



Winter Wheat Soil Fertility Research: Focusing on Autumn Management and Beyond

2025 Report to the Michigan Wheat Program

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Location: Lansing, MI	Pre-plant soil: soil pH 6.9, OM 2.1%, 10.3 CEC, 32ppm Bray P, 55 ppm K
Planting Date: 20 Sept. 2021	Treatments: see Table 3
Harvesting: 9 July 2022	Replications: 4
Variety and Population: Soft Red Winter Wheat 'Wharf' at 1.8 million seeds A ⁻¹	Tillage: Conventional

INTRODUCTION

Sulfur (S) deficiencies have been diagnosed in wheat across the upper Midwest and Canada. Reduced atmospheric S deposition, continued and increasing crop removal of S, higher amounts of crop residues, greater use of no tillage, and earlier wheat planting dates under more intensive cropping rotations all contribute to why S deficiency is more common. Yellowing of the upper foliage is often mis-diagnosed as N deficiency when in fact often is S-deficiency.

Planting time can be an optimal time to address wheat S application but also does depend on when wheat is getting planted. A question that often arises is whether autumn or spring is the optimal time to apply S in winter wheat. The answer to this question does involve predicting precipitation volumes between autumn and spring green-up but also depends on how much risk a grower is willing to accept as sulfate S is an anion and can leach from the rootzone during the winter and spring months when excessive rainfall occurs. Sulfur can move extensively throughout the rootzone so multiple years of this study across different growing environments will enhance our understanding on management of this nutrient. We will investigate multiple S sources including ammonium sulfate, ammonium thiosulfate, gypsum, and MESZ applied during both autumn and spring to determine impacts on plant growth and development, plant tissue S concentrations, and yield.

Depending on initial soil test values and when wheat is planted timely, our research has shown autumn nutrient management practices can have a substantial impact on yield. We will investigate 6 nutrient management practices at two application rates (low vs high with rate dependent on nutrient) to better address what growers can or should consider applying during the fall season and address the concerns of “if some is good, then more is better”. This study will also employ site-specific soil test reports that will allow growers to both witness and visually see wheat response to a variety of nutrients and the response at a specific soil test value.

When should growers apply the bulk of their N? The answer to this question will vary across the 8,000+ wheat growers in Michigan and will be field-specific, site-specific, and depend to some extent on individual grower infrastructure. However, field research the last several years has consistently shown green-up (Feekes 4/5) N applications to outperform freeze-up N applications (early-March) by anywhere from 5-15 bu/A. However, there can be a number of reasons or factors for growers to apply N during less optimal times including infrastructure, cropping rotations, and weather patterns. The key factor to identify is when these less than optimal conditions occur and how can the grower respond. Additionally, late N applications have proven less effective when the initial N application is applied at the optimal growth stage or timing. Studies will continue to investigate three general N application windows individually and in conjunction with late-season applied N. These factors will add to the multi-year data base for appropriate N application timings for Michigan winter wheat.

OBJECTIVE AND HYPOTHESES

Objective 1. Identify autumn nutrient management practices that may bring a greater return on grower investment and focus on application rates for these practices. Our *working hypothesis* is that growers often subscribe to the “some is good and more is better” approach to specific practices but in many instances low rates can be as effective as greater application rates depending on soil test concentrations. These practices may also allow for improved stand establishment and overwintering success thus allowing wheat to withstand variable Michigan spring weather.

Objective 2. Identify differences in S timing and solubility of different products and impacts on plant S concentrations and yield. Our *working hypothesis* is product differences in S solubility exist and more soluble autumn source application will enhance yield compared to spring applications.

Objective 3. Identify optimal N application timing and strategy database for growers to draw from year over year. Our *working hypothesis* is that green-up N application at Feekes 4/5 tend to outperform earlier N applications, but weather will greatly influence these results, and autumn N applications may be getting a closer look given the ever-changing winter and spring weather conditions Michigan has received the last several growing season.

MATERIALS AND METHODS

Experiments were arranged as a randomized complete block with 4+ replications. Projects will be initiated at the MSU Agronomy Farm and or Mason Farm with planting dates

between late-September through early-October. Wheat was seeded in 7.5-inch rows at 1.4 - 1.8 million seeds/A using a top-10 variety trial red wheat.

Autumn nutrient management strategies were implemented either preplant incorporated or broadcast immediately after planting. When comparing sulfur sources and timing, S application occurred either pre-plant or during early March. At planting, plots may receive P₂O₅ and K₂O as maintenance applications to account for crop removal. Bulk N applications were applied at Feekes 4/5. Plant vegetative sampling occurred throughout the season with timing depending on which specific nutrient being studied.

Other data collection varied by individual project but included: soil analysis, soil analysis for NH₄ and NO₃ at specific soil depths, weekly NDVI readings from green-up through maturity, Canopeo stand density readings, autumn tiller counts, March tiller counts, tissue sampling and analysis at Feekes g.s. 5 and Feekes g.s.9, lodging ratings, head counts, disease incidence, grain moisture, grain test weight, and grain yield.

RESULTS AND DISCUSSION

Rainfall was near normal for most of the wheat growing season but air and soil temperatures were slow to warm throughout spring. Cooler spring temperatures moderated early season growth potential but supported additional spring tiller development. Soil temperatures did not rise above 50F permanently until June 3, delaying some early season nitrification of spring applied N fertilizer.

Research specifics for the growing season included: 9/20/2024 planting date, soil temperatures dropping below 50F permanently on 11/22/2024, FreezeUp N applications on 3/6/2025, GreenUp N applications on 4/8/2025, Feekes 5 growth stage 4/14/2025, Feekes 7 growth stage on 4/24/2025, Feekes 9 growth stage on 5/13/2025, Feekes 10.5.1 growth stage on 5/30/2025, and wheat harvest on 7/10/2025.

Autumn Nutrient Management – Hi-Lo Study

Autumn nutrient management practice significantly affected grain yield (Table 2). Please see initial soil test concentrations on page one of this report. Also remember that all treatments (other than check) did receive a base N application of 100 lbs. N A⁻¹ at greenup in spring. Treatments involving S application yielded significantly greater than remaining autumn nutrient practices. It is important to note that the greater rate of S-only application did not yield greater than the lower S-only rate. Perhaps of greater importance is the finding that autumn S application increased flag leaf tissue N concentrations greater than autumn N only applications (Table 2). Increasing the efficiency of N applications by applying S would seem to indirectly implicate N:S ratio which often hovers near 10:1 (N:S) but may range anywhere from 8:1 to 14:1 depending on cropping system and environmental conditions. Producers should not forget to account for all N applied when accounting for the overall nutrient management program.

Phosphorus application did not have a significant impact on grain yield at either the low or high autumn applied P rate. The residual STP value for this project was 32 ppm Bray P1 which is above the critical STP value of 25 ppm thus a response to P application was not necessarily expected unless lack of soil moisture limited diffusive P movement. It is important to

remember that the P source in this study was triple superphosphate, a product that does not contain N. Thus with other P sources (MAP, DAP, APP) be sure to determine whether any response observed is due to P application and not the residual N that went along with the P application. Potash applications had little to no impact in the current study even at extremely low STK values because as STK values decrease well below critical values K fixation tends to increase limiting the amount of K solubility in the current year soil. This impact is one reason producers should not allow soil test values to drop well below critical thresholds.

Sulfur – Autumn vs. Spring Applications

To account for incidental N with some S sources, all treatments other than the check were balanced to receive 25 lbs N A⁻¹ applied in the autumn followed by 100 lbs N A⁻¹ applied at green-up. Sulfur application included either 15 lb S A⁻¹ autumn applied top-dress immediately after planting or 15 lb S A⁻¹ spring applied at Greenup Feekes 4. Sulfur sources included AMS, ATS, gypsum, and 12-40-0-10-1. No interactions occurred between S source and S timing on grain yield (Table 3). Grain yield was not significantly affected by S source or S application timing. However, S application increased grain yield 17-33 bu A⁻¹ when compared to no S application. Fall applications of the four S sources demonstrated no significant differences in Feekes 5 tissue N or S concentrations. Feekes 9 tissue N also did not significantly differ by treatment. Feekes 9 tissue S concentrations were significantly impacted by S source and timing strategies. Ammonium sulfate showed minimal differences in flag leaf tissue S concentrations between autumn and spring applications. ATS and 12-40-0-10-1 demonstrated greater Feekes 9 tissue S% with autumn applications while gypsum demonstrated greater Feekes 9 tissue S% with spring S applications. Sulfur source and timing responses will be greatly impacted by weather conditions and may change year-to-year. Autumn S application increased grain yield 4 bu A⁻¹ as compared to spring S application but results were not statistically significant.

Nitrogen Application Timings 2025

Treatments received 100 lbs N A⁻¹ or 140 lbs N A⁻¹ if receiving a late Feekes 7 N application. Nitrogen application timing dates were 9/23/2024 for at-plant N, 11/22/2024 for Fall ST<50 F N, 3/6/2025 for FreezeUp N, and 4/8/2025 for GreenUp N. Feekes 7 late-N applications occurred on 4/24/2025. Rainfall intensities and volumes influence the yield response to singular versus multi-pass N application strategies. Rainfall totals between specific N application strategies were as follows: planting to ST<50F 3.5 inches; ST<50F to freezeup 3.6 inches; freezeup to greenup 4.0 inches; greenup to flag leaf 3.3 inches.

Nitrogen application strategy significantly affected grain yield (Table 4). Amongst singular N application strategies, few yield differences occurred between Fall ST<50F, FreezeUp, and GreenUp N application timings. Fall at-plant N yielded about 30 bu A⁻¹ less than the remaining singular N strategies. Remember that when autumn N application occurs with soil temperatures >50F, the nitrification process still proceeds relatively quickly resulting in much of the applied N as nitrate thus potential leaching or denitrification N losses. Soil temperatures remained >50F for nearly two months after the Fall at-plant N application. Despite 7+ inches of additional rainfall between ST<50F and GreenUp N applications, yield was not affected. One

explanation again could be the lack of nitrification after N application but also the cool spring soil temperatures delaying early season plant development.

The greater degree of N loss early often results in a better yield response to later N applications. An additional 40 units of N increased grain yield for fall at-plant by 17 bu A⁻¹ but statistically did not have an impact on the Fall ST< 50F or FreezeUp application strategies. The additional 40 units N at Feekes 7 increased the GreenUp strategy by 17 bu A⁻¹. Again, N application strategies and timing responses will be impacted by weather conditions, including soil temperatures, and will vary year-to-year. Growers need to remain fluid and able to adjust as there is no year-to-year relationship between wheat N rate and grain yield. Flag leaf %N concentrations paralleled grain yield results with greater F9 tissue N resulting in greater grain yields (Table 4). Feekes 9 tissue N was also a better predictor of grain yield than NDVI measurements at Feekes 7 or 9 growth stages. Many of these studies will be repeated in 2026 under different environmental conditions so stay tuned for new results and updates later summer 2026. You can always check out additional results at soil.msu.edu or feel free to reach out at ksteinke@msu.edu

Table 1. Mean monthly and 30-yr. precipitation, temperature, and 15-yr relative humidity for the winter wheat growing season. Lansing, MI, 2025. †

Year	Mar.	Apr.	May	Jun.	Jul.	Total
	inches					
2025	3.10	2.30	4.10	2.80	2.70	15.00
30-yr. Ave‡	2.13	3.26	3.66	3.76	2.94	15.75

†Precipitation data were collected from MSU Enviro-weather (<https://mawn.geo.msu.edu/>).

‡ 30-yr means obtained from the National Oceanic and Atmospheric Administration (<https://www.ncdc.noaa.gov/cdo-web/datatools/normals>).

Table 2. Winter wheat grain yield (13.5 % moisture) and flag leaf tissue N, P, K, and S concentrations as affected by autumn nutrient management practice, Lansing, MI, 2025. All treatments other than check received 100 lbs N A⁻¹ at green-up with autumn nutrient treatments top-dressed immediately after planting.

Treatment	Grain Yield	Feekes 9 Tissue N	Feekes 9 Tissue P	Feekes 9 Tissue K	Feekes 9 Tissue S
	Bu A⁻¹	%	%	%	%
Check- nothing applied	34.9 f	2.9 e	0.32 e	1.84 abc	0.24 e
Spring N Only	80.2 cde	4.6 abcd	0.38 ab	1.87 abc	0.31 bcde
20 N Fall	69.4 de	4.3 d	0.36 bcd	1.75 cd	0.27 de
40 N Fall	81.2 cd	4.4 cd	0.36 bcd	1.72 cd	0.31 bcde
65 P2O5 Fall	86.0 bc	4.6 abcd	0.38 abc	1.72 cd	0.32 bcde
130 P2O5 Fall	83.0 c	4.5 bcd	0.38 ab	1.74 cd	0.29 cde
25 S Fall	106.4 a	4.9 a	0.36 bcd	1.82 bc	0.41 a
50 S Fall	97.1 ab	4.5 abcd	0.35 cd	1.85 abc	0.38 ab
75 K2O Fall	76.0 c	4.3 cd	0.36 bcd	2.07 ab	0.27 de
150 K2O Fall	69.0 e	4.3 d	0.38 abc	2.08 a	0.28 de
125 lbs A ⁻¹ 12-40-0-10-1	105.2 a	4.8 ab	0.38 ab	1.71 cd	0.36 abc
250 lbs A ⁻¹ 12-40-0-10-1	105.1 a	4.9 a	0.39 a	1.55 d	0.41 a
AMS 15N, 12.5S	104.0 a	4.7 abc	0.34 de	1.71 cd	0.38 ab
AMS 30N, 25S	105.1 a	4.6 abcd	0.30 e	1.85 abc	0.33 abcd
P > F	<0.0001	<0.0001	<0.0002	<0.02	<0.003
LSD (0.05)	11.8	0.36	0.028	0.253	0.078

Table 3. Winter wheat grain yield (13.5 % moisture), Feekes 5 N and S concentrations, and Feekes 9 N and S concentrations as affected by S source and S timing, Lansing, MI, 2025. All treatments other than check received 100 lbs N A⁻¹ at green-up with 15 lb A⁻¹ autumn S applied top-dress immediately after planting and 15 lb A⁻¹ spring S applied at Greenup Feekes 4.

Treatment	Grain Yield	Feekes 5 Tissue N	Feekes 5 Tissue S	Feekes 9 Tissue N	Feekes 9 Tissue S
	Bu A ⁻¹	%	%	%	%
Check- No S, Yes N	76.2 b				
Fall AMS	102.6 a	3.29 a	0.24 a	4.52 a	0.373 abc
Spring AMS	96.4 a	----	----	4.48 a	0.368 abcd
Fall ATS	103.3 a	3.10 a	0.24 a	4.68 a	0.375 abc
Spring ATS	103.9 a	----	----	4.26 a	0.338 d
Fall Gypsum	101.5 a	3.06 a	0.22 a	4.57 a	0.358 bcd
Spring Gypsum	93.1 a	----	----	4.69 a	0.393 a
Fall 12-40-0-10-1	109.6 a	2.95 a	0.22 a	4.90 a	0.388 ab
Spring 12-40-0-10-1	106.2 a	----	----	4.35 a	0.345 cd
P > F	< 0.0001	0.97	0.54	0.08	0.03
LSD (0.05)	14.2	NS	NS	NS	0.039

Table 4. Winter wheat grain yield (13.5 % moisture), Feekes 9 tissue N concentrations, and Feekes 7 and 9 NDVI measurements as affected by N application timing, Lansing, MI, 2025. Treatments received either 100 lbs N A⁻¹ or 140 lbs N A⁻¹ if receiving a late Feekes 7 N application. Nitrogen application timing dates were 9/23/2024 for at-plant N, 11/22/2024 for Fall ST<50 F N, 3/6/2025 for FreezeUp N, and 4/8/2025 for GreenUp N. Feekes 7 late-N applications occurred on 4/24/2025.

Treatment	Grain Yield	Feekes 9 Tissue N	NDVI Feekes 7	NDVI Feekes 9
	Bu A ⁻¹	%		
Check- No N	33.3 e	2.91 e	0.61 ef	0.23 d
Fall- at plant (100N)	60.8 d	3.31 d	0.77 a	0.38 bc
Fall ST<50F (100N)	91.8 b	4.47 b	0.76 ab	0.50 a
FreezeUp (100N)	90.7 bc	4.56 b	0.69 bcd	0.44 ab
GreenUp (100N)	88.9 bc	4.69 ab	0.66 def	0.45 ab
Fall- at plant + 40 F7 (140N)	77.0 c	3.87 c	0.72 abcd	0.49 ab
Fall ST<50F + 40 F7 (140N)	97.5 ab	4.41 b	0.75 ab	0.55 a
FreezeUp + 40 F7 (140N)	102.0 ab	4.62 b	0.74 abc	0.51 a
GreenUp +40 F7 (140N)	105.7 a	4.98 a	0.67 cde	0.47 ab
40 N F7 Only (40 N)	47.6 d	4.05 c	0.59 f	0.29 cd
P > F	< 0.001	<0.001	<0.001	<0.001
LSD (0.05)	13.7	0.32	0.07	0.11