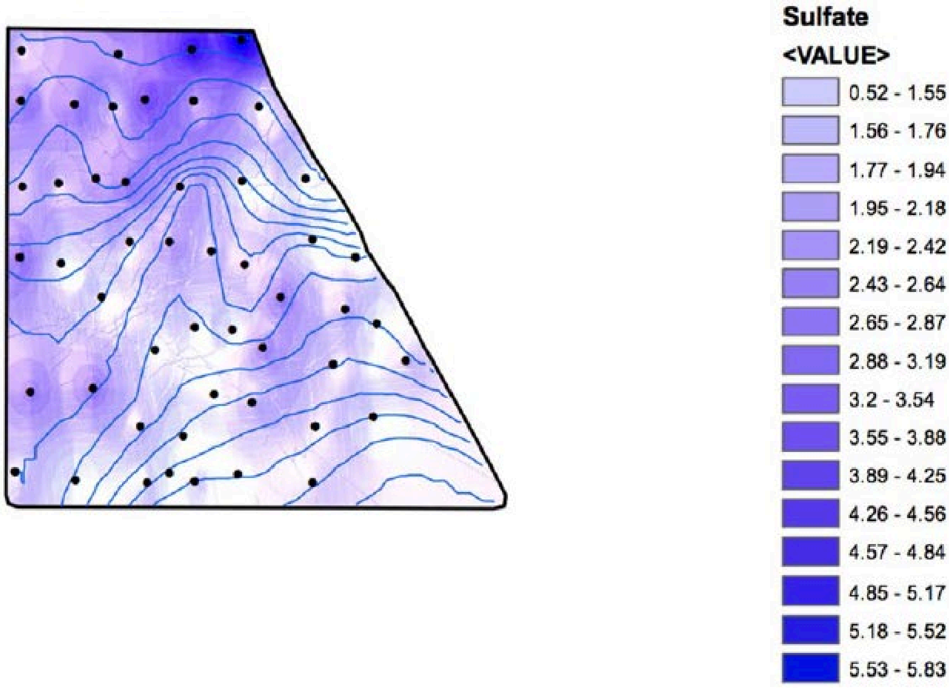


Figure 9. Potassium at 3 feet.



SULFUR as SULFATE (Saturated Paste Extractable; mg/kg)

Figure 10. Sulfate at 1 foot.



NOTE: For context, the sufficiency level for dryland small grain production is 8 mg/kg.

Figure 11. Sulfate at 2 feet.

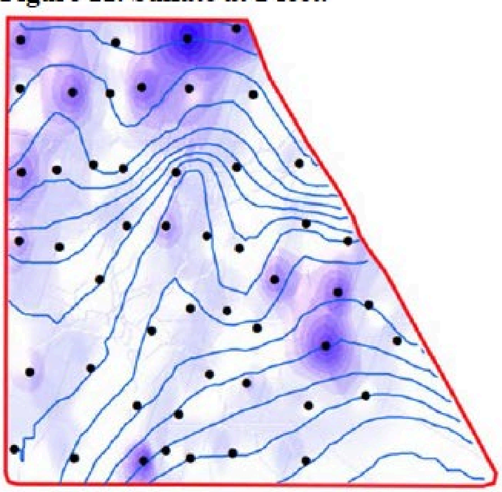
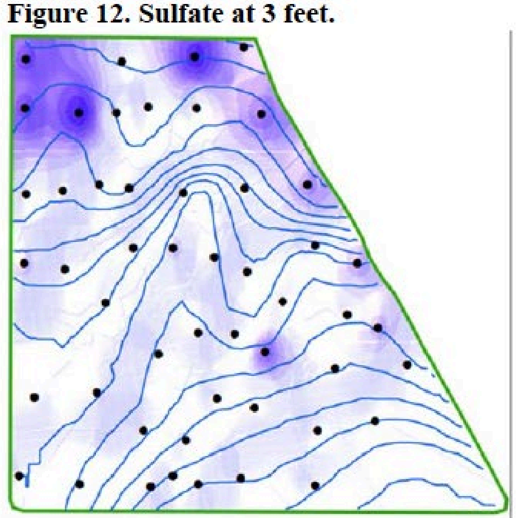
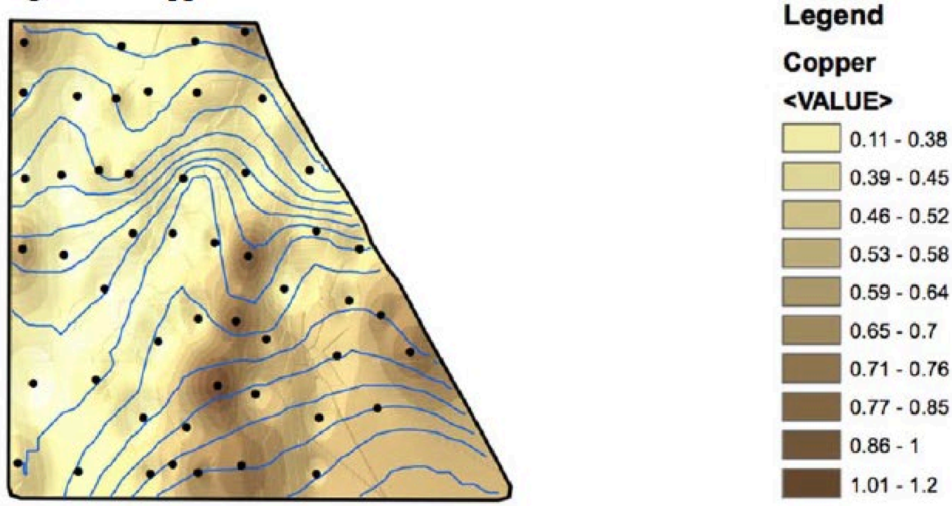


Figure 12. Sulfate at 3 feet.



COPPER (DTPA Extractable; mg/kg)

Figure 13. Copper at 1 foot.



NOTE: For context, the sufficiency level for dryland small grain production is 0.2 mg/kg.

Figure 14. Copper at 2 feet.

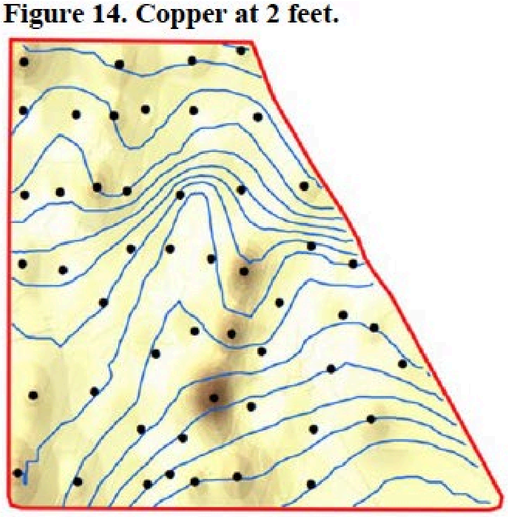
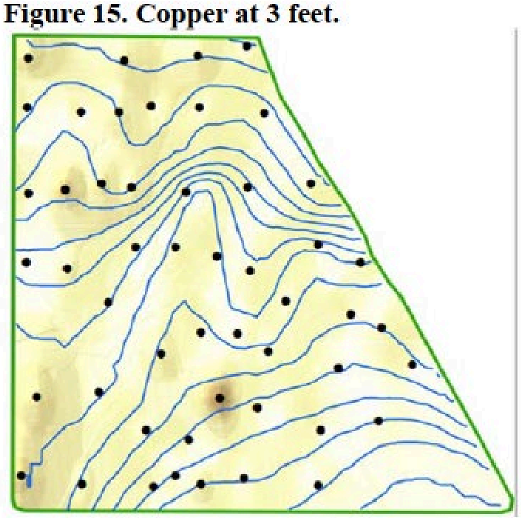
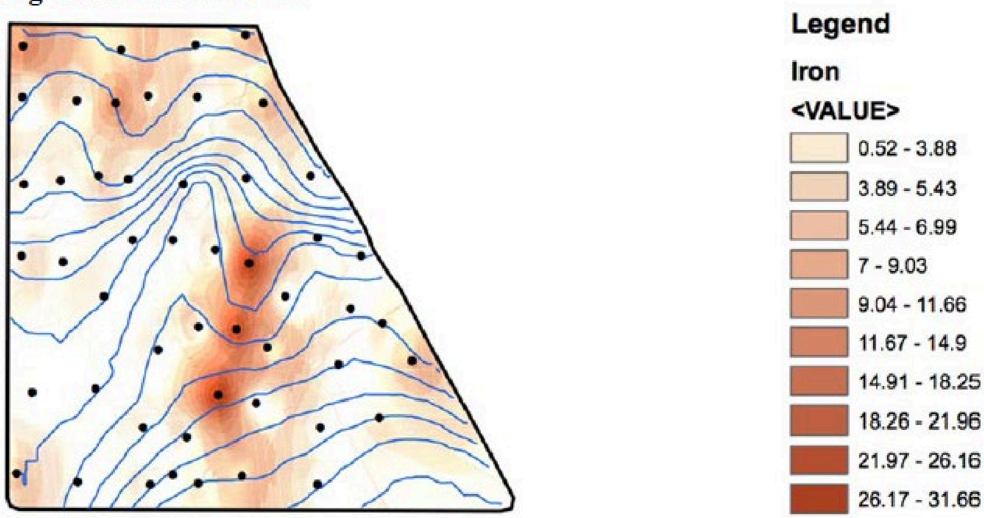


Figure 15. Copper at 3 feet.



IRON (DTPA Extractable; mg/kg)

Figure 16. Iron at 1 foot.



NOTE: For context, the sufficiency level for dryland small grain production is 5 mg/kg.

Figure 17. Iron at 2 feet.

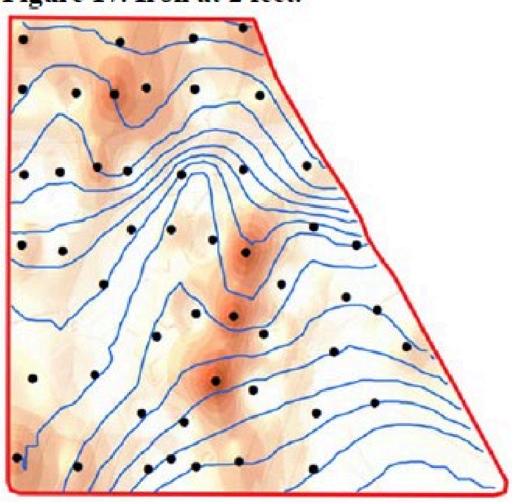
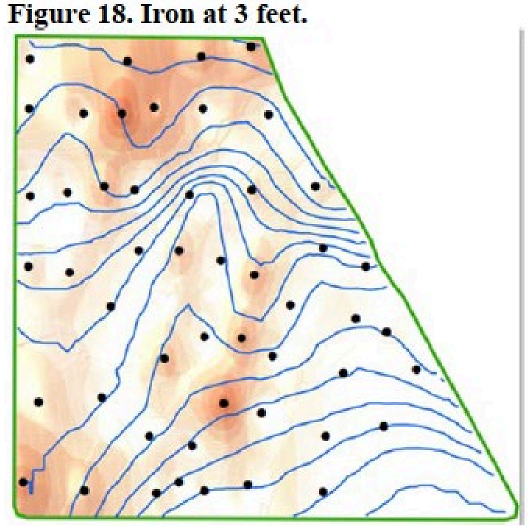
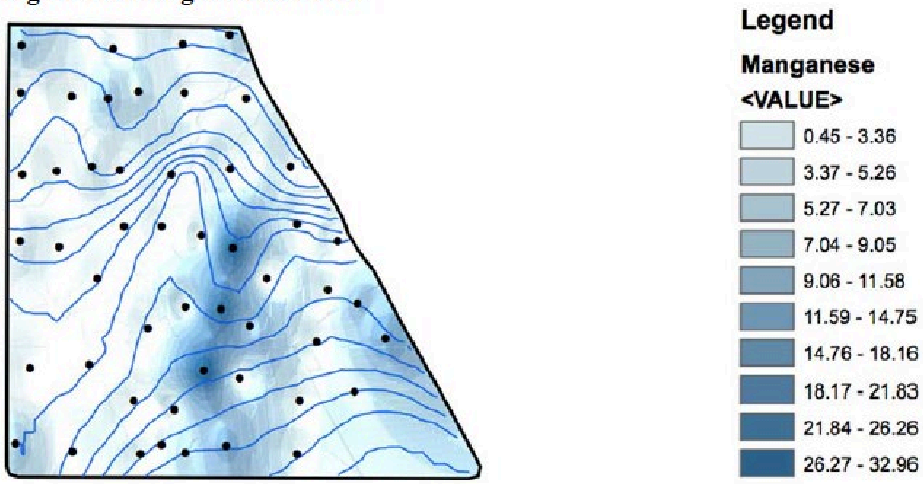


Figure 18. Iron at 3 feet.



MANGANESE (DTPA Extractable; mg/kg)

Figure 19. Manganese at 1 foot.



NOTE: For context, the sufficiency level for dryland small grain production is 1 mg/kg.

Figure 20. Manganese at 2 feet.

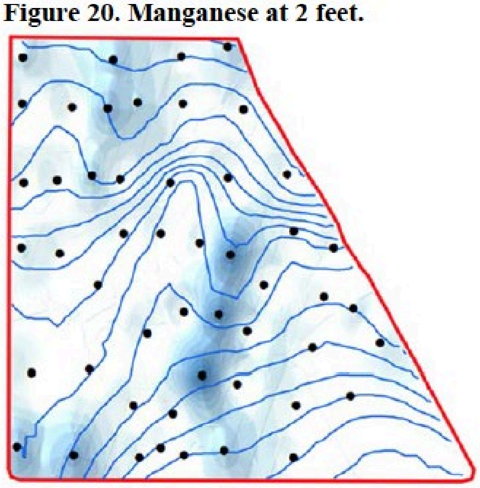
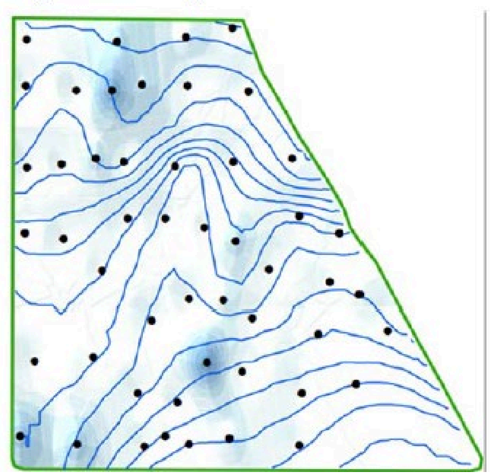
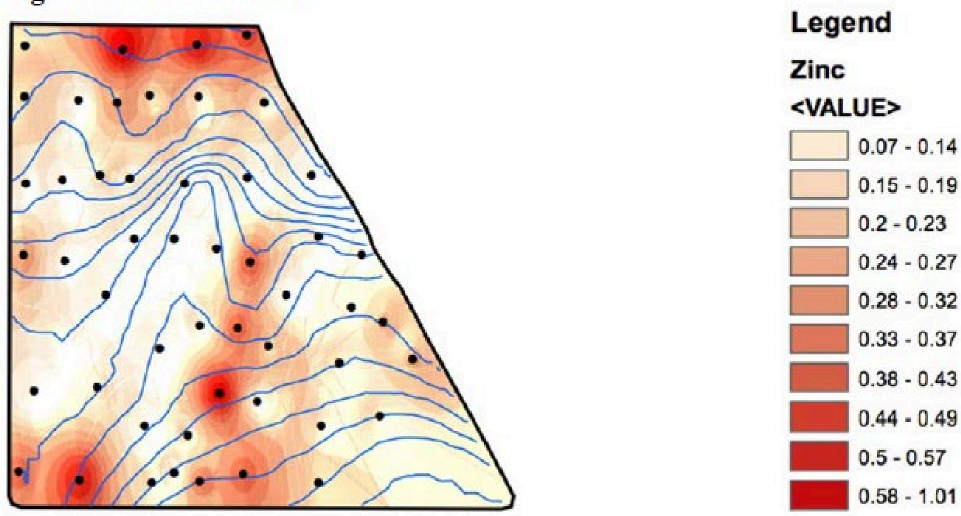


Figure 21. Manganese at 3 feet.



ZINC (DTPA Extractable; mg/kg)

Figure 22. Zinc at 1 foot.



NOTE: For context, the sufficiency level for dryland small grain production is 1 mg/kg.

Figure 23. Zinc at 2 feet.

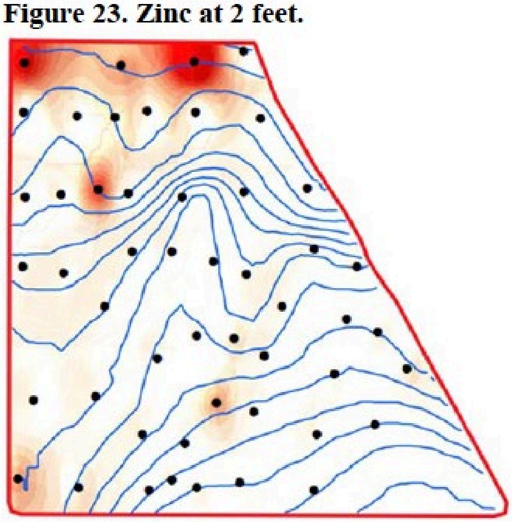
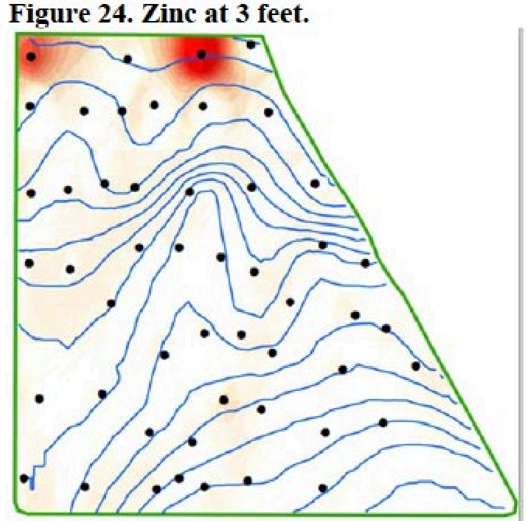
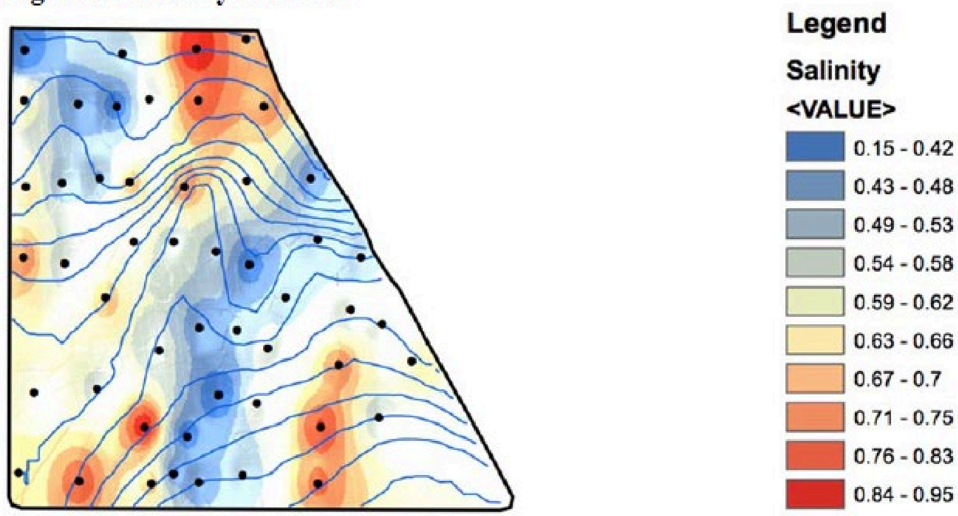


Figure 24. Zinc at 3 feet.



SALINITY (Saturated Paste Extractable; dS/m)

Figure 25. Salinity at 1 foot.



NOTE: For context, the upper acceptable level for dryland small grain production is 3 dS/m.

Figure 26. Salinity at 2 feet.

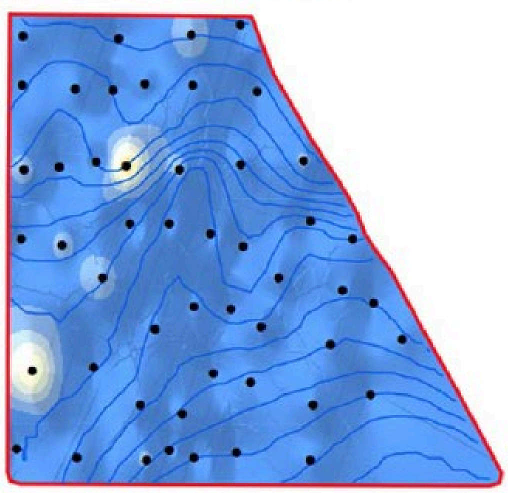
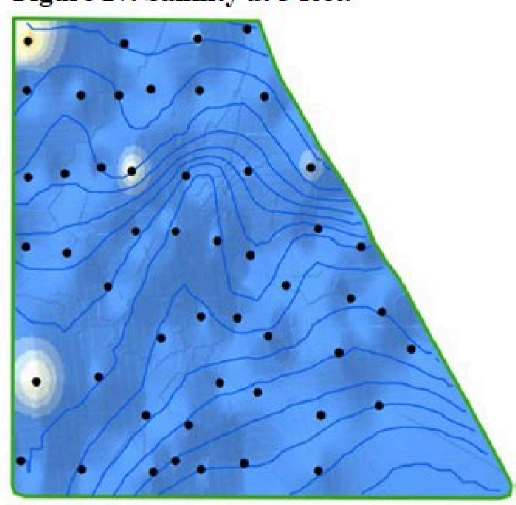
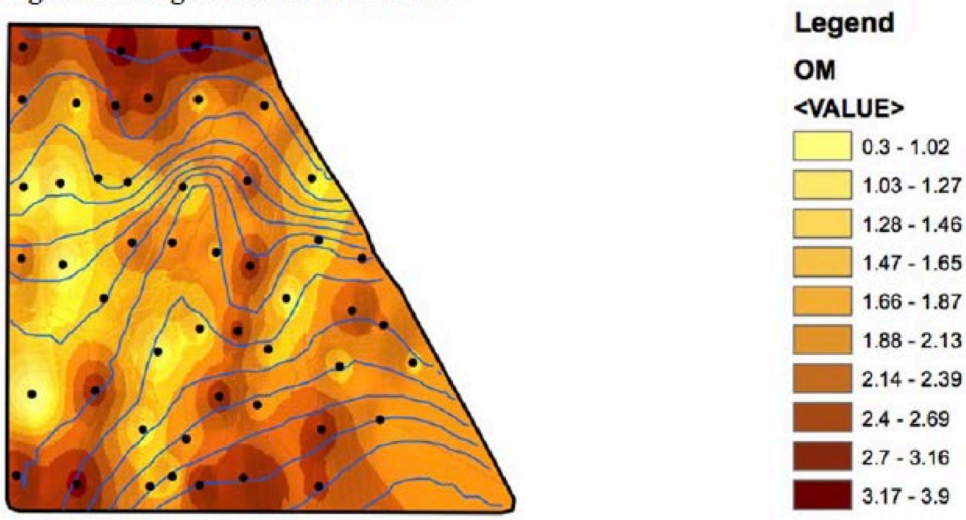


Figure 27. Salinity at 3 feet.



ORGANIC MATTER (Loss on Ignition; %)

Figure 28. Organic Matter at 1 foot.



NOTE: For context, there are no limits associated with organic matter content, but lower values in the surface soil layer are generally evidence of topsoil erosion. Subsurface layers are typically low in organic matter in the arid/semi-arid western U.S.

Figure 29. Organic Matter at 2 feet.

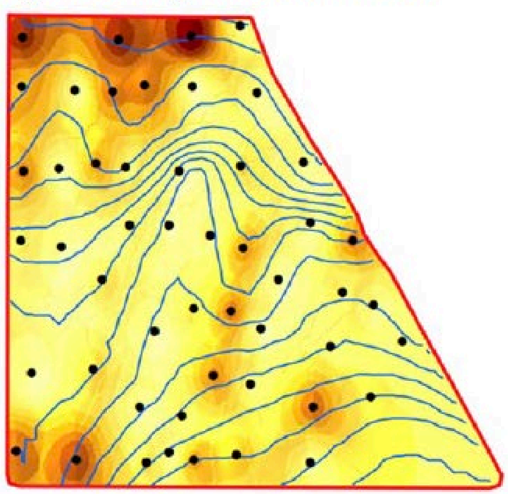
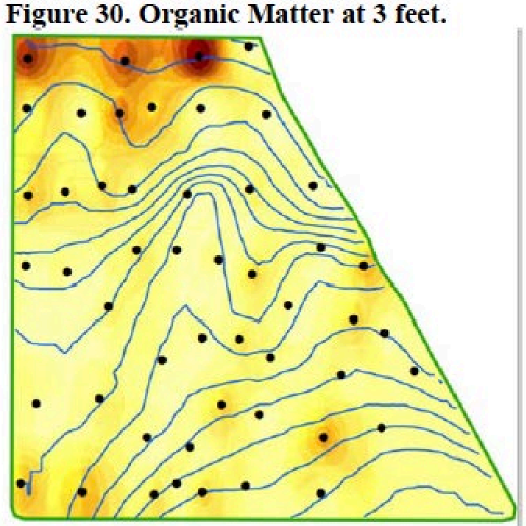
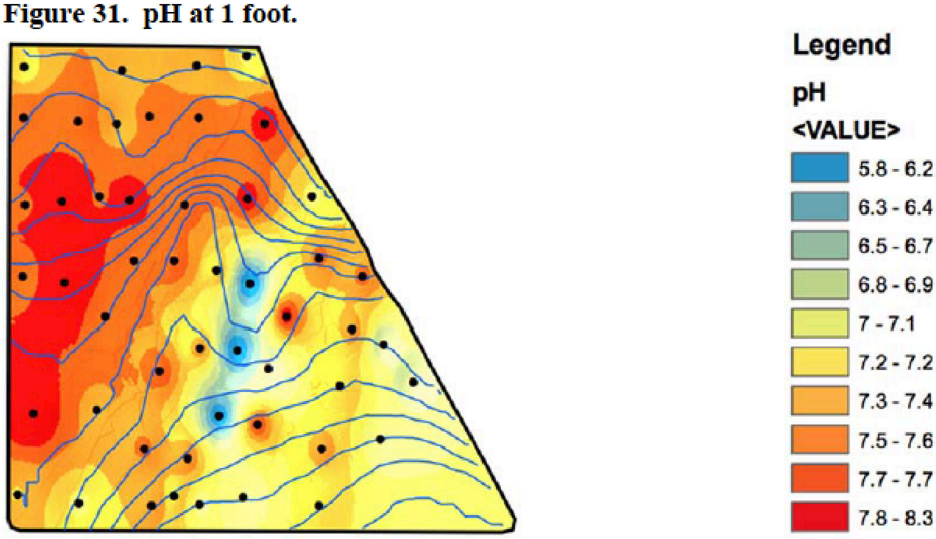


Figure 30. Organic Matter at 3 feet.



pH (Saturated Paste)

Figure 31. pH at 1 foot.



NOTE: For context, the normal pH range for crop production is 6.1 to 8.4.

Figure 32. pH at 2 feet.

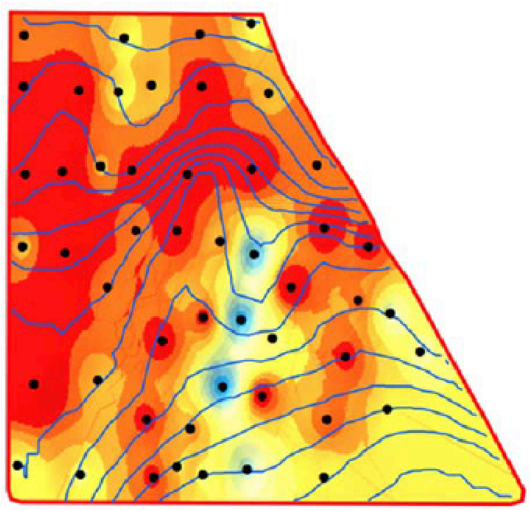


Figure 33. pH at 3 feet.