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KANSAS FERTILIZER RESEARCH 2022

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KANSAS FERTILIZER RESEARCH 2022

Contents

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Nitrogen Fertilizer Timing and Phosphorus and Potassium Fertilization Rates for Established Endophyte-Free Tall Fescue: Year 3

D.W. Sweeney, B. Pedreira, J.K. Farney, J.L. Moyer, and D.A. Ruiz Diaz[1]

Summary

Tall fescue production was measured during the third production year of a study with locations started in fall of 2016 and fall of 2017. Phosphorus (P) fertilization rate affected spring harvest yield at Site 1, but not at Site 2. Applying nitrogen (N) in late fall or late winter resulted in greater spring yields than applying N in spring or not applying N. However, fall harvest yields at Site 1 were greater with spring N application, but not at Site 2. The third-year tall fescue total yield rank as affected by N fertilizer timing was late winter>late fall=spring>no N at Site 1 and late winter=late fall>spring>no N at Site 2.

Introduction

Tall fescue is the major cool-season grass in southeastern Kansas. Perennial grass crops, as with annual row crops, rely on proper fertilization for optimum production; however, meadows and pastures are often under-fertilized and produce low quantities of low-quality forage. The objective of this study was to determine the effect of N fertilizer timing and P and potassium (K) fertilization rates on tall fescue yields.

Experimental Procedures

The experiment was conducted on two adjacent sites of established endophyte-free tall fescue beginning in the fall of 2016 (Site 1) and 2017 (Site 2) at the Parsons Unit of the Kansas State University Southeast Research and Extension Center. The soil at both sites was a Parsons silt loam. The experimental design was a split-plot arrangement of a randomized complete block. The six whole plots received combinations of P_2O_5 and K_2O fertilizer rates allowing for two separate analyses: 1) four rates of P_2O_5 consisting of 0, 25, and 50 lb/a each year and a fourth treatment of 100 lb/a only applied at the beginning of the study; and 2) a 2 × 2 factorial combination of two rates of P_2O_5 (0 and 50 lb/a) and two levels of K_2O (0 and 40 lb/a). Subplots were four application timings of N fertilization consisting of none, late fall, late winter, and spring (E2 growth stage). Phosphorus and K fertilizers were broadcast applied in the fall as 0-46-0 (triple superphosphate) and 0-0-60 (potassium chloride). Nitrogen, as 46-0-0 (urea) solid at 120 lb N/a, was broadcast applied to appropriate plots on December 4, 2018, March 18, 2019, and April 25, 2019, at Site 1. Nitrogen was applied on December 5, 2019, March 3, 2020, and April 15, 2020, at Site 2. Third-year harvest dates from each site were as follows: (1) spring yield was measured at R4 (half bloom) on May 17, 2019, at

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Site 1 and at R5 (post anthesis) on May 17, 2020, at Site 2; (2) fall harvest was taken on September 10, 2019, at Site 1 and on October 22, 2020, at Site 2.

Results and Discussion

In the third year of the study at Site 1 in 2019, spring harvest and total yield of tall fescue was increased by P fertilization, but was unaffected by rate (Table 1). Spring harvest yield was greatest when N was applied either in late fall or late winter. Even though applying N fertilizer at the E2 growth stage in spring resulted in greater yield compared with no N, delaying N application resulted in about a 35% reduction in spring yield compared with the more traditional timings of either late fall or late winter. However, fall harvest tall fescue yield increased with more recent N applications. Average annual total tall fescue yield was approximately doubled by applying N. Late winter application resulted in greatest total yield than with either fall or spring (E2) fertilization.

Third-year tall fescue spring harvest, fall harvest, or total yields in 2020 at Site 2 were unaffected by P fertilization (Table 2). As for the third year at Site 1 (Table 1), spring tall fescue yield was greatest with late fall or late winter N fertilization compared with N fertilizer applied at the E2 growth stage or with no N (Table 2). In contrast to results from Site 1 (Table 1), there were no differences in fall yield as affected by N fertilizer treatments (Table 2). Third-year tall fescue total yield mirrored spring yields.

Potassium fertilization resulted in inconsistent and small third-year yield responses in different harvests at the two sites (data not shown). Adding 40 lb K_2O/a resulted in less than 0.40 ton/a increase in yield in the fall harvest at Site 1 in 2019 and in the R4 harvest at Site 2 in 2020.

Acknowledgment

This work is supported by the U.S. Department of Agriculture National Institute of Food and Agriculture, Hatch project KS00-0104-HA.

Table 1. Third-year yield of established tall fescue in the spring (R4-half bloom) and fall 2019 as affected by P_2O_5 fertilization rates and nitrogen (N) application timing at Site 1

Treatment	Spring harvest	Fall harvest	Total harvest (R4 + Fall)
P_2O_5 (lb/a)	---------------- ton/a, 12% moisture ----------------		
0	1.26	1.79	3.05
25	2.04	1.64	3.68
50	2.18	1.60	3.77
100[1]	1.92	1.46	3.38
LSD (0.05)	0.35	NS	0.40
N application timing			
None	0.77	1.28	2.05
Late fall	2.50	1.43	3.92
Late winter	2.53	1.73	4.25
Spring	1.61	2.05	3.66
LSD (0.05)	0.22	0.13	0.27

[1]The 100 lb P_2O_5/a rate was only applied at the beginning of the study (fall 2016).

Table 2. Third-year yield of established tall fescue in the spring (R4-half bloom) and fall 2020 as affected by P_2O_5 fertilization rates and nitrogen (N) application timing at Site 2

Treatment	Spring harvest	Fall harvest	Total harvest (R4 + Fall)
P_2O_5 (lb/a)	---------------- ton/a, 12% moisture ----------------		
0	2.00	0.98	2.98
25	2.24	0.99	3.23
50	2.53	1.05	3.59
100[1]	2.34	1.07	3.41
LSD (0.05)	NS	NS	NS
N application timing			
None	1.04	1.06	2.09
Late fall	2.93	1.04	3.97
Late winter	3.01	1.01	4.00
Spring	2.13	0.99	3.14
LSD (0.05)	0.22	NS	0.31

[1]The 100 lb P_2O_5/a rate was only applied at the beginning of the study (fall 2017).

Evaluation of Soil Test Phosphorus Extractants and Tissue Analysis for Corn

G.A. Roa-Acosta and D.A. Ruiz Diaz

Summary

The objective of this study was to evaluate the relationship of four different soil test phosphorus methods (Mehlich 3, Bray 1, Bray 2, and Haney H3A) for corn production, and determine critical P tissue concentration at different growing stages. The experiment was conducted at 12 locations, and the fertilizer treatments consisted of five phosphorus fertilizer rates applied by broadcast pre-plant. Soil samples were collected at 0- to 6-in. depth, then samples were collected before treatment application by block. Tissue samples were collected at the V6 and R1 growth stages. The relationship between the different soil test phosphorus methods and the R^2 varies between 0.24–0.93. Mehlich 3 and Bray 1 have a higher correlation, and Bray 1 and Bray 2 have a lower correlation. Linear plateau determined the critical phosphorus levels for the V6 growth stage was 0.42%, and for the R1 stage was 0.22%. The relationship between the concentration at V6 and R1 was moderately correlated with $R^2 = 0.62$, having a higher phosphorus concentration in the early stage.

Introduction

Phosphorus (P) is a macronutrient that plays several essential roles in plants and is required in relatively large quantities. The available fraction of the total soil phosphorus is typically low, and phosphorus fertilizer is needed to meet crop phosphorus requirements. Understanding the adequate phosphorus rate in corn production is necessary to sustain high yield potentials. Phosphorus fertilizer may not be enough to replace what the crop is removing in the long term if rates are too low. Therefore, soil testing should be performed to determine the correct fertilizer rate for an economic yield response (Mallarino and Blackmer, 1992; Coelho et al., 2019). Critical concentrations of soil test phosphorus (STP) and critical tissue concentrations can be used to identify the response to phosphorus fertilization that should be expected. Critical levels could depend on many factors, including specific crops as well as soil characteristics, environmental, and other factors. Determining an appropriate concentration of STP and its relationship is a fundamental step required to make fertilizer recommendations. Error in determining the critical concentration results in an incorrect decision relating to fertilizer application (Mallarino and Blackmer, 1992). New STP methods for corn have not been evaluated recently in Kansas. The objective of this study was to evaluate the relationship of four different STP methods for corn production and determine critical P tissue concentration at different growing stages.

Procedures

Field experiments were conducted at 12 locations across Kansas (Table 1). The experimental design was a randomized complete block design with four replications; plots were 10-ft width × 40-ft length. Fertilizer treatments were four rates of P fertilizer (30, 60, 90, and 120 lb/a of P_2O_5), using mono-ammonium phosphate (MAP) (11-52-0). Five treatments were established, including one control; all fertilizer was applied one time by broadcast pre-plant. Before treatment application, soil samples were collected, and composited by blocks at 0- to 6-in. depth using a hand probe. Corn was harvested, and yield was calculated and corrected to 15.5% moisture. Soil samples were dried at 104°F (40°C), plant tissue samples were dried at 140°F (60°C), and both were ground to pass a 2-mm sieve. Soil samples were analyzed for pH, Mehlich 3, Bray 1, Bray 2 and Haney H3A, each with their respective methods extractions. Extractable P was measured at 660 nm using a colorimeter. The plant tissue samples were digested using nitric-perchloric acid digestion and analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Relationships between different STP levels were evaluated using linear regression models. Critical levels were performed between relative yield and plant tissue concentrations using linear plateau models. Data analyses were performed in R version 4.1.

Results

Correlations Between Different Soil Test Phosphorus Methods

Results showed that methods Mehlich 3 vs. Bray 1 and Mehlich 3 vs. Haney H3A were strongly correlated ($R^2 = 0.93$ and 0.80, respectively) and exhibit a linear relationship (Figure 1a, and Figure 1b). The Bray 1 and Haney H3A relationship was moderately correlated with $R^2 = 0.60$ (Figure 1c). All methods correlated with Bray 2 (Mehlich 3 vs. Bray 2, Bray 1 vs. Bray 2, and Haney H3A vs. Bray 2) were poorly correlated, with $R^2 = 0.31$, 0.24 and 0.47, respectively (Figure 1d, 1e, 1f).

Critical Phosphorus Concentrations

The critical tissue P levels for the whole plant at the V6 growth stage were 0.42 %, and the model R^2 value was 0.26 (figure 2a), as determined by a linear plateau. The critical P levels for the ear leaf at the R1 stage were 0.22%, and the model R^2 value was 0.18 (Figure 1b). Both R^2 values are low, with the ear leaf at R1 having lower value than the whole plant at V6. Stammer and Mallarino (2018) found a similar critical P concentration with a linear plateau for the whole plant at growth stage V6 of 0.48% and 0.25% for the ear leaf at the R1.

The relationship between the concentration in the whole plant at V6 and the ear leaf at R1 was moderately correlated with $R^2 = 0.62$ (Figure 3). The P tissue concentrations ranged from 0.25 to 0.64% for V6 and 0.15 to 0.42% for R1. The tissue P concentrations at the V6 stage were higher than at the R1 stage; this suggests that the value of tissue testing to assess plant phosphorus nutritional status may differ during the growing season.

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Table 1. Study sites and soil properties for corn studies in 2021

Location	County	Soil series	pH	Mehlich 3 P	Bray 1 P	Bray 2 P	Haney H3A P
				ppm			
1	Republic	Crete	6.5	5	6	31	5
2	Republic	Crete	6.1	7	8	41	7
3	Franklin	Woodson	6.0	9	11	28	9
4	Dickinson	Geary	5.8	21	23	65	14
5	Shawnee	Bismarckgrove	7.6	21	19	70	23
6	Gove	Keith	7.2	20	19	183	25
7	Logan	Keith	6.4	22	21	145	23
8	Gove	Keith	6.6	25	23	160	30
9	Gove	Ulysses	6.2	35	37	148	26
10	Saline	Longford	5.4	38	41	79	23
11	Riley	Bourbonais	6.3	45	34	134	55
12	Brown	Kennebec	6.3	45	43	96	40

Samples were collected at 0- to 6-in. depth.

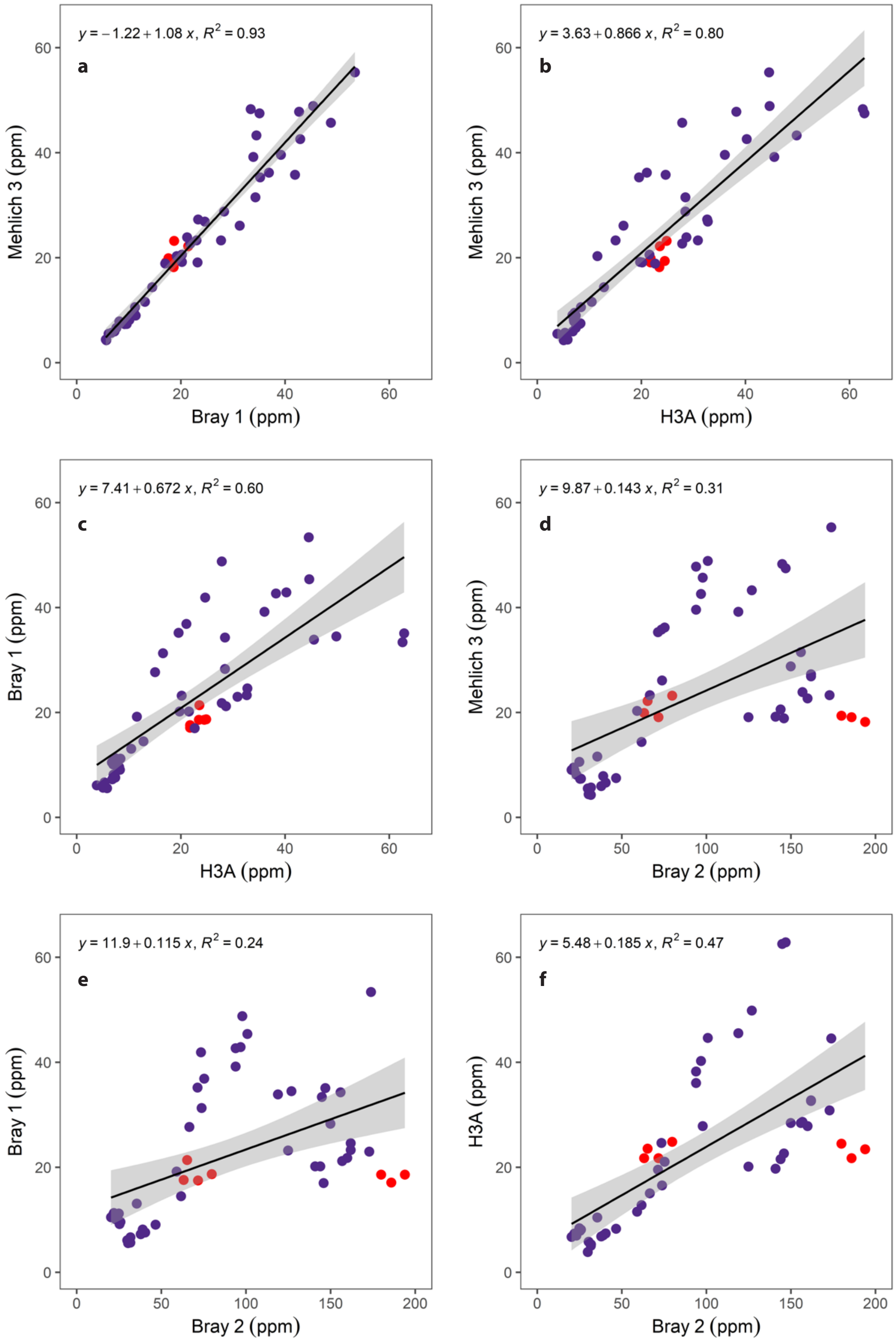

Figure 1. Relationship between different soil test phosphorus methods (a) Mehlich 3 vs. Bray 1, (b) Mehlich 3 vs. H3A, (c) Bray 1 vs. H3A, (d) Mehlich 3 vs. Bray 2, (e) Bray 1 vs. Bray 2, and (f) H3A vs. Bray 2. Soils with a pH > 7.0 are indicated by red dots.

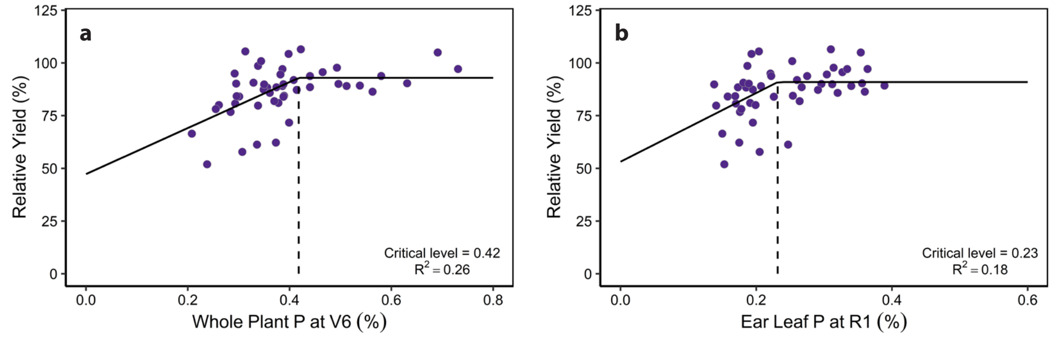

Figure 2. Relationship between relative yield and the P concentration of (a) whole plants at the V6 growth stage or (b) ear leaf blades at the R1 stage. Vertical lines indicate a critical P level with a linear plateau.

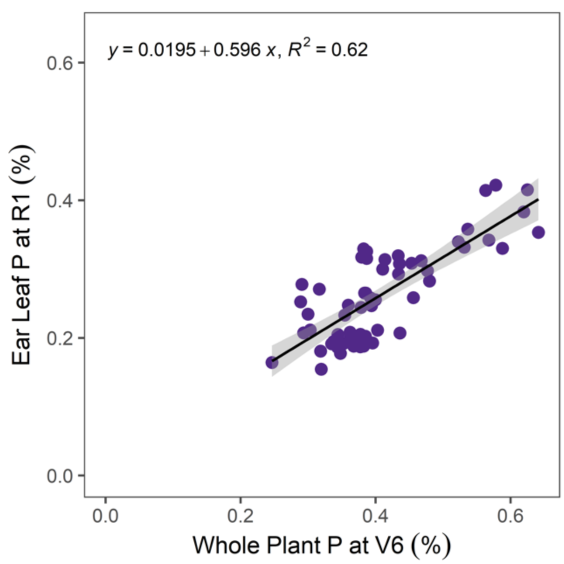

Figure 3. Relationships between P concentrations at the ear leaf at the R1 stage and the whole plant at the V6 growth stage.

Early-Season Corn Response to Broadcast Pre-Plant Phosphorus Fertilizer Application

G.A. Roa-Acosta and D.A. Ruiz Diaz

Summary

The objective of this study was to evaluate early-season corn response to different rates of pre-plant broadcast phosphorus fertilizer and determine the optimum levels using four different soil test methods. The study was conducted in 11 locations across Kansas in 2021. The experimental design is a randomized complete block design with four replications. Fertilizer treatment consisted of five rates of phosphorus fertilizer (0, 30, 60, 90, and 120 lb/a of P_2O_5). Fertilizer was applied one time by broadcast pre-plant. Soil samples were collected at 0- to 6-in. deep before treatment application, composited by blocks, and analyzed for soil test phosphorus using Mehlich 3, Haney H3A, Bray 1, and Bray 2 test methods. Whole plant sampling at V6 was collected for phosphorus uptake analysis. Results show that using early season phosphorus uptake response provided critical levels of 23 and 17 ppm of phosphorus for the Mehlich 3 and Bray 1 methods, respectively. For the Haney H3A method, the critical level was estimated at 15 ppm and for the Bray 2 method had an estimated critical value of 69 ppm. Phosphorus uptake at early season (V6) showed a significant response to broadcast phosphorus fertilization at four of eleven sites.

Introduction

Phosphorus (P) is an essential macronutrient required in relatively large quantities. Usually, the available fraction of the total soil phosphorus is typically low, and phosphorus fertilizer needs to meet crop phosphorus needs (Preston et al., 2019). Inadequate early season P supply can result in limited corn growth. A combination of soil available P and pre-plant fertilization can help meet early corn establishment and growth demands. Soil testing should be performed to determine the correct fertilizer rate for an economic yield response (Mallarino and Blackmer, 1992; Coelho et al., 2019). Critical concentrations of soil test phosphorus (STP) in the early season can be used to identify the response to phosphorus fertilization. Identifying the critical STP could depend on many factors, including soil characteristics, environmental, and other factors. This can also vary depending on the crop; current soil test interpretation guidelines with the Mehlich 3 method suggest a critical value of 20 ppm for all crops in Kansas (Leikam et al., 2003). Determining an appropriate concentration of STP for a specific extract is a fundamental step in making fertilizer recommendations. The objective of this study was to evaluate early-season corn response to different rates of pre-plant broadcast phosphorus fertilizer and determine the optimum levels using four different soil test methods (Mehlich 3, Haney H3A, Bray 1, and Bray 2).

Procedures

The study was conducted in 11 locations across Kansas during 2021 (Table 1). The experimental design was a randomized complete block design with four replications; plots were 10-ft width × 40-ft length. Fertilizer treatments were five rates of phosphorus fertilizer (0, 30, 60, 90, and 120 lb/a of P_2O_5), using mono-ammonium phosphate (MAP) (11-52-0). All fertilizer was applied one time by broadcast pre-plant. Soil samples were collected at 0- to 6-in. deep using a hand probe before treatment application, composited by block. Soil samples were dried at 104°F (40°C) and ground to pass a 2-mm sieve then analyzed colorimetrically for soil test P using four different extraction methods (Mehlich 3, Haney H3A, Bray 1, and Bray 2). Whole plant samples collected at V6 were dried at 140°F (60°C), were ground to pass a 2-mm sieve for P uptake analysis using the nitric-perchloric acid digestion method, and then analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Statistical analysis was performed using R version 4.1 ($P < 0.05$). The critical level for each soil test method was determined using the linear plateau model across locations.

Results

Preliminary results show that using early season P uptake response provided critical levels of 23 and 17 ppm for the Mehlich 3 and Bray 1 methods with an R^2 of 0.88 and 0.87, respectively (Figure 1a, and Figure 1b). The critical level for the Haney H3A method was estimated at 15 ppm with an R^2 of 0.87 (Figure 1c). The critical level for the Bray 2 method was estimated at 69 ppm with an R^2 value of 0.87 (Figure 1d).

Phosphorus uptake at early season (V6) showed a significant response to broadcast P fertilization at four of eleven sites. The responsive sites were 1, 2, 4, and 5 (Table 1). The STP for Mehlich 3 methods showed between 5–21 ppm for the responsive sites. Phosphorus uptake responses across sites were statistically significant, up to 90 lb/a of P_2O_5; a higher rate of P did not increase P uptake (Figure 2a). Across the nonresponsive sites, P uptake per plant was more than 0.4 g (Figure 2b). By comparison, at responsive sites, the highest P uptake was less than 0.2 g per plant (Figure 2b).

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Coelho, M.J.A., D.A. Ruiz Diaz, G.M. Hettiarachchi, F.D. Hansel, and P.S. Pavinato. 2019. Soil phosphorus fractions and legacy in a corn-soybean rotation on Mollisols in Kansas, USA. Geoderma Regional. 18:228. https://doi.org/10.1016/j.geodrs.2019.e00228.

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7	Gove	Keith	6.6	25	23	160	30
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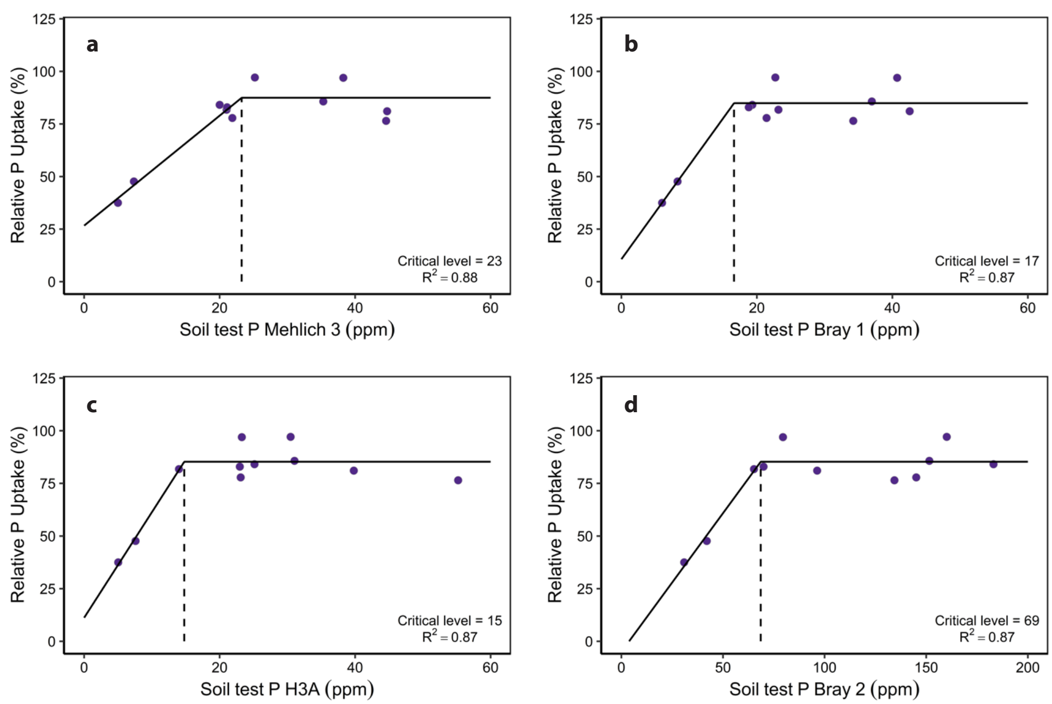

Figure 1. Relative P uptake in corn at the V6 growth stage using four different soil P extraction methods and analyzed colorimetrically.

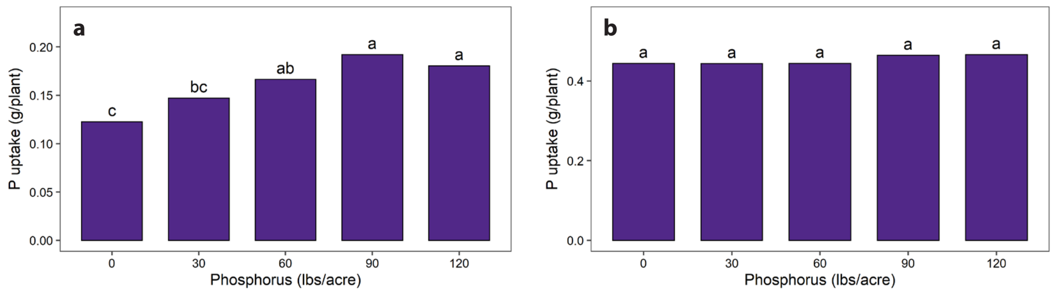

Figure 2. Phosphorus uptake at different phosphorus (P_2O_5) application rates across responsive sites (a) and non-responsive sites (b).

†Means with the same letter are not significantly different among treatments ($P < 0.05$)

Nitrogen Fertilization and Wheat Variety Interact with Environment Independently to Determine Wheat Yield in Kansas

N. Giordano and R.P. Lollato

Summary

Both nitrogen (N) management and variety selection are crucial elements that influence wheat yield; however, there is limited research exploring whether wheat varieties differ in their response to N rate. Thus, our objectives were to determine potential variety by N rate interactions among modern winter wheat varieties. Factorial field experiments were established in four Kansas locations during the 2020–2021 growing season, including two fields near Ashland Bottoms, one field near Hutchinson, and one near Manhattan. Whole plot treatments were four N rates (0, 40, 80, and 120 lb N/a) applied in the spring and subplots were 14 commercially available winter wheat varieties. Initial soil NO_3-N in the 0- to 24-in. soil profile at sowing ranged from 45 to 67 lb N/a. The weather conditions were overall favorable for crop yields across all studied environments. Wheat grain yield response to the spring-applied N fertilizer depended on location, ranging from 0.1 to 0.5 bushel per lb of N applied, with greater responses to the first 40 to 80 pounds of N per acre in three out of four environments. Likewise, variety grain yield depended on location, and varieties ranking changed accordingly. However, there was no variety by nitrogen interaction, suggesting that all varieties responded similarly to the applied N.

Introduction

Nitrogen is one of the largest yield-limiting factors for wheat produced in U.S. central Great Plains, not only in small plot research (Lollato et al., 2019a; 2021), but also in commercial wheat fields, as indicated by a recent survey of management practices in central Kansas (Lollato et al., 2019b; Jaenisch et al., 2021). Nitrogen management impacts not only the yield produced by wheat but also milling and baking quality attributes (Lollato et al., 2021). Thus, the consequences of suboptimal management of N fertilizer can cascade down the entire wheat product chain.

Another important factor determining wheat yield in the U.S. central Great Plains is wheat variety selection and the inherent traits of each variety that make it more or less adapted to a given production system and region (Munaro et al., 2020; Jaenisch et al., 2022). While there are variety differences in nitrogen-related traits, such as N uptake at maturity and N utilization efficiency (de Oliveira Silva et al., 2020a, b), there is very little information about whether current varieties respond differently to N management, which is true for many other agronomic practices (Munaro et al., 2020). Still, understanding how the different N fertilization rates interact with genotype and environment is crucial to maximize overall efficiency of the wheat cropping systems (Lollato et al., 2021). Thus, our aim was to quantify potential variety by environment interactions as they pertain to N availability in terms of grain yield.

Procedures

Field experiments were conducted during the 2020–2021 cropping season in four locations across Kansas, namely two fields near Ashland Bottoms (one Belvue silt loam and a second Bismarck grove silt loam), one field near Manhattan (Kahola silt loam), and a fourth field near Hutchinson (Ost loam). Soil characteristics are provided in Table 1. Treatment structure consisted of two-way factorial combination of N rates and varieties arranged in a split-plot design with three or four replications depending on the location. Four N rates were the whole plot, applied as granulated urea (46-0-0) during early spring at Feekes 3 growing stage at a rate of 0, 40, 80, and 120 lb/a. Fourteen commercial winter wheat varieties were the sub-plots. To avoid interacting effects between N and sulfur, all plots received 20 lb/a of sulfur in the form of gypsum fertilizer together with N application. All plots were harvested with a Massey Ferguson 8XP small plot combine.

Crop husbandry operations were common across all locations. Winter wheat was sown during the last two weeks of October 2020, at a rate of 1.2 million seeds per acre with 7.5 inches row spacing with a Great Plains 506 no-till drill. All plots received at sowing 50 lb/a of DAP fertilizer, which added about 9 lb/a of N fertilizer to all treatments. Adequate weed control was performed to ensure this was not a limiting factor. At the stage of anthesis (Feekes 10.5.1), foliar fungicide was applied to all plots as a tank mix of carboxamide and propiconazole so that fungal diseases were not a limiting factor. Soil samples were collected at each location before planting from the 0 to 6 in. and from the 6 to 24 in. layers (Table 1). Statistical analysis was performed in R Studio using linear mixed-effects models from *lme4* package.

Results

Environments Description

The 2020–2021 season was characterized by a cold start of the growing season, coupled with low rainfalls during the fall, and with below-normal February temperatures across all locations (Fig. 1). The latter contributed to negative impacts on tiller winter survival. During the winter, available water for the crop was enough to meet the atmospheric demand (Fig. 2). The spring started with adequate precipitation, with colder temperatures that were extended throughout the grain filling period contributing to higher-than normal yields in our evaluated locations, contrasting with the typical harsh weather in Kansas (Lollato et al., 2020).

From the initial soil test analysis, available N-NO_3 at sowing was 44.8, 48.4, 64.5, and 66.5 lb per acre for Ashland Bottoms Belvue silt loam and Bismarckgrove silt loam fields, Hutchinson, and Manhattan, respectively (Table 1). Moreover, Manhattan started with a considerably greater amount of available N-NH_4 at sowing of 82 lb per acre, as compared with the other locations which on average had 45 lb of N-NH_4 per acre. Noticeably, Manhattan also was the site with higher soil organic matter (OM) percentage on the top soil layer (3.9%), while other locations had on average 2.2% OM.

Grain Yield

In all sites, grain yield increased significantly with increasing N rates, however the response to N rate varied significantly depending on location ($P < 0.001$) (Table 2, Figure 3). The greatest yield increases per unit of applied N resulted from the single application of 40 lb N/a in two out of four sites, and from the 80 lb N/a application rate in a third site. As expected, N response decreased with increasing N rates in all sites except Manhattan, which was equal across all N rates, accounting for 0.2 bu/lb N. The previously described soil characteristics can partially explain why yield response to N was lower in Manhattan as compared to the rest of the sites. Current research may determine why we observe an unsaturated response to N under particular environmental conditions.

There was no significant variety by nitrogen interaction, suggesting that all varieties responded similarly to N rates (Table 2). However, the different varieties showed contrasting performance on the different sites, with a significant genotype × environment interaction ($P < 0.001$) (Table 2, Figure 4). The top yielding varieties in Ashland Bottoms Belvue silt loam site were WB4303 and Bentley, which yielded on average 80.2 bu/a as compared to the second yielding group which yielded 71.9 bu/a. At Ashland Bottoms Bismarckgrove silt loam soil, the top performing group included Tatanka, WB4303, and WB-Grainfield averaging 73.9 bu/a, representing a 14% yield increase as compared to the environment mean yield. In Hutchinson, the higher yielding varieties were Tatanka, Bentley, SY Monument, WB4303, Bob Dole, WB-Grainfield, and Larry, with an average grain yield of 61.8 bu/a. Manhattan was the lowest yielding site with an average of 46.3 bu/a. The top yielding group included Tatanka, WB Grainfield, Larry, SY Monument, WB4303, LCS Chrome, and WB4269.

Conclusions

Determining an optimum N rate is among the most complex decisions a wheat farmer has to make during the season. Reinforcing this complexity, we showed that the different locations had different responses to the N rates applied, partially attributed to differences in weather and soil conditions. Variety selection is another complex decision due to the number of varieties available. Likewise, different varieties ranked differently depending on environment. However, we showed preliminary data suggesting that these factors (variety and nitrogen rate) did not interact, facilitating—at least to some extent—wheat management on the farm.

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Table 1. Soil characteristics for the topsoil (0–6 inches) and subsoil (6–24 inches) layers for the different sites of the study

Location	pH	Depth	CEC	K	Mg	Ca	P Mehlich	Na	N-NO_3	N-NH_4	OM
		inches	meq 100g^{-1}	----------------------	----------------------	ppm	----------------------	----------------------	lb/a		%
Ashland 2A2	6.1	0 - 6	23.17	345.2	266.3	2,524	32.8	10	13.9	14.2	2.5
Ashland 2A2	6.4	6 - 24	23.45	314.9	299.1	2,834	20	12.4	30.7	38.8	2.3
Ashland M3	5.5	0 - 6	14.63	224.4	145.1	1,313	30.2	9.8	22.5	11.5	1.8
Ashland M3	6.3	6 - 24	11.83	175.7	150.5	1,465	13.4	10.2	25.8	24.0	1.3
Hutchinson	5.9	0 - 6	19.28	226.8	171.7	1,774	71.1	11.5	24.4	14.2	2.2
Hutchinson	6.9	6 - 24	25.73	228.2	217.6	3,969	34.5	21.8	40.0	33.3	2.1
Manhattan	7.4	0 - 6	34.05	347.4	229.9	6,064	16.2	14	15.4	23.8	3.9
Manhattan	7.4	6 - 24	34.89	328.9	225.1	6,227	12.7	15.1	51.1	58.5	3.7

Table 2. Significance of location, N rate variety and their interactions for grain yield, during the 2020–2021 growing season

Effect	Df	Grain yield significance
(Intercept)	1	>0.001
Location (L)	3	0.59
Variety (V)	13	>0.001
N rate (N)	3	>0.001
L × V	39	>0.001
L × N	9	>0.001
V × N	39	0.90
L × V × N	117	0.99

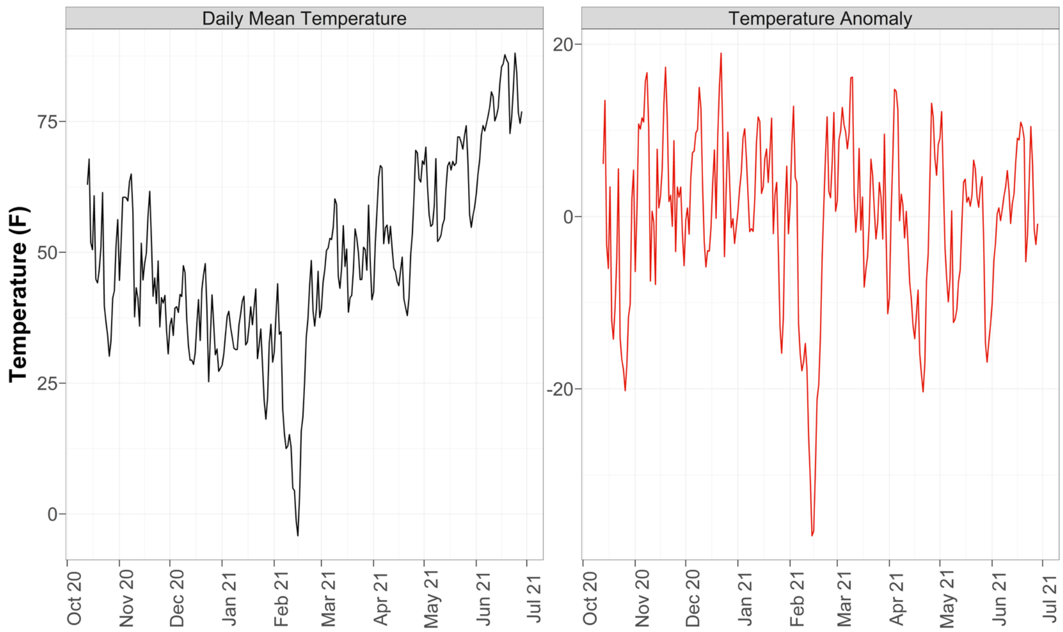

Figure 1. Daily mean temperature and daily mean temperature anomaly during the 2020–2021 growing season averaged across the four locations. Anomalies were calculated comparing the current growing season with the most-recent 20-year average.

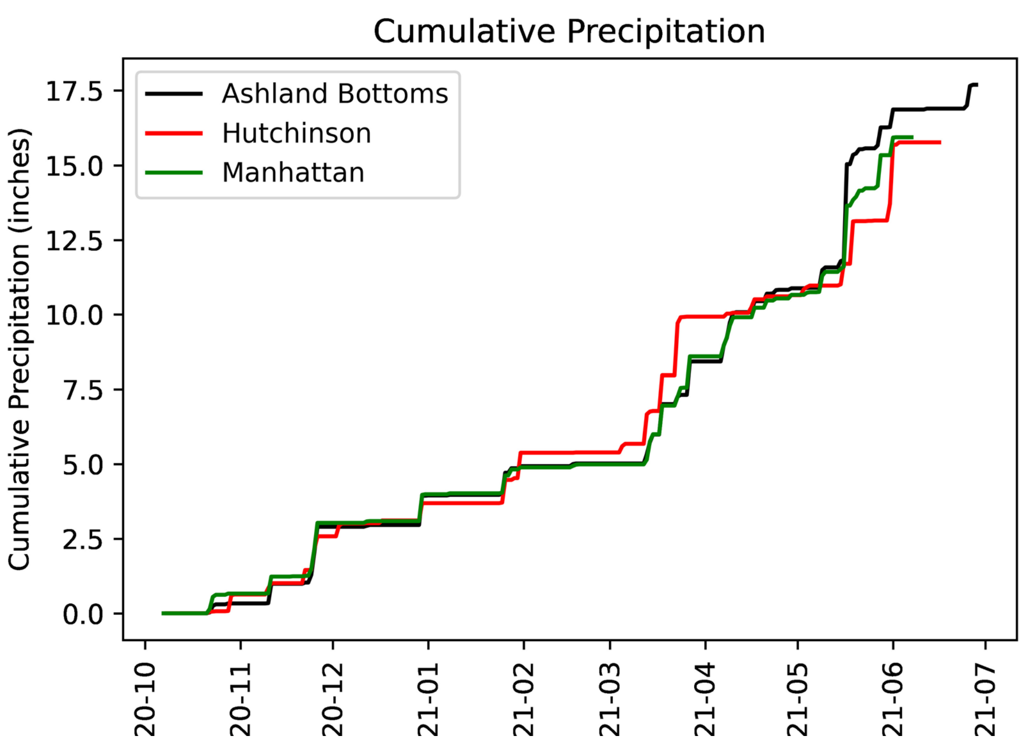

Figure 2. Cumulative precipitation for the different locations in which the trials were placed. Ashland Bottoms summarizes both fields 2A2 and M3.

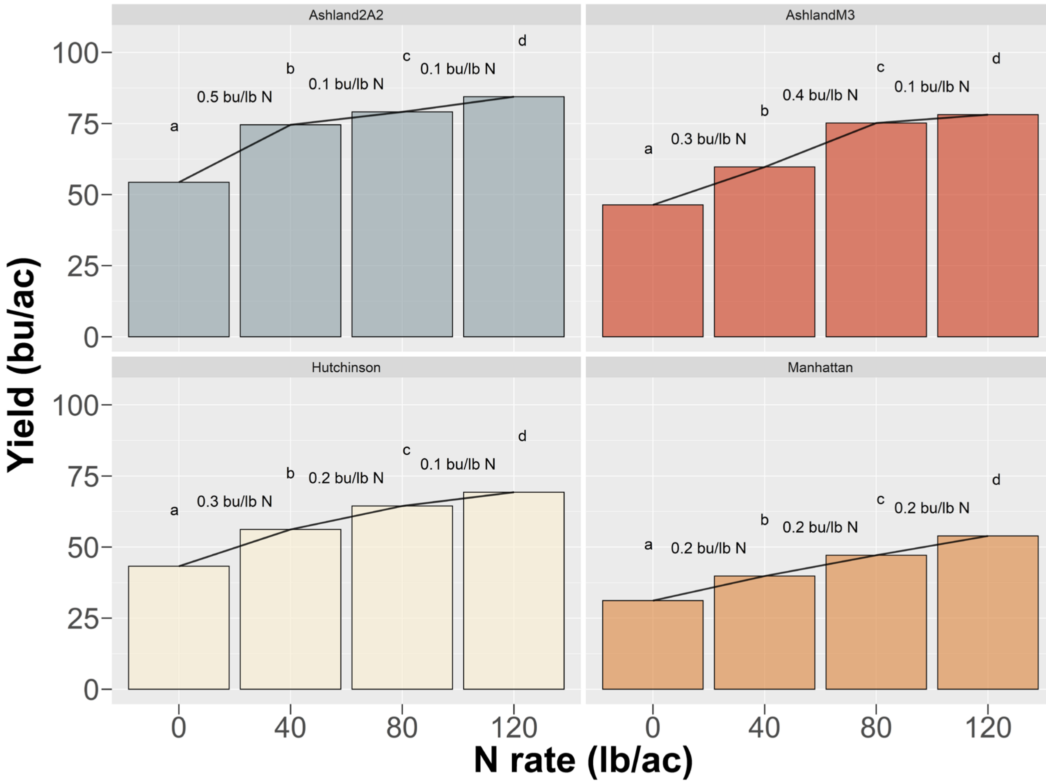

Figure 3. Average grain yield (bu/a) as affected by N rate (lb/a) for trials conducted in Ashland Bottoms 2A2, Ashland Bottoms M3, Hutchinson, and Manhattan. Differences between letters indicate statistically significant differences at $\alpha = 0.05$. Values between columns represent the average yield increase in bushels, per unit applied nitrogen (lb) between two successive N rates tested.

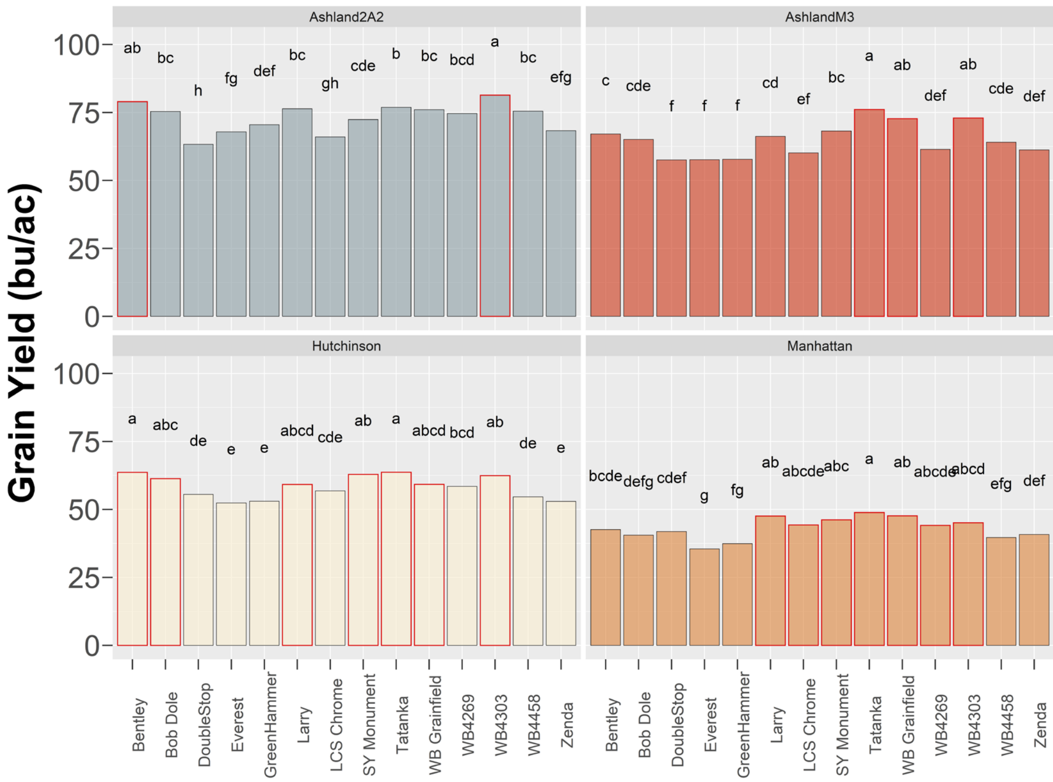

Figure 4. Average grain yield (bu/a) for each of the tested varieties in the four locations. Differences between letters indicate statistically significant differences at α = 0.05. Red colored bar-lines represent the top yielding group for each of the locations.

Environment and Nitrogen Rate Play Significant Roles in Winter Wheat Response to Nitrogen Management Intensification

L.M. Simão, D.A. Ruiz Diaz, and R.P. Lollato

Summary

Poor nitrogen (N) management is among the leading causes of winter wheat (*Triticum aestivum* L.) yield gaps in Kansas, and sowing date—which is impacted by crop rotation—is among the most important variables determining winter wheat's attainable yields in the U.S. central Great Plains. This research aimed to investigate the relationship between N management strategies and various cropping systems in Kansas. The treatments consisted of nine combinations of three N management practices (standard, progressive, and green N) and five crop sequences (WtWt = continuous winter wheat; SyWt = winter wheat after soybean; TrSyWt = triticale (hay) – soybean – winter wheat rotation; CpWt = winter wheat after cowpea; TpDPwt = dual-purpose winter wheat after tepary bean; MoDPwt = dual-purpose winter wheat after moth bean). Standard N-management consisted of one single broadcast N application at 80 lb/a as UAN at spring greenup. Progressive N-management consisted of a split-N application at 40 and 27 lb/a each at greenup and jointing, using streamer bar nozzles and N-inhibitors added to the fertilizer. Green N management consisted of no fertilizer application except for the carryover N from the previous terminated legume crop. Crop sequences that allowed winter wheat to be sown at the optimum sowing date had the greatest yields. Green N management decreased dual-purpose winter wheat grain yield and shoot biomass. Both standard and progressive N management practices had similar results within crop sequences. Overall, our results suggested that intensive N management produced the same yields as the standard, but at lower N rates. Dual-purpose winter wheat combined with green N (i.e., relying exclusively on carryover N) was detrimental to winter wheat yield.

Introduction

Kansas is an important wheat (*Triticum aestivum* L.) producing state in the U.S. and accounts for 22% of wheat produced in the country. Most cropping systems in Kansas are winter wheat-based crop sequences. Different cropping systems can impact sowing dates for winter wheat, depending on the previous crop. For example, winter wheat grown for forage or dual-purpose (graze plus grain) is usually sown earlier in the fall (Lollato et al., 2019a). Winter wheat double-cropping with a summer crop (e.g., soybean (*Glycine max* (L.) Merrill), maize (*Zea mays* L.), and sorghum (*Sorghum bicolor* (L.) Moench) is sown later in the season and usually past the optimum sowing date (Jaenisch et al., 2021; Munaro et al., 2020). Recent studies showed that sowing date is the most important variable determining winter wheat yield in the U.S. central Great Plains (Munaro et al., 2020; Jaenisch et al., 2021). Also, it is estimated that there is an approximate 50% winter wheat yield gap in Kansas (Lollato et al., 2017). Poor nitrogen (N) management is among the leading causes of the gap (De Oliveira Silva et al., 2020; Jaenisch et al., 2021; Lollato et al., 2019b), which can also reduce wheat protein and quality (Corassa et al., 2018). Recent evidence suggests that wheat sown later due to cropping system influence may also warrant changes in N management for improved N use efficiency (Lollato et al., 2021).

However, optimal N-management depends on yielding environments (Lollato et al., 2019c), and little is known about the performance of different N management strategies within different cropping systems. This research aimed to investigate the relationship between N management and various cropping systems in Kansas.

Procedures

Treatments Description

A rainfed field experiment with different crop rotations was established in the fall of 2019 near Ashland Bottoms, KS (fine-silty, mixed, mesic Cumulic Haplustoll). While crops planted and crop rotations depended on year of the study, this report will cover the results from the 2020-2021 growing season. The treatments consisted of nine combinations of three N management strategies (standard, progressive, and green N; Table 1) and five crop sequences (WtWt = continuous winter wheat; SyWt = winter wheat after soybean; TrSyWt = triticale (hay) – soybean – winter wheat rotation; CpWt = winter wheat after cowpea; TpDPwt = dual-purpose winter wheat after tepary bean; MoDPwt = dual-purpose winter wheat after moth bean). Standard and progressive N-management (Table 1) differed in application timing, placement, presence or absence of N inhibitors, and rate. The green N treatments did not receive inorganic N applications since the treatment is expected to include residual N from the previous legume crop. The rate of N applied in the progressive treatment was according to an in-season N recommendation, based on crop modeling that uses cropland observation through monitoring crop conditions and water balance.

Field Setup and Measurements

Winter wheat variety Zenda was sown at 90 lb/a when at optimum date (WtWt and TrSyWt, October 15); and at 120 lb/a when sown early for dual purpose (TpDPwt and MoDPwt, September 24), or late after the harvest of a summer crop (SyWt, November 7). Plots were 2000 ft^2 (40-ft wide × 50-ft long), had 7.5-in. row spacing, and were sown using a Great Plains 506 no-till drill. Diammonium phosphate (DAP; 18-46-0) starter fertilizer was applied to all plots at 50 lb/a. Grains were harvested on 6 June 2021 using a Massey Ferguson XP8 small-plot, self-propelled combine on the center of each plot (200 ft^2 area). Pests, weeds, and diseases were monitored regularly and, as they never reached critical levels, they were not considered limiting factors in this experiment.

Before harvest, whole plant biomass was collected from a representative 3.2-ft row, in which total shoot biomass weight, grain weight, harvest index, number of heads, a thousand grain weight, and grains per head were estimated. Plant N concentration (N%) was measured using dry combustion (LECO TruSpec CN combustion analyzer); shoot N uptake was estimated as the sum of the product between the sample weight and N%. Grain yield and grain protein were also measured.

Experimental Design and Statistical Analysis

The experiment was arranged as a randomized complete block design with four replications. Treatments and replications were considered fixed effects. Tukey's HSD ($\alpha = 0.05$) was used to contrast treatments and find statistically similar groups post-hoc.

Regression analyses were performed using lm function available in R software with the R-Studio 9.4 interface (R Studio, PBC, Boston, MA).

Results

Weather Conditions

The 30-yr normal average precipitation (1990–2020) during winter wheat growing season in Ashland Bottoms is 26 inches. During this study, total precipitation received during winter wheat growing season was approximately 18 inches, which is below the historical average. Seasonal evapotranspiration was approximately 30 inches, therefore, precipitation likely did not supply enough water to meet the demand of the crop.

Grain Yield and Protein Concentration, and Yield Components

Winter wheat grain yield ranged from 18 to 66 lb/a across treatments (Figure 1A). Continuous winter wheat and TrSyWt rotation had the greatest yield, regardless of the N-management, while dual-purpose winter wheat under the green N treatment had the lowest yield. Grain protein concentration ranged from 7.8 to 10.5% across treatments (Figure 1B) and was similar among treatments, except for TrSyWt and progressive SyWt, which had the lowest protein content. For TrSyWt, rotation was more significant under standard N-management. Grain test weight was also similar among treatments, except for green N MoDPwt, which had greater values than WtWt, regardless of the N-management. Overall, number of heads/ft^2 and grain/ft^2 was lower for crop sequences under green N-management, and all the treatments had similar seed sizes (Table 2).

The differences in grain yield among treatments were more related to crop sequence than N-management since all N management treatments had similar yields within crop sequence. In this case, crop sequences in which winter wheat was sown at the optimum date had the greatest yield, followed by late planting, and lastly, early sowing date. We note that the treatments sown early also did not receive inorganic N and had dual-purpose winter wheat, all of which potentially contributed to reduced yields. The progressive N treatment had similar grain yield to the standard however used less inorganic N fertilizer, which can be overall beneficial to the system. The lack of difference between N-management within crop sequences was likely due to the area's weather being drier than normal. Drier environments are less susceptible to N fertilizer volatilization losses (Perin et al., 2020) which may have caused the standard N-management to behave similarly to progressive N-management in terms of the likelihood of N losses to the atmosphere.

Overall, grain yield and protein content had a significantly negative relationship (Figure 1D) likely due to the N dilution effect (De Oliveira Silva et al., 2020). The dilution effect is more apparent based on the significant negative relationships between grain and shoot N uptake and protein content (Figures 1E, F), meaning that increases in grain N uptake were driven more by increases in yield than in protein concentration.

Biomass and Nitrogen Uptake

Shoot biomass for each treatment is depicted in Figure 1C. The green N management treatment managed as dual-purpose wheat, had the lowest shoot biomass production, which was expected due to simulated grazing and no inorganic N received. Lower shoot biomass was also noted for winter wheat sown later under progressive N-management (Pr_SyWt and Pr_CpWt), which was likely caused by lower fall tillering due to later sowing date and lower N rate applied under progressive N-management than standard. Shoot biomass at maturity was a strong driver of grain yield and shoot N uptake (Figure 1G and 1H, respectively).

Preliminary Conclusions

Overall, crop sequences that allowed winter wheat to be sown near the optimum date resulted in greater grain yields than other crop sequences with early or late sowing dates. Dual-purpose winter wheat relying on green N seems to be infeasible as the N supply may not meet the N demand. Nitrogen management intensification resulted in similar yields to the standard N management though using less N fertilizer per acre.

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Table 1. Nitrogen management (i.e., application timing, N inhibitor additive, and placement method) in winter wheat at Feekes 4 and Feekes 7 stages of plant development at Ashland Bottoms, KS, during 2020–2021 growing season

	Feekes 4		Feekes 7		
N Management	Nitrogen[1]	Additive[2]	Nitrogen	Additive	Placement
Standard [St]	80 lb/a	---	---	---	Broadcast
Progressive [Pr]	40 lb/a	Nitrogen inhibitors	27 lb/a	Nitrogen inhibitors	Streamer bar
Green N [Gr]	---	---	---	---	---

[1]Source: Urea ammonium nitrate (UAN 32-0-0).
[2]Nitrification inhibitor (Centuro, Koch Agronomic Services Co., Wichita, KS, 67220) at 5 gallons per ton of fertilizer (UAN); and urease + nitrification inhibitor (Agrotain Plus SC, Koch Agronomic Services Co., Wichita, KS, 67220) at 3 gallons per ton of fertilizer (UAN).

Table 2. Winter wheat grain yield components under various nitrogen (N) management and crop sequence treatments near Manhattan, KS, during 2020–2021 growing season

Nitrogen[1]	Crop sequence[2]	Test weight (lb/bu)	Heads/ft²	Grain/ft²	Seeds/lb
Standard	WtWt	60 ± 0.2§ ab†	87 ± 5 abc	1566 ± 93 abc	17.7K[3] ± 236 a
Progressive	WtWt	59 ± 0.2 ab	63 ± 5 abc	1336 ± 93 abc	17.7K ± 236 a
Standard	SyWt	59 ± 0.2 ab	73 ± 5 abc	1223 ± 93 abc	17.5K ± 236 a
Progressive	SyWt	60 ± 0.2 ab	61 ± 5 abc	1014 ± 93 abc	17.2K ± 236 a
Standard	TrSyWt	60 ± 0.2 ab	77 ± 5 abc	1346 ± 93 abc	17.7K ± 236 a
Progressive	TrSyWt	60 ± 0.2 ab	86 ± 5 abc	1521 ± 93 abc	16.9K ± 236 a
Progressive	CpWt	60 ± 0.2 ab	72 ± 5 abc	1935 ± 93 abc	16.7K ± 236 a
Green N	TpDPwt	60 ± 0.2 ab	55 ± 5 abc	1753 ± 93 abc	16.8K ± 236 a
Green N	MoDPwt	61 ± 0.2 ab	49 ± 5 abc	1742 ± 93 abc	16.6K ± 236 a

[1]N-management: Standard (single N-application using broadcasting applicator with the absence of N-inhibitors at 80 lb/a of N); Progressive (split N-application into two timings using streamer bars with the presence of N-inhibitors at 80 lb/a of N); and Green N (absence of N application from fertilizer).

[2]WtWt = continuous winter wheat; SyWt = winter wheat after soybean; TrSyWt = triticale (hay) – soybean – winter wheat rotation; CpWt = winter wheat after cowpea; TpDPwt = dual purpose winter wheat after tepary beans; MoDPwt = dual purpose winter wheat after moth beans.

[3]K = thousand.

§Standard error of the mean.

†Means within the same column followed by the same letter are not significantly different at $\alpha = 0.05$ probability level of significance using Tukey's HSD test.

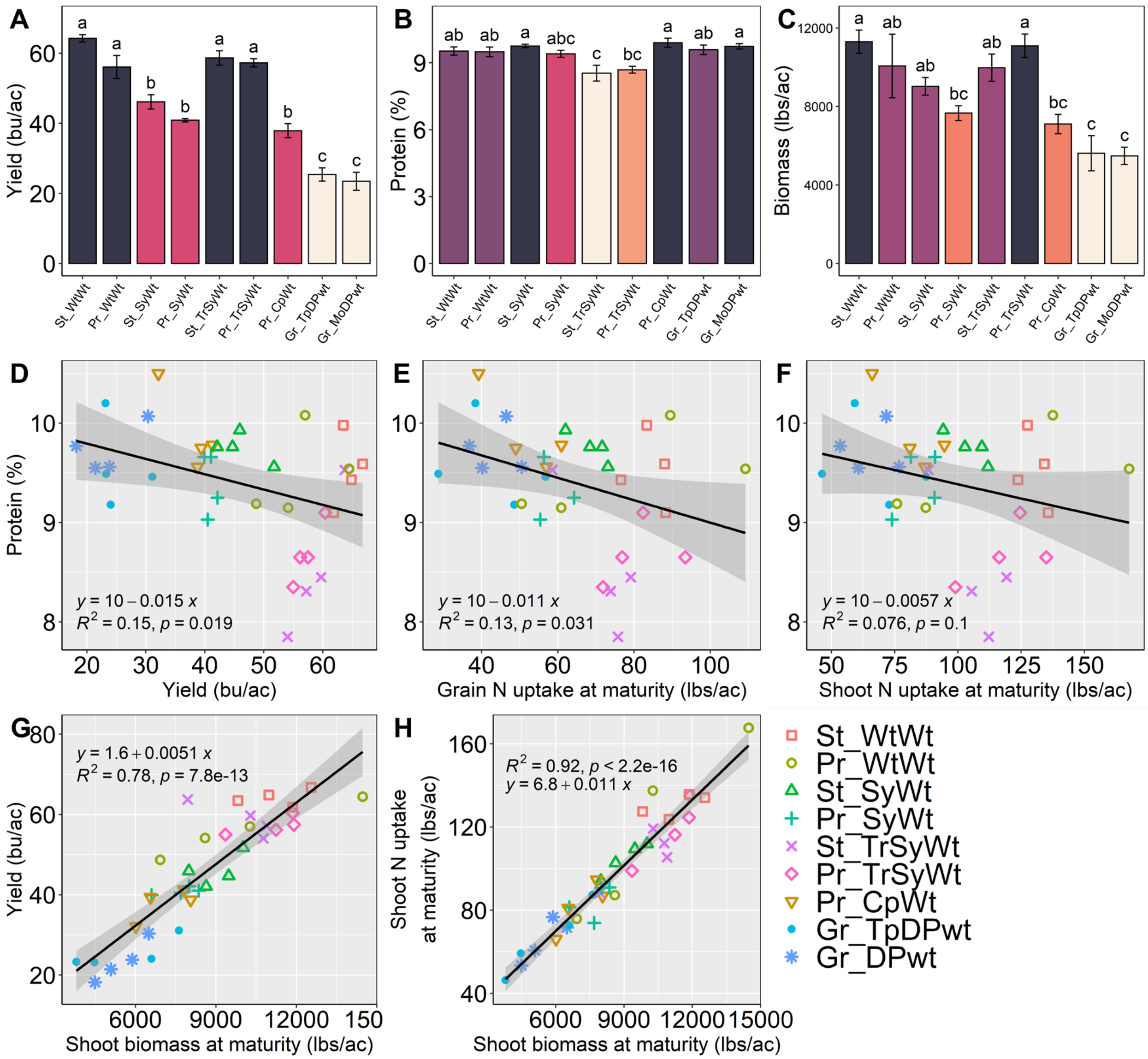

Figure 1. Grain yield (A), grain protein content (B), and shoot biomass (C); relationship of grain protein content with grain yield (D), with grain nitrogen [N] uptake at maturity (E), and shoot N uptake at maturity (F); and relationship of shoot biomass at maturity with grain yield (G), and with shoot N uptake at maturity (H) for winter wheat under nine treatments' combination of N-management and crop sequence near Manhattan, KS, during 2020–2021 growing season. N management treatments were Standard [St] (single N-application using broadcasting applicator with the absence of N inhibitors at 80 lb/a of N); Progressive [Pr] (split N application into two timings using streamer bars with the presence of N-inhibitors at 80 lb/a of N); and Green N [Gr] (absence of N application from fertilizer). Crop sequences included WtWt = continuous winter wheat; SyWt = winter wheat after soybean; TrSyWt = triticale (hay) – soybean – winter wheat rotation; CpWt = winter wheat after cowpea; TpDPwt = dual-purpose winter wheat after tepary beans; MoDPwt = dual-purpose winter wheat after moth beans.

Comparison of Mehlich-3 and DTPA Soil Tests for Analysis of Micronutrients in Kansas Soils

B. Rutter, D. Ruiz Diaz, and L. Hargrave

Summary
Mehlich-3 (M3) was designed as a multi-nutrient soil test procedure and has become common at soil testing labs across the U.S. In Kansas, Mehlich-3 is predominately used as a soil test for phosphorus (P) and potassium (K), but recent studies have also investigated the use of M3 for the extraction of base cations and cation exchange capacity estimation. However, data relating M3 to traditional methods for soil micronutrient extraction remain scarce. The objective of this study was to investigate the relationship between M3 and diethylenetriamine pentaacetate (DTPA) extractable copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) across a wide range of Kansas soils. Strong positive correlations were observed between M3 and DTPA for each metal (Fe, r = .91; Zn, r = .98; Cu, r = .92). Correlations between M3 and DTPA were positive but weak for Mn (r = 0.17). Regression analyses suggest these relationships were not one-to-one and were dependent on soil pH. Results from this study show that conversion of M3 to a "DTPA equivalent" is possible but should take soil pH into consideration, especially for Fe and Mn.

Introduction
The Mehlich-3 soil test procedure has become part of the routine workflow for soil analysis at soil testing labs across the U.S. This procedure allows for the simultaneous measurement of numerous essential plant nutrients from a single extraction and reduces lab operating costs and the cost of soil testing for farmers and homeowners (Rutter et al., 2022). The interpretation of a soil test requires knowledge of its relationship to nutrient uptake by crops, or its correlation to existing soil testing methods. However, data relating M3 extractable micronutrient metals to the conventional soil test (DTPA) for micronutrient metals are scarce for Kansas soils. Previous research conducted in other regions have included the investigation of relationships between these methods (Cancela et al., 2007; Iatrou et al., 2015). Iatrou et al. (2015) found strong correlations between M3 and DTPA for Zn and Cu in Greek soils, but a poor correlation for Mn. Positive correlations between M3 and DTPA extractable Fe were also observed, but the relationship was substantially influenced by soil pH. Similar observations were made by Cancela et al. (2007) in soils collected from the Iberian Peninsula (Spain, Portugal). This study was performed at the Kansas State Research and Extension Soil Testing Laboratory to evaluate the relationship between M3 and DTPA extractable Cu, Fe, Mn, and Zn in Kansas soils.

Procedures
Soil samples were selected randomly from those submitted to the lab by Kansas farmers and homeowners over a six-month period (a total of 308 soil samples for this study), and covered a wide range of pH, organic matter, and micronutrient content (Table 1*)*. Soils were dried in a forced-air oven at 104°F (40°C) and ground to pass a 2-mm sieve

using a flail-type soil mill (Custom Laboratory Equipment, MO, U.S.). Samples were stored at 70°F (21°C) until analysis. A summary of general soil characteristics can be found in Table 1.

The extraction procedures employed during this study are described in Chapter 9 of the Recommended Soil Testing Procedures for the North Central Region handbook (Whitney, 2015). Briefly, 10 g of soil were extracted with 20 mL of DTPA extracting solution (0.005 M DTPA, 0.01 M triethanolamine (TEA), pH = 7.3) on a reciprocating shaker at 180 rpm for 2 hours. Subsequent extracts were filtered using Ahlstrom 74 filter paper, and the concentrations of Cu, Fe, Mn, and Zn were measured using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Soil pH was measured from 1:1 soil-water suspensions using a dual probe robotic pH meter equipped with glass electrodes (Skalar Analytical, Netherlands). Buffer pH was determined using the Sikora buffer method. Soil organic matter (SOM) content was determined using the loss on ignition method at 752°F (400°C) and a 4-hour ignition phase.

Results

Correlations between the M3 and DTPA were positive and relatively strong for Zn, Fe, and Cu but weak for Mn (Figure 1). Simple linear regression models between M3 and DTPA indicated that, on average, micronutrient concentrations were higher in M3 extracts than DTPA extracts. However, more complex regression models suggest these relationships were also influenced by soil pH (Table 2; Figure 2). Using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values to compare the models provides further weight toward including soil pH, as AIC and BIC values were minimized when soil pH was included in the model for all four micronutrients (Table 2). This pH dependence complicates the interpretation of micronutrients from the Mehlich-3 soil test, as the soil test indices and crop response calibrations currently available were based on the traditional DTPA soil test.

Conclusion

Relationships between M3 and DTPA extractable micronutrient metals were investigated in soils collected from across Kansas. Mehlich-3 and DTPA micronutrients were positively correlated between the two methods. However, Mehlich-3 extracted substantially higher amounts of Cu, Fe, Mn, and Zn in some soils with a high pH. Regression analysis suggests M3 and DTPA soil tests results do not follow “one-to-one” relationships and appear to be influenced by soil pH. Results from this study show that conversion of M3 extractable to a “DTPA equivalent” is possible, but soil pH should be taken into consideration to improve accuracy, especially for Fe and Mn.

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Table 1. General soil information and summary statistics for soil samples (n = 308) included in the study

Statistic	Soil pH	SOM	CEC	Cu	Fe	Mn	Zn
		%	meq 100 g^{-1}	------------------------ ppm ------------------------			
Range	4.4 - 8.2	0.8 - 10.0	9.3 - 39	0.3 - 7.3	2.8 - 317	1.8 - 203	0 - 243
Median	6.7	3.0	19.7	1.0	18.4	14.5	1.3

SOM = soil organic matter. CEC = cation exchange capacity. Cu = copper. Fe = iron. Mn = manganese. Zn = zinc. Soils with SOM contents exceeding 10% were removed from the study (n = 2). The reported concentrations of copper, iron, manganese and zinc were determined from DTPA extracts.

Table 2. Comparison of regression models with varying complexity for the relationships between Mehlich-3 (M3), DTPA, and soil pH for zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn)

Element	IVs	Adj. R^2	BIC
DTPA-Zn	M3-Zn	0.90	467
	M3-Zn + Soil pH	0.92	394
	M3-Zn + M3-Zn: Soil pH	*0.95*	*294*
	M3-Zn + Soil pH + M3-Zn: Soil pH	0.95	300
DTPA-Fe	M3-Fe	0.76	1363
	M3-Fe + Soil pH	0.88	1231
	M3-Fe + M3-Fe: Soil pH	*0.90*	*1181*
	M3-Fe + Soil pH + M3-Fe: Soil pH	0.90	1186
DTPA-Cu	M3-Cu	0.72	227
	M3-Cu + Soil pH	*0.86*	*27*
	M3-Cu + M3-Cu: Soil pH	0.84	62
	M3-Cu + Soil pH + M3-Cu: Soil pH	0.86	31
DTPA-Mn	M3-Mn	0.00	2481
	M3-Mn + Soil pH	0.50	2276
	M3-Mn + M3-Mn: Soil pH	*0.65*	*2172*
	M3-Mn + Soil pH + M3-Mn: Soil pH	0.65	2176

Independent variables (IVs) are shown, as well as various statistics such as adjusted coefficient of determination (Adj. R^2) and Bayesian Information Criterion (BIC) for each respective model. Models with the lowest BIC value are indicated in underlined italic font for each element. Soils with extremely high soil test values were omitted prior to fitting regression models to focus on the range of agronomic relevance (e.g., DTPA-Zn > 10 ppm).

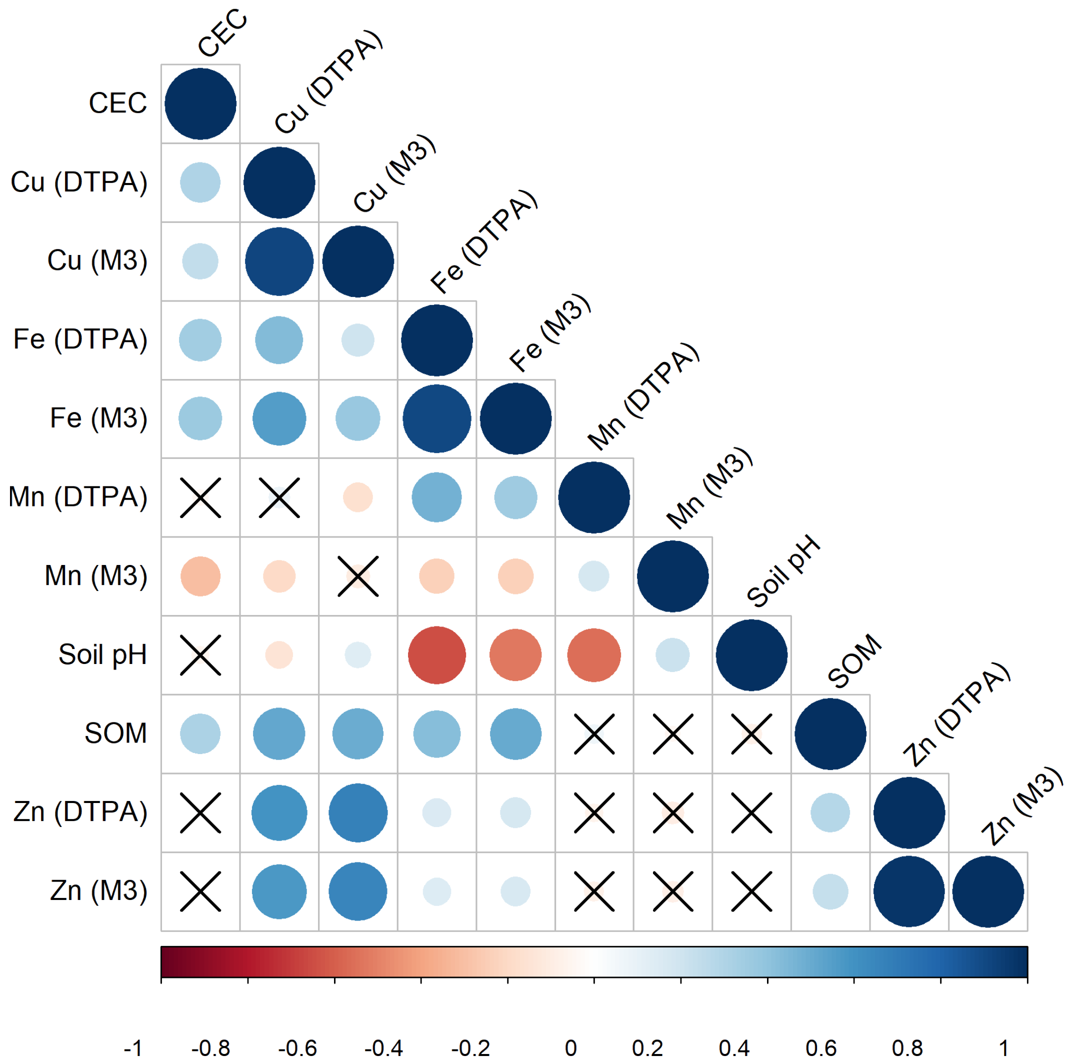

Figure 1. Pearson's correlations between Mehlich-3 (M3) and DTPA extractable copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), soil pH, soil organic matter (SOM), and cation exchange capacity (CEC) measured from 308 soils collected across Kansas. Positive correlations are indicated by blue colors and negative correlations are indicated by red colors. Non-significant correlations are indicated by cross hash marks ($P > 0.05$).

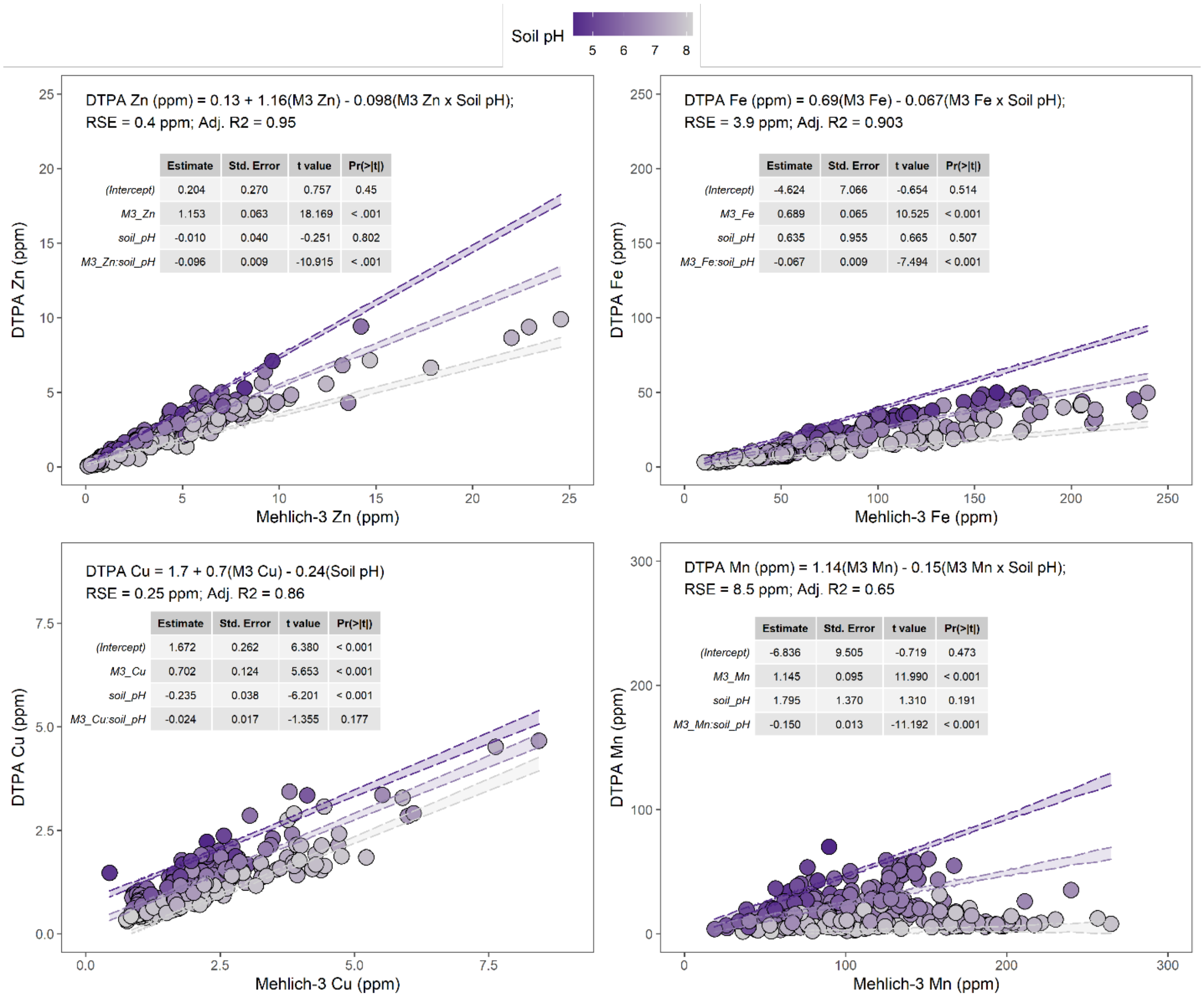

Figure 2. Multiple linear regression models were used to investigate the relationships between Mehlich-3 (M3) and DTPA extractable Zn (top-left), Fe (top-right), Cu (bottom-left), and Mn (bottom-right). The effects of soil pH were also taken into consideration. Model fit estimates are illustrated with the shaded ribbons. The soil pH is indicated by color for both soils (points) and models (ribbons); where lighter shades correspond to higher soil pH and darker shades to lower soil pH. Soils with extremely high soil test values were omitted prior to fitting regression models to place focus on the range of agronomic concern (e.g., DTPA-Zn > 10 ppm).

2021 Fertilizer Weather Station Report

Table 1. Precipitation at Abilene, Ashland Bottoms, and Belleville

	Abilene		Ashland Bottoms		Belleville	
	Actual	**Normal**	**Actual**	**Normal**	**Actual**	**Normal**
January	1.08	0.86	0.99	0.65	0.56	0.49
February	0.05	1.43	0.09	0.96	0.08	0.77
March	3.94	2.23	3.41	1.83	3.80	1.58
April	2.46	3.26	2.45	3.13	1.47	2.93
May	8.35	5.20	5.39	4.65	3.20	4.55
June	1.78	4.18	1.42	4.83	0.79	4.06
July	4.05	4.75	5.92	4.01	4.54	4.63
August	1.42	4.27	1.54	4.64	5.97	3.24
September	7.07	2.54	3.76	2.69	1.79	2.75
October	2.92	2.47	2.78	2.18	4.23	2.11
November	0.26	1.59	1.40	1.54	0.17	1.2
December	0.33	1.50	0.13	1.06	0.03	1.03
Annual	33.71	34.28	29.28	32.17	26.63	29.34
Last spring freeze	4/23/2021		4/23/2021		4/23/2021	
First fall freeze	10/31/2021		10/31/2021		10/22/2021	
Frost free days	191		191		182	
Number of days > 90°	59		53		40	
Number of days > 100°	9		6		3	
Number of days < 10°	15		15		19	

Table 2. Precipitation at Gove, Hiawatha, and Kiro

	Gove		Hiawatha		Kiro	
	Actual	Normal	Actual	Normal	Actual	Normal
January	0.36	0.56	1.38	0.77	1.86	0.89
February	0.09	0.55	0.07	1.15	0.06	1.31
March	3.95	1.27	4.40	2.01	3.79	2.25
April	0.72	2.11	1.66	3.58	2.68	3.81
May	3.88	3.45	3.27	4.83	5.93	5.17
June	0.74	2.71	8.04	5.03	3.26	4.92
July	1.77	3.66	2.65	4.46	2.99	3.99
August	0.23	2.73	4.21	3.86	3.06	4.55
September	1.61	1.92	1.74	3.22	2.73	3.52
October	1.55	1.88	5.06	2.86	4.37	2.85
November	0.20	0.64	2.91	1.72	1.14	1.78
December	0.22	0.72	0.71	1.22	0.25	1.49
Annual	15.32	22.20	36.10	34.71	32.12	36.53
Last spring freeze	4/22/2021		5/14/2021		4/23/2021	
First fall freeze	10/16/2021		10/23/2021		10/31/2021	
Frost free days	177		162		191	
Number of days > 90°	86		27		48	
Number of days > 100°	32		0		1	
Number of days < 10°	20		17		15	

Table 3. Precipitation at Manhattan, Ottawa, and Parsons

	Manhattan		Ottawa, ECK		Parsons	
	Actual	**Normal**	**Actual**	**Normal**	**Actual**	**Normal**
January	0.90	0.64	3.26	1.22	3.86	1.42
February	0.10	1.14	0.16	1.57	0.36	1.70
March	3.61	2.17	4.78	2.29	6.05	2.95
April	2.06	3.38	3.24	3.79	2.27	4.77
May	4.68	5.23	12.07	5.82	5.78	6.84
June	2.03	5.47	5.49	5.55	7.11	5.64
July	7.41	4.62	4.66	3.75	9.45	4.23
August	2.52	4.4	2.74	4.63	4.22	4.07
September	2.83	3.41	2.70	4.05	2.15	4.83
October	3.60	2.5	4.61	3.08	5.18	3.64
November	1.14	1.62	0.63	2.39	0.53	2.80
December	0.32	1.19	0.34	1.71	1.23	2.00
Annual	31.20	35.77	44.68	39.85	48.19	44.89
Last spring freeze	4/23/2021		4/23/2021		4/23/2021	
First fall freeze	11/13/2021		11/4/2021		11/14/2021	
Frost free days	204		195		205	
Number of days > 90°	55		36		44	
Number of days > 100°	5		1		0	
Number of days < 10°	13		14		8	

Table 4. Precipitation at Rossville, Russell Springs, and Salina

	Rossville, KRV		Russell Springs		Salina	
	Actual	Normal	Actual	Normal	Actual	Normal
January	2.06	0.74	0.33	0.31	1.10	0.71
February	0.06	1.18	0.10	0.54	0.02	0.87
March	4.39	2.08	2.97	0.86	4.02	1.82
April	2.68	3.48	0.52	1.83	2.78	2.72
May	6.77	5.06	7.23	2.66	5.68	5.04
June	2.81	5.11	2.40	2.34	1.34	3.75
July	3.29	4.32	1.87	3.00	1.53	3.92
August	2.21	4.6	1.67	2.56	1.82	3.71
September	2.68	3.75	3.37	1.58	2.69	2.65
October	3.61	2.71	1.06	1.37	2.25	2.16
November	1.19	1.67	0.07	0.60	0.00	1.22
December	0.31	1.37	0.09	0.54	0.01	1.12
Annual	32.06	36.07	21.68	18.19	23.24	29.69
Last spring freeze	4/23/2021		4/22/2021		5/6/2021	
First fall freeze	10/31/2021		10/16/2021		10/17/2021	
Frost free days	191		177		164	
Number of days > 90°	38		61		64	
Number of days > 100°	0		9		9	
Number of days < 10°	14		18		18	

Table 5. Precipitation at Scandia and Topeka

	Scandia		Topeka, KRV	
	Actual	**Normal**	**Actual**	**Normal**
January	0.48	0.49	1.86	0.89
February	0.03	0.77	0.06	1.31
March	4.35	1.58	3.79	2.25
April	1.40	2.93	2.68	3.81
May	2.89	4.55	5.93	5.17
June	0.97	4.06	3.26	4.92
July	1.60	4.63	2.99	3.99
August	3.46	3.24	3.06	4.55
September	1.02	2.75	2.73	3.52
October	2.84	2.11	4.37	2.85
November	0.16	1.2	1.14	1.78
December	0.06	1.03	0.25	1.49
Annual	19.26	29.34	32.12	36.53
Last spring freeze	5/14/2021		4/23/2021	
First fall freeze	10/15/2021		10/31/2021	
Frost free days	154		191	
Number of days > 90°	33		48	
Number of days > 100°	0		1	
Number of days < 10°	21		15	

Table 6. Location references per field locations

Field Location	Mesonet site (Actual precipitation, temperatures)	Normals site (Normal precipitation)
Abilene	Rock Springs	Abilene (ABLK1)
Ashland Bottoms	Ashland Bottoms	Manhattan ASOS (MHK)
Belleville	Belleville 2W	Scandia (SCDK1)
Gove	Gove 5SE	Gove 4W (GOVK1)
Hiawatha	Hiawatha	Hiawatha 1S (HIAK1)
Kiro	Silver Lake 4E	Topeka ASOS (TOP)
Manhattan	Manhattan	Manhattan (MHTK1)
Ottawa, ECK	Ottawa 2SE	Ottawa (OTTK1)
Parsons	Parsons	Parsons 2NW (PARK1)
Rossville, KRV	Rossville 2SE	Rossville (RVEK1)
Russell Springs	Russell Springs 3SW	Russell Springs 3N (RLLK1)
Salina	Gypsum	Salina FAA Airport (SLN)
Scandia	Scandia	Scandia (SCDK1)
Topeka, KRV	Silver Lake 4E	Topeka ASOS (TOP)

KANSAS FERTILIZER RESEARCH 2022

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