IMPACTS FROM AUTUMN STARTER FERTILIZER, LATE-SEASON NITROGEN, AND FUNGICIDE TIMING ON WINTER WHEAT YIELD, STRAW, AND GRAIN QUALITY

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INTRODUCTION

Michigan winter wheat (*Triticum aestivum* L.) encompasses nearly 500-600 thousand acres and is the third most planted annual row crop following soybean and corn (*FAOSTAT*, n.d.). To mitigate seasonal yield and soil spatial variabilities, growers continue to explore more intensive production practices. Current guidelines suggest 40-120 lb. N A^{-1} top-dressed at green-up with foliar fungicide applied five to six days following early flowering (i.e., Feekes [FK] 10.5.1) to protect against Fusarium head blight (FHB) (*Fusarium graminearum* Schwabe [telemorph *Giberella zea* (Schweinit) Petz]. Given the rising demand for wheat amid climate uncertainties, growers increasingly wish to address specific winter wheat production challenges beginning in autumn and lasting through harvest. This field study investigated the influence of autumn starter fertilizer, late-season nitrogen (FK 7), and multiple fungicide timings on the yield and quality of winter wheat grain and straw.

MATERIALS AND METHODS

Field studies were established in Lansing, MI on a Conover loam soil (Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*) following silage corn (SC) and soybean (SB) during the 2022-2023 growing season. Soft red winter wheat 'Wharf', a short-strawed, high-yielding variety (Michigan Crop Improvement Association, Okemos, MI), was planted following SC (30 Sept. 2022) and SB (04 October 2022). Treatments were arranged in a full factorial, randomized complete block design with three experimental factors across four replications (2×5×2). Experimental factors included two levels of autumn starter (AS) (12-40-0-10-1, N-P-K-S-Zn) (0 and 250 lb AS A^{-1}) applied at planting, five levels of fungicide timing (FT) (none, FK 5-7 and 10.5.1, FK 9 and 10.5.1, FK 10.5.1 individually, and FK 5-7, 9 and 10.5.1) and two levels of late-season N (LN) (0 and 30 lb N A^{-1}) applied at FK 7. All treatments received a base green-up N application of 100 and 75 lb N A^{-1} at FK 5 following SC and SB, respectively, except for the non-treated check. Pre-plant and spring soil characteristics are summarized in Table 1.

RESULTS

<u>Environmental Condition.</u> Cooler autumn air temperatures provided fewer growing degree days (GDD) resulting in delayed spring plant development. March precipitation was +83% above the 30-year average while May, June, and July 2023 precipitation was -73%, -82%, and -40%, respectively, from 30-year averages resulting in a narrowed grain-filling growth stage (Table 1).

Grain Yield, Quality, and Straw Yield. Following SC, grain yield ranged from 33.1 – 115.2 bu. A^{-1} with a mean of 90.0 bu. A^{-1}. An interaction between AS and FT significantly affected SC grain yield (Table 2, p = 0.0682). Across FT, AS consistently increased mean grain yield by 20.8 – 38.2 bu. A^{-1}. Conversely, FT only had a significant effect on mean grain yield with no AS and no fungicide (84.8 bu. A^{-1}) as compared to fungicide applications at FK 5-7 and 10.5.1 (67.3 bu. A^{-1}). The interaction between AS and LN significantly influenced grain protein content (Table 4, p = 0.038). With AS application, LN increased protein concentration but without LN application AS decreased protein concentration. Straw yield ranged from 0.2 – 1.8 T A^{-1} with a mean of 1.1 T A^{-1}. Only AS had a significant influence on mean straw yield with 0.60 T A^{-1} greater than no AS (Table 3, p < 0.0001).

Following SB, grain yield ranged from 57.3 – 134.8 bu. A^{-1} with a mean of 103.3 bu. A^{-1}. Neither AS (p = 0.1544), FT (p = 0.8609), or LN (p = 0.7767) significantly influenced grain yield. Grain protein content was significantly affected by AS and LN main effects. AS and LN improved mean grain protein content by 0.34% (p = 0.0109) and 0.78% (p < 0.0001), respectively (Table 5). Straw yield ranged from 0.3 – 2.3 T A^{-1} with an average of 1.2 T A^{-1}. Autumn starter increased mean straw yield by 0.30 T A^{-1} when compared to no AS (Table 3, p < 0.0001).

Potential Economic Profitability. Traditional management was defined as green-up N applications of 100 and 75 lb N A^{-1} following SC and SB, respectively, during FK 5 and late-season fungicide spray at FK 10.5.1.

Following SC, mean grain and grain + straw potential economic profitability (PEP) for traditional management (GRNUP + L) was USD 456.49 and USD 566.69, respectively. Without late-fungicide spray at FK 10.5.1, the addition of AS increased mean grain PEP by USD 95.20 (p = 0.0452). Meanwhile, incorporating multiple fungicide spray programs and LN decreased grain PEP by USD 98.25 – 156.58 (p = 0.0014 – 0.0389). Autumn starter increased grain + straw PEP by USD 111.20 – 158.99, regardless of mid-season fungicide spray at FK 9 (p = 0.0738 – 0.0117). Incorporating additional early (FK 5-7) and mid-season (FK 9) fungicide sprays with LN reduced grain + straw PEP by USD 111.05 – 171.09 (p = 0.0069 – 0.0742).

Following SB, the mean grain and grain + straw PEP for traditional management (GRNUP + L) was USD 606.69 and USD 768.78, respectively. The addition of AS with LN or multiple fungicide sprays at FK 5-7 or 9 reduced grain PEP by USD 129.33 – 188.70 (p = 0.0075 – 0.0624). Further, the addition of AS with mid-season fungicide spray at FK 9 decreased grain + straw PEP by USD 185.89 (p = 0.03).

DISCUSSION

Influence of autumn starter on yield and agronomic components.

Tillering and headcount. One of the benefits of autumn starter application was increased spring tiller density. In SC, tiller density ranged from 62 – 233 tillers ft^{-2}, with an average of 161 tillers ft^{-2}. In SB, tiller density ranged from 146 – 386 tillers ft^{-2}, with an average of 232 tillers ft^{-2}. Autumn starter increased tiller density in SC and SB by 34% ($p < 0.0001$) and 27% ($p = 0.0002$), respectively. However, only in SC, did tiller density have a moderate positive influence on grain yield ($r = 0.60$, Table 6).

Tiller production helps determine the potential headcount. In SC, headcount ranged from 37 – 102 spikes ft^{-2} with a mean of 67 spikes ft^{-2}. In SB, headcount ranged from 48 – 150 spikes ft^{-2} with a mean of 83 spikes ft^{-2}. Autumn starter increased headcount 31% ($p < 0.0001$) and 23% ($p < 0.0001$), following SC and SB, respectively. Consequently, headcount exerted a moderate positive influence on grain yield (SC $r = 0.63$, SB $r = 0.42$, Table 6). Results align with Quinn and Steinke (2019) where both tiller and head production were enhanced by the application of autumn starter in a low-input management system. The minimal influence of tiller density on grain yield highlights the significance of tiller survival to develop into productive wheat heads later in the season.

Head length. Head development is most rapid during stem elongation (FK 5-7). As the wheat stem elongates, the “heading stage” is initiated suggesting that as the stem extends, there is a greater opportunity for the head to stretch thereby producing a longer head (Simmons et al., 1985). Longer head length corresponds to more spikelets that can be filled with grain. Autumn starter increased the mean head length at both sites (SC $p < 0.0001$; SB $p < 0.0001$). However, only in SC did head length have a moderate positive influence on grain yield ($r = 0.62$, Table 6). According to Broeske et al., (2020), the number of spikes per head is determined at FK 5. Early nutrient application offers the potential for greater stem elongation, especially in unfavorable mid-season environments such as hot and dry May – June 2023 weather conditions that resulted in a shorter grain-filling period.

Plant height and straw yield. Autumn starter increased mean plant height. Autumn starter increased plant height 15% ($p < 0.0001$) and 1% ($p = 0.0549$) following SC and SB, respectively. Consequently, plant height exerted a moderate to strong positive influence on straw yield (SC $r = 0.82$, SB $r = 0.57$, Table 6).

The positive correlation between straw yield and plant height demonstrates stem elongation's influence during straw accumulation. The active growing stage of wheat starts at FK 5 when leaf sheaths are fully elongated and pseudostems are strongly erect up until FK 10 when the head is visible in the leaf sheath (Broeske et al., 2020). Rapid N uptake begins at FK 5 to 7 (Waldren & Flowerday, 1979). The early nutrient application promoted N uptake and improved stem elongation translating into enhanced straw production.

Influence of late-season N at Feekes 7 on flag leaf N, grain N, and protein content.

As a yield-limiting nutrient, insufficient N application risks suboptimal photosynthetic capacity leading to lower grain yield potential while excessive N fertilizer may result in over-application, environmental contamination, and reduced profitability.

Growers benefit from the application of N fertilizer depending on the wheat crop stage. Early N application promotes yield component formation while later N fertilization often boosts post-yield parameters such as grain protein content.

In the current study, main effects of late-season N at FK 7 improved mean grain protein content following soybean ($p < 0.0001$) where autumn starter had less impact on tiller counts. Late-season N interacted with autumn starter ($p = 0.038$) following silage corn where tiller counts were more affected than following soybean. Results may indicate that where autumn starter had greater impacts on tiller counts, LN increased protein due to N dilution across a greater number of spikes. Conversely, where LN was not applied, AS may have decreased protein content also due to growth dilution across a greater number of spikes. Previous studies observed variability regarding the influence of late-season applied N on grain yield, nutrient concentration, and quality (De Oliveira Silva et al., 2021; Sowers et al., 1994). This can be attributed to low N fertilizer recovery of wheat ranging from 30-50% (Raun et al., 2002) and increases at anthesis from 55 to 80% in irrigated wheat (Wuest & Cassman, 1992) which demonstrates that the late N can be supplemented with available soil moisture.

Flag leaf N and grain N concentrations were measured at FK 9 and harvest, respectively. The interaction between late-season N and autumn starter significantly influenced flag leaf N concentration (SC $p = 0.0802$, SB $p = 0.0035$). Late-season N increased flag leaf N regardless of autumn starter application. The flag leaf contributes 30-50% of assimilates for grain filling (Sylvester-Bradley et al., 1990), and its longevity correlates with grain protein accumulation (Blake et al., 2007). Flag leaf N concentration had a moderate positive influence on grain protein content only in SB (SB $r = 0.45$, Table 6). Late-season N increased grain N content (SC $p < 0.0001$, SB $p < 0.0001$). Further, grain N content had a strong positive influence on grain protein content (SC $r = 0.87$, SB $r = 0.93$, Table 6). These results were supported by Waldren and Flowerday (1979) in which the N accumulation peaked at the grain-filling stage with 70% of N uptake going into grain.

Table 1. Site description, soil chemical properties and mean P, K, S, and Zn nutrient concentrations (0 – 8 inches) obtained prior to winter wheat planting and spring soil nitrate levels (0 – 12 in.) before green-up application at Feekes 5, following silage corn and soybean, Lansing, MI, 2022-2023.

									Soil Nitrate	
		Soil pH	**OM**	**P**	**K**	**S**	**Zn**	**CEC**	**Pre-plant**	**Spring**
Site	**Soil Description**		**g kg^{-1}**		**——ppm——**			**meq 100g^{-1}**	**——NO_3-N kg^{-1} soil——**	
Foll. silage corn	Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*	7.2	18	55	68	12	2.5	8.2	4	No AS: 2.0 AS †: 3.75
Mehlich-3≠				74 (30)	78 (120)		(2)			
Foll. soybean	Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*	7.8	18	142	96	9	6.1	16.2	5	No AS: 1.75 AS: 2.0
Mehlich-3≠				192 (30)	109 (120)		(2)			

† Autumn starter (12-40-0-10-1, N-P-K-S-Zn) applied at a rate of 250 lb N A^{-1} at planting.
≠ Conversions of soil analyses into Mehlich-3 values. Soil test values in parentheses represent critical values. Bulletin 974: Tri-State Fertilizer Recommendations, pp. 28, 41

Table 2. Interaction of autumn starter (12-40-0-10-1, N-P-K-S-Zn) and fungicide timing on grain yield (bu A^{-1}) in field following silage corn, Lansing, MI., 2022-2023.

	Autumn Starter		
Treatment	0 lb AS A^{-1}	250 lb AS A^{-1}	
Fungicide Timing	——Grain Yield§ bu A^{-1}——		P > F †
No fungicide	84.75aB	108.45aA	***
Feekes 5-7, 10.5.1	67.32cB	105.50aA	***
Feekes 10.5.1	84.48aB	107.00aA	***
Feekes 9, 10.5.1	75.38bcB	108.49aA	***
Feekes 5-7, 9, 10.5.1	81.41abB	102.25aA	***
P > F **#**	**	ns	
Nontreated check	38.90		

§ Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Asterisks indicate thresholds of significance (ns, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001). Nontreated check is not included in the analysis. **#** Means within columns followed by the same lower-case letters are not statistically different (LSD, P < 0.10). † Means within rows followed by the same upper-case letters are not statistically different (LSD, P < 0.10).

Table 3. Mean straw yield (T A^{-1}) as influenced by autumn starter (12-40-0-10-1, N-P-K-S-Zn) in field following silage corn (SC) and following soybean (SB), Lansing, MI., 2022-2023.

Treatment	**SC**	**SB**
Autumn Starter Fertilizer	—— Straw Yield§ T A^{-1}——	
0 lb AS A^{-1}	0.79b	1.09b
250 lb AS A^{-1}	1.39a	1.38a
P > F	***	***
Nontreated check	0.27	0.52

§ Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Values followed by the same lowercase letter are not significantly different. Asterisks indicate thresholds of significance (ns, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001). Nontreated check is not included in the analysis.

Table 4. Interaction of autumn starter (12-40-0-10-1, N-P-K-S-Zn) and late-season nitrogen on grain protein content (%) in field following silage corn, Lansing, MI., 2022-2023.

	Late-season Nitrogen		
Treatment	0 lb N A^{-1}	30 lb N A^{-1}	
Autumn Starter Fertilizer	—— Grain Protein §%——		P > F †
0 lb AS A^{-1}	10.70aA	10.88aA	ns
250 lb AS A^{-1}	9.96bB	10.74aA	**
P > F #	**	ns	
Nontreated check	8.76		

§ Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Asterisks indicate thresholds of significance (ns, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001). Nontreated check is not included in the analysis. # Means within columns followed by the same lower-case letters are not statistically different (LSD, P < 0.10). † Means within rows followed by the same upper-case letters are not statistically different (LSD, P < 0.10).

Table 5. Mean grain protein content (%) as influenced by autumn starter (12-40-0-10-1, N-P-K-S-Zn) and late-season applied nitrogen in field following soybean, Lansing, MI, 2022-2023§.

Treatment	
Autumn Starter Fertilizer	——— **Grain Protein§ %**———
0 lb AS A^{-1}	10.60b
250 lb AS A^{-1}	10.94a
P > F	**
Late-season Nitrogen	
0 lb N A^{-1}	10.38b
30 lb N A^{-1}	11.16a
P > F	***
Nontreated check	9.02

§ Treatments were compared at 0.10 probability level, Fisher's least significant difference (LSD). Values followed by the same lowercase letter are not significantly different. Asterisks indicate thresholds of significance (ns, P > 0.10; *, P < 0.10; **, P < 0.05; ***, P < 0.001). Nontreated check is not included in the analysis

Table 6. Correlations between agronomic components, flag leaf (Feekes 9), and grain nutrient concentrations at harvest with grain yield, straw yield, and grain protein content in fields following silage corn (SC) and soybean (SB), Lansing, MI, 2022-2023. †

	Agronomic				Flag leaf at Feekes 9				Grain				
Following silage corn (SC)													
	T	PH	HC	HL	N	P	S	N:S ratio	N	P	S	N:S ratio	KW
GY	0.60***	0.88***	0.63***	0.60***	0.63***	-0.05	0.84***	-0.85***	-0.47***	-0.43***	0.76***	-0.81***	-0.69***
SY	0.61***	0.82***	0.60***	0.41**	0.56***	0.05	0.76***	-0.75***	-0.30*	-0.38**	0.73***	-0.70***	-0.72***
GP	-0.42**	-0.43***	-0.20	-0.47***	-0.07	0.34**	-0.28*	0.44**	0.87***	0.30*	-0.26*	0.57***	0.20
Following soybean (SB)													
	T	PH	HC	HL	N	P	S	N:S ratio	N	P	S	N:S ratio	KW
GY	-0.05	0.75***	0.42**	0.10	0.34**	0.06	0.49***	-0.53***	-0.15	-0.12	0.20	-0.46***	0.03
SY	0.33**	0.57***	0.44***	0.35**	0.38**	0.37**	0.64***	-0.66***	0.25*	0.13	0.52***	-0.46***	-0.40**
GP	0.41**	-0.05	0.06	0.38**	0.45**	0.39**	0.33**	-0.14	0.93***	0.40**	0.59***	0.12	-0.58***

† Pearson correlation coefficient analysis using PROC CORR procedure. Asterisks indicate thresholds of significance (*, P < 0.05; **, P < 0.01; ***, P < 0.001). Nontreated check is not included in the analysis. Abbreviations: GY – grain yield; SY – straw yield; GP – grain protein; T – tiller population; PH – plant height; HC – head count; HL – head length; KW – 1000-kernel weight

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