Start Right to Finish Well: Wheat Grain and Straw Production - Year 2
2021 Report to the Michigan Wheat Program

Participating PI's/Co PI's: Kurt Steinke, Associate Professor, Dept. of Plant, Soil, and Microbial Sciences, Michigan State University, East Lansing, MI.
Lacie Thomas, Graduate Research Assistant (M.S.) Michigan State University

Location: Lansing, MI	**Tillage**: Conventional
Planting Date: September 22, 2020	**Nitrogen Rates**: 50, 100, 150 lbs. N/A
Soil Type: Conover Loam; 6.8 pH, 12.3 meq $100g^{-1}$ CEC, 3.1% OM, 35 ppm P (Bray P-1), 8 ppm S, 3.1 ppm Zn	**Population**: 1.8 million seeds/A
Variety: Flipper & Red Dragon (SRWW)	**Replicated**: 4 replications

Location: Richville, MI	**Tillage**: Conventional
Planting Date: September 24, 2020	**Nitrogen Rates**: 60, 120, 180 lbs. N/A
Soil Type: Tappan-Londo Loam; 7.4 pH, 15.8 meq $100g^{-1}$ CEC 2.4% OM, 21 ppm P (Olsen P) 7 ppm S, 4.1 ppm Zn	**Population**: 1.8 million seeds/A
Variety: Jupiter & AC Mountain (SWWW)	**Replicated**: 4 replications

Introduction:

Increases in wheat (*Triticum aestivum* L.) grain and straw yield along with heightened awareness of soil spatial variability have motivated growers to focus on season-long soil nutrient availability. Michigan produces some of the nation's greatest wheat yields averaging between 75-81 bu A^{-1} in 2020-2021 (USDA-NASS, 2020-2021). As the demand for wheat straw increases (e.g., livestock bedding, feed, and biofuel), management strategies that consider both grain yield and straw production will be critical to the economic return for Michigan wheat growers.

Previous studies indicate a positive correlation between wheat yield and biomass production. For maximum production, methods of determining N fertilization rates in winter wheat are often based on fixed N removal rates per unit of produced grain and projected yield goals (Lukina et al., 2001). Nitrogen deficiency during establishment may result in reduced tiller counts and growth rates setting limitations on grain yield and biomass production before initiating primary development (Zhang et al., 2020). Application of autumn starter provides greater nutrient availability during early crop development stages thus impacting yield potential (Nkebiwe et al., 2016; Steinke et al., 2021). To promote autumn tillering and stand establishment, 25 lb N A^{-1} may be utilized in Michigan winter wheat production (Warncke et al., 2009). Autumn starter recommendations are impacted by residual soil nitrate levels which may depend on crop rotation, diversity, and frequency (Mourtzinis et al., 2017).

Variety selection is an important management strategy for achieving high yielding grain but among small grain cereals increases in yield potential have primarily come from improved harvest index through shorter plants thus potentially at the expense of straw production. Taller wheat varieties are better suited for stressed environments due to improved emergence and harvestability. However, selecting varieties less susceptible to lodging and shattering is important to both grain and straw production (Klein, 2007). Although, short statured varieties are often overlooked for straw production, responses to input manipulation have overcome limitations specific to wheat variety and environmental conditions (Beuerlein et al., 1989; Karlen & Gooden, 1990).

Objective and Hypothesis:

Objective: Evaluate soft red winter wheat (SRWW) and soft white winter wheat (SWWW) grain and straw yield response to autumn applied starter fertilizer, spring N, and varietal stature. Our *working* hypothesis is that autumn-applied starter fertilizer will increase wheat stand resilience (soil-test dependent) prior to spring greenup for improved grain yield, straw production, and grower profitability.

Methods and Procedures:

A randomized complete block split-plot design with four replications was used to evaluate three 12-40-0-10S-1Zn autumn starter rates, three spring N rates, and two varietal statures (Table 1, 2). Main plots consisted of three rates of autumn starter fertilizer while sub-plots consisted of three spring N rates. The untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Variety stature was an additional component of this study. One short statured SRWW variety (i.e., 'Flipper') and one tall statured SRWW variety (i.e., 'Red Dragon') were selected to evaluate autumn starter implications on plant height and biomass production in Lansing, MI. One short statured SWWW variety (i.e., 'Jupiter') and one tall statured SWWW variety (i.e., 'AC Mountain') were selected for Richville, MI.

Table 1. Overview of split plot trial design, treatment names, and inputs applied to soft red winter wheat, Lansing, MI 2020 and 2021.

Treatment	**Treatment Name**	------Autumn Starter and Spring Nitrogen (N)	
		Rate† 12-40-0-10S-1Zn	**Rate‡ UAN (28%)**
1	No Starter, Low N	0 lb A^{-1}	50 lb A^{-1}
2	No Starter, Base N	0 lb A^{-1}	100 lb A^{-1}
3	No Starter, High N	0 lb A^{-1}	150 lb A^{-1}
4	Mid Starter, Low N	125 lb A^{-1}	50 lb A^{-1}
5	Mid Starter, Base N	125 lb A^{-1}	100 lb A^{-1}
6	Mid Starter, High N	125 lb A^{-1}	150 lb A^{-1}
7	High Starter, Low N	250 lb A^{-1}	50 lb A^{-1}
8	High Starter, Base N	250 lb A^{-1}	100 lb A^{-1}
9	High Starter, High N	250 lb A^{-1}	150 lb A^{-1}
10	**Check**		

† Autumn starter (12-40-0-10S-1Zn) applied as top-dress application 6 Oct. 2020.

‡ Spring nitrogen (UAN 28%) applied at green-up 23 Mar. 2021.

Table 2. Overview of split plot trial design, treatment names, and inputs applied to soft white winter wheat, Richville, MI 2020 and 2021.

Treatment	**Treatment Name**	------Autumn Starter and Spring Nitrogen (N)	
		Rate† 12-40-0-10S-1Zn	**Rate‡ UAN (28%)**
1	No Starter, Low N	0 lb A^{-1}	60 lb A^{-1}
2	No Starter, Base N	0 lb A^{-1}	120 lb A^{-1}
3	No Starter, High N	0 lb A^{-1}	180 lb A^{-1}
4	Mid Starter, Low N	125 lb A^{-1}	60 lb A^{-1}
5	Mid Starter, Base N	125 lb A^{-1}	120 lb A^{-1}
6	Mid Starter, High N	125 lb A^{-1}	180 lb A^{-1}
7	High Starter, Low N	250 lb A^{-1}	60 lb A^{-1}
8	High Starter, Base N	250 lb A^{-1}	120 lb A^{-1}
9	High Starter, High N	250 lb A^{-1}	180 lb A^{-1}
10	**Check**		

† Autumn starter (12-40-0-10S-1Zn) applied as top-dress application 6 Oct. 2020.

‡ Spring nitrogen (UAN 28%) applied at green-up 30 Mar. 2021.

Results and Discussion (2020-2021):

Soft Red Winter Wheat Yield

Autumn starter fertilizer and spring N interacted to affect both grain and straw yield in SRWW variety ‘Flipper’ (Table 3 & 4). The high starter, low nitrogen treatment resulted in an increase of 22.5 bu A^{-1} as compared to the no starter, high N treatment (Table 3). No significant difference in straw yield occurred between mid-autumn starter, base or high N as compared to no autumn starter, base or high N treatments (Table 4). However, straw yield increased 0.89 T A^{-1} with the high autumn starter, low N treatment as compared to no autumn starter, low N treatment in 2021. Main effects of autumn starter increased both grain and straw yield in tall-statured 'Red Dragon' by 17.2 bu A^{-1} and 0.34 T A^{-1}, respectively in 2021 (Table 3 & 4). Tiller development was significantly greater with high application of autumn starter for 'Red Dragon' (Table 10). Optimal fertilization can promote tiller production and increase the number of stems for grain and straw yield potential. Increase in biomass of productive stems is closely related to grain per gram of spike and can result in greater yield efficiency (Slafer et al., 2015).

Soft White Winter Wheat Yield

The high rate of autumn starter increased 'Jupiter' grain yield compared to no starter but yield was similar to the mid starter application rate (Table 5). Application of autumn starter resulted in a 19.8 bu A^{-1} and 0.77 T A^{-1} increase in grain and straw yield, respectively (Table 5 & 6). High spring N increased grain yield by 3.3 and 11.5 bu A^{-1} as compared to the base and low spring N rates. Additionally, autumn starter and spring N interacted to affect grain yield in 'AC Mountain' (Table 5). The high autumn starter, base spring N was the highest yielding treatment and increased production by 16.7 bu A^{-1} as compared to no autumn starter, base spring N. There was no significant increase in grain yield between no, mid, or high autumn starter in combination with high spring N. Straw yield for 'AC Mountain' increased with application of autumn starter (Table 6). Base and high spring N application increased straw yield by 0.28 T A^{-1}. Application of autumn starter positively impacted tiller production in both SRWW varieties. Greatest tiller establishment in 'AC Mountain' occurred with high autumn starter. Tiller counts were similar for 'Jupiter' with mid and high autumn starter increasing tillers as compared to no autumn starter.

Profitability

Net profitability analysis of grain and straw yield was conducted to evaluate SRWW and SWWW return on investment (Table 3,4,5,6). Local grain and straw market price, total treatment cost, and harvest cost (i.e., threshing and baling) were assessed to determine the estimated net return based on observed yields. Net grain yield profitability was highest in SRWW variety 'Flipper' with the high starter, low N treatment but was not significantly different from any combination of mid or high starter, spring N application (Table 3). When including net straw profitability, high starter, low and high N treatments yielded the greatest return, but were not significantly greater than any combination of mid starter, spring N treatment (Table 4). In SRWW variety 'Red Dragon,' application of autumn starter increased both grain and straw yield profitability. Additionally, mid-autumn starter did not significantly differ from high autumn starter (Table 3 &4). In SWWW variety 'AC Mountain' autumn starter and spring N interacted to affect grain yield profitability with high starter, base N as the most profitable treatment (Table 5). With inclusion of straw yield, increased net profit was driven by application of base spring N rate. Grain yield profitability individually and grain + straw yield profitability were both driven by mid-autumn starter application rates or greater for SWWW variety 'Jupiter' (Table 5 & 6). Net profitability decreased with low spring N application as compared to base and high spring N rates for both grain and straw yield net profitability.

Straw nutrient removal is an important factor influencing economic return of straw production. The average straw fertilizer equivalent is 13.0-16.2 lbs T^{-1} N, 2.4-3.3 lbs T^{-1} P_2O_5, 23.0-26.8 lbs T^{-1} K_2O, and 0.8 lbs T^{-1} sulfur (S) (Culman et al., 2020; Reiter et al., 2015; Warncke et al., 2009). In 2021, straw nutrient removal values for SRWW and SWWW varieties were lower than average for N, P_2O_5, and K_2O with slightly above average S removal (Table 7 & 8). For SRWW, nutrient removal was greatest for N and P_2O_5 with the no starter, high N treatment (Table 7). No significant difference was observed in K_2O removal across any autumn starter or spring N treatment. Sulfur removal was greatest with high autumn starter and high spring N. In SWWW, removal of N, P_2O_5, and K_2O was not affected by autumn starter application (Table 8). S removal was highest with the inclusion of autumn starter. High spring N resulted in the greatest removal of all nutrients.

Pre plant K was 99-166 ppm, exceeding critical levels for Lansing and Richville, respectively. The uptake rate of K increases in the period of resuming growth to booting stage with peak uptake at full to end of flowering (Ali et al., 2019; Malhi et al., 2011). April and May cumulative rainfall differed by -48 and -72% in Lansing and -75 and -65% in Richville, respectively from the 30-yr mean in 2021. Lack of soil moisture throughout vegetative and flowering stages likely reduced K accessibility for uptake resulting in no change of K_2O removal by treatment. An overall increase in nutrient removal was consistent with above recommended N rates (i.e., additional N application drove additional nutrient removal). Differences in N and S uptake may be driven by nutrient availability (i.e. fertilizer application) while changes in uptake of P and K may be attributed to changes in shoot biomass (Silva et al., 2021).

Optimum nutrient management is essential to reduce nutrient losses to the environment and to improve nutrient use efficiency (i.e., yield per unit of fertilizer applied) (Silva et al., 2021). Elevated fertility costs increase the importance of site-specific nutrient management and application efficiency. Oct. 2021 mean price per pound of N, K_2O, and P_2O_5 increased 25-110% as compared to Oct. 2019 values (Table 9). Continued increase in fertilizer pricing combined with decreased availability drives the economic importance for precise, timely, and soil-test based application of autumn starter and spring N to maximize net profitability.

Table 3. SRWW mean grain yield and net profitability analysis**.**

Treatment	Flipper		Treatment	Red Dragon	
	--Bu A^{-1}--	**--US$ A^{-1}--**		**--Bu A^{-1}--**	**--US$ A^{-1}--**
No Starter, Low N	90.6 ef	$508.84 b	No Starter	71.4 b	$362.52 b
No Starter, Base N	98.3 de	$531.41 ab	Mid Starter	88.6 a	$439.21 a
No Starter, High N	88.6 f	$444.15 c	High Starter	92.3 a	$431.55 a
Mid Starter, Low N	106.7 bcd	$578.97 a	*Pr > F*	< 0.01	= 0.05
Mid Starter, Base N	104.0 cd	$536.14 ab			
Mid Starter, High N	113.8 ab	$571.42 ab	Low N	64.9 b	$316.83 b
High Starter, Low N	111.1 abc	$575.19 a	Base N	92.4 a	$463.31 a
High Starter, Base N	105.6 bcd	$514.85 ab	High N	94.9 a	$453.14 a
High Starter, High N	118.0 a	$567.06 ab	*Pr > F*	< 0.01	< 0.01
Check‡	43.7	$240.56			
$P_r > F$	= 0.04	= 0.04	Check‡	40.8	$222.38

† Values followed by the same lowercase letter are not significantly different at α=0.1
‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Table 4. SRWW mean straw yield and net profitability analysis grain & straw combined.

Treatment	Flipper		Treatment	Red Dragon	
	--T A^{-1}--	**--US$ A^{-1}--**		**--T A^{-1}--**	**--US$ A^{-1}--**
No Starter, Low N	1.07 c	$646.83 c	No Starter	1.07 b	$495.26 b
No Starter, Base N	1.38 bc	$712.29 bc	Mid Starter	1.41 a	$630.34 a
No Starter, High N	1.36 bc	$622.72 c	High Starter	1.53 a	$633.45 a
Mid Starter, Low N	1.48 bc	$773.62 ab	*Pr > F*	= 0.04	= 0.01
Mid Starter, Base N	1.66 ab	$756.88 ab			
Mid Starter, High N	1.54 ab	$775.67 ab	Low N	1.00 a	$450.58 b
High Starter, Low N	1.96 a	$837.14 a	Base N	1.48 a	$653.75 a
High Starter, Base N	1.52 b	$715.98 bc	High N	1.53 a	$654.73 a
High Starter, High N	2.00 a	$835.42 a	*Pr > F*	< 0.01	< 0.01
Check‡	0.53	$302.78			
$P_r > F$	= 0.04	= 0.05	Check‡	0.58	$291.60

† Values followed by the same lowercase letter are not significantly different at α=0.1
‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Table 5. SWWW mean grain yield and net profitability analysis**.**

Treatment	AC Mountain		Treatment	Jupiter	
	--Bu A^{-1}--	--US$ A^{-1}--		--Bu A^{-1}--	--US$ A^{-1}--
No Starter, Low N	80.5 e	$448.33 d	No Starter	83.9 b †	$438.85 b
No Starter, Base N	96.6 c	$519.53 bc	Mid Starter	103.7 a	$533.91 a
No Starter, High N	103.6 b	$533.21 ab	High Starter	108.2 a	$531.56 a
Mid Starter, Low N	88.3 d	$451.80 d	*Pr > F*	< 0.01	< 0.01
Mid Starter, Base N	105.4 b	$547.46 ab			
Mid Starter, High N	106.7 b	$521.85 bc	Low N	89.8 c	$476.60 b
High Starter, Low N	93.0 cd	$465.72 d	Base N	101.3 b	$518.98 a
High Starter, Base N	113.3 a	$564.17 a	High N	104.6 a	$508.74 a
High Starter, High N	105.5 b	$482.66 cd	*Pr > F*	< 0.01	< 0.01
Check‡	48.0	$372.34			
$P_r > F$	= 0.06	= 0.10	Check‡	52.3	$299.71

† Values followed by the same lowercase letter are not significantly different at α=0.1
‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Table 6. SWWW mean straw yield and net profitability analysis grain & straw combined.

Treatment	AC Mountain		Treatment	Jupiter	
	---T A^{-1}---	--US $ A^{-1}--		--T A^{-1}--	--US $ A^{-1}--
No Starter	1.34 b †	$676.18	No Starter	0.88 b	$550.43 b
Mid Starter	1.50 a	$702.21	Mid Starter	1.21 a	$690.73 a
High Starter	1.61 a	$714.57	High Starter	1.22 a	$689.77 a
Pr > F	= 0.03	NS	*Pr > F*	< 0.01	< 0.01
Low N	1.29 b	$601.62 b	Low N	0.98 b	$601.62 b
Base N	1.57 a	$665.67 a	Base N	1.13 a	$665.67 a
High N	1.59 a	$663.64 a	High N	1.19 a	$663.64 a
Pr > F	< 0.01	< 0.01	*Pr > F*	< 0.01	< 0.01
Check‡	0.80	$372.34	Check‡	0.58	$368.93

† Values followed by the same lowercase letter are not significantly different at α=0.1
‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Table 7. 2021 SRWW mean straw nutrient removal.

Treatment	Nitrogen	P_2O_5	Treatment	K_2O	Sulfur
	--------------------------------	---lbs T^{-1}---	--------------------------------		
No Starter, Low N	9.65 c†	2.70 bc	No Starter	12.45	0.91 b
No Starter, Base N	9.70 c	2.70 bc	Mid Starter	12.77	1.00 b
No Starter, High N	14.75 a	4.83 a	High Starter	12.77	1.18 a
Mid Starter, Low N	8.93 c	2.36 c	*Pr > F*	NS	< 0.01
Mid Starter, Base N	9.58 c	2.36 c			
Mid Starter, High N	11.50 b	2.93 b	Low N	11.84	0.97 b
High Starter, Low N	9.68 c	2.59 bc	Base N	12.92	0.94 b
High Starter, Base N	9.38 c	2.42 bc	High N	12.23	1.18 a
High Starter, High N	12.00 b	2.93 b	*Pr > F*	NS	< 0.01
Check‡					
$P_r > F$	=0.03	< 0.01	Check‡		

† Values followed by the same lowercase letter are not significantly different at α=0.1
‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Table 8. 2021 SWWW mean straw nutrient removal.

Treatment	Nitrogen	P_2O_5	K_2O	Sulfur
	--------------------------------	---lbs T^{-1}---	--------------------------------	
No Starter	9.63 †	1.86	19.11	0.83 b
Mid Starter	9.62	1.73	19.24	1.09 a
High Starter	9.99	1.96	19.37	1.22 a
Pr > F	NS	NS	NS	< 0.01
Low N	8.15 c	1.63 b	16.93 c	0.90 c
Base N	9.70 b	1.80 b	19.25 b	1.05 b
High N	11.38 a	2.11 a	21.54 a	1.19 a
Pr > F	< 0.01	< 0.01	< 0.01	< 0.01
Check‡				

† Values followed by the same lowercase letter are not significantly different at α=0.1
‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis

Table 9. Mean fertilizer pricing autumn 2019 and 2021.

Product	2019	2021	Nutrient	2019	2021
	------------- **$/T^{-1}** -------------			----------- **$/lb^{-1}** ----------	
Urea 46-0-0	$485	$810	Nitrogen	$0.53	$0.88
UAN 28-0-0	$385	$475	Nitrogen	$0.68	$0.85
MAP 11-52-0	$428	$885	P_2O_5	$0.41	$0.85
MOP 0-0-60	$370	$776	K_2O	$0.31	$0.65

† Mean fertilizer price obtained from USDA Illinois Department of Agriculture Market News Report Oct. 2019 and 2021 (https://mymarketnews.ams.usda.gov/filerepo/sites/default/files/3195/2021-10-21/518047/ams_3195_00044.txt).

Table 10. Influence of autumn starter (12-40-0-10S-1Zn) on tillers ft^2.

Variety	Location	No Starter	Med Starter	High Starter	
		-------------------- Height cm^{-1}		----------------------	*Pr > F*
Red Dragon	Lansing	156 b	165 b	228 a	= 0.03
Flipper	Lansing	162	165	171	NS
AC Mountain	Richville	142 b	157 b	187 a	= 0.03
Jupiter	Richville	106 b	148 a	158 a	< 0.01

† Values followed by the same lowercase letter are not significantly different at α=0.1
‡ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.
€ Heights obtained from 10 plants per plot used for this analysis.

Discussion

Results from the SRWW varieties indicate application of high (i.e., above recommended) spring N did not compensate for the lack of autumn applied starter at plant establishment. When pre-plant soil nitrate concentrations are below 10 ppm (which occurred in the current study), positive yield responses to autumn N are more probable (Alley et. al., 2009). Soil nitrate concentrations were 5.9 and 3.7 ppm indicating a positive response to autumn N may be probable especially considering the timely planting. In addition to N, the interaction between sulfur and nitrogen has shown to have an impact on the physiological attributes to wheat biomass and grain yield (Salvagiotti & Miralles, 2008). Research has shown that nitrogen use efficiency can be increased when there is no sulfur deficiency of the current crop (Salvagiotti & Miralles, 2008). Pre-plant soil S levels were 7 and 8 ppm in Lansing and Richville, respectively but soil S testing may not a reliable indicator for S response. Sulfur application may be cost effective considering ~25 lbs. A^{-1} is all that may be required. The critical soil test P concentration for winter wheat is 25 ppm (Warncke et al., 2009). A high pre-plant Bray P-1 phosphorous concentration of 35 in Lansing and 21 Olsen-P in Richville reduced the likelihood of a yield response to phosphorous application.

Results from SRWW varieties ‘Flipper’ and ‘Red Dragon’ agree with (Steinke et. al, 2021) who observed a grain yield decrease of 18.7 and 37.5 bu A^{-1} when autumn starter fertilizer was removed from enhanced management and a grain yield increase from 17.4 and 25.9 bu A^{-1} when autumn starter fertilizer was added to traditional management at Richville and Lansing, MI, respectively. Low pre-plant residual nitrate concentrations, inclusion of the sulfur component, and timely autumn planting likely resulted in the positive grain and straw yield response to autumn starter fertilizer observed at this location. Be sure to consider a pre-plant nitrate test as part of a proactive approach to address soil variability. Autumn starter can help winter wheat “Start Right to Finish Well” for optimal grain and straw production but response will be field- and site-specific.

References

Ali, I., Khan, A. A., Munsif, F., He, L., Khan, A., Ullah, S., Saeed, W., Iqbal, A., Adnan, M., & Ligeng, J. (2019). Optimizing rates and application time of potassium fertilizer for improving growth, grain nutrients content and yield of wheat crop. *Open Agriculture*, *4*(1), 500–508. https://doi.org/10.1515/OPAG-2019 0049

Alley, M. M., Scharf, P., Brann, D. E., Baethgen, W. E., & Hammons, J. L. (2009). Nitrogen management for winter wheat. Principles and recommendations (*Virginia Cooperative Extension Circular 424-026*). Blacksburg: Virginia Polytechnic Institute and State University.

Beuerlein, J. E., Oplinger, E. S., & Reicosky, D. (1989). Yield and Yield Components of Winter Wheat Cultivars as Influenced by Management-A Regional Study. *Journal of Production Agriculture*, *2*(3), 257–261. https://doi.org/10.2134/jpa1989.0257

Culman, Fulford, Camberato, & Steinke. (2020). Tri-State Fertilizer Recommendations for Corn, Soybean, Wheat, and Alfalfa. https://www.canr.msu.edu/soilfertility/Files/Main-page/FINAL%20PRINT.pdf (accessed 21 Dec 2021)

De Oliveira Silva, A., Jaenisch, B. R., Ciampitti, I. A., & Lollato, R. P. (2021). Wheat nitrogen, phosphorus, potassium, and sulfur uptake dynamics under different management practices. *Agronomy Journal*, *113*(3), 2752–2769. https://doi.org/10.1002/AGJ2.20637

Karlen, D. L., & Gooden, D. T. (1990). Intensive Management Practices for Wheat in the Southeastern Coastal Plains. *Journal of Production Agriculture*, *3*(4), 558–563. https://doi.org/10.2134/jpa1990.0558

Klein, R. N. (2007). How to Select the Winter Wheat Varieties Best for Your Operation | CropWatch | University of Nebraska–Lincoln. *Univeristy of Nebraska: Institute of Agriculture and Natural Resourcs*. https://cropwatch.unl.edu/how-select-winter-wheat-varieties-best-your-operation

Lukina, E. V., Freeman, K. W., Wynn, K. J., Thomason, W. E., Mullen, R. W., Stone, M. L., Solie, J. B., Klatt, A. R., Johnson, G. V., Elliott, R. L., & Raun, W. R. (2001). Nitrogen fertilization optimization algorithm based on in-season estimates of yield and plant nitrogen uptake. *Journal of Plant Nutrition*, *24*(6), 885–898. https://doi.org/10.1081/PLN-100103780

Malhi, S. S., Johnston, A. M., Schoenau, J. J., Wang, Z. H., & Vera, C. L. (2011). Seasonal biomass accumulation and nutrient uptake of wheat, barley and oat on a Black Chernozem Soil in Saskatchewan. *Https://Doi.Org/10.4141/P05-116*, *86*(4), 1005–1014. https://doi.org/10.4141/P05-116

Nkebiwe, P. M., Weinmann, M., Bar-Tal, A., & Müller, T. (2016). Fertilizer placement to improve crop nutrient acquisition and yield: A review and meta-analysis. *Field Crops Research*, *196*, 389–401. https://doi.org/10.1016/J.FCR.2016.07.018

Reiter, M. S., Deitch, U. T., Frame, W. H., Holshouser, D. L., & Thomason, W. E. (2015). The Nutrient Value of Straw. *Virignia Cooperative Extension*.

Salvagiotti, F., & Miralles, D. J. (2008). Radiation interception, biomass production and grain yield as affected by the interaction of nitrogen and sulfur fertilization in wheat. *European Journal of Agronomy*, *28*(3), 282–290. https://doi.org/10.1016/j.eja.2007.08.002

Slafer, G. A., Elia, M., Savin, R., García, G. A., Terrile, I. I., Ferrante, A., Miralles, D. J., & González, F. G. (2015). Fruiting efficiency: an alternative trait to further rise wheat yield. *Food and Energy Security*, *4*(2), 92–109. https://doi.org/10.1002/FES3.59

Steinke, K., S. Purucker, and M. Chilvers. 2021. Integrating multiple inputs for soft red and white winter wheat. Agron. J. 113:4306-4322. doi: 10.1002/agj2.20790.

USDA/NASS 2019 State Agriculture Overview for Michigan. (n.d.). Retrieved January 21, 2021, https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MICHIGAN

Warncke, D., J. Dahl, and L. Jacobs. 2009. Nutrient recommendations for field crops in Michigan. Ext. Bull. E2904. Michigan State Univ. Ext., East Lansing, MI. https://soil.msu.edu (accessed 20 May 2020).

Zhang, L., He, X., Liang, Z., Zhang, W., Zou, C., & Chen, X. (2020). Tiller development affected by nitrogen fertilization in a high-yielding wheat production system. *Crop Science*, *60*(2), 1034–1047. https://doi.org/10.1002/CSC2.20140