UTILIZING FERTILIZER AND FUNGICIDE STRATEGIES TO ENHANCE WINTER WHEAT GRAIN AND STRAW PRODUCTION

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ABSTRACT

Improvement of winter wheat (*Triticum aestivum* L.) grain and straw yields have increased the adoption of intensive management. The objective of this study was to evaluate the effects of autumn-applied starter fertilizer, fungicide application timings, and late-season applied nitrogen on grain yield, straw production, and grain nutritive quality. Autumn starter and late-season applied nitrogen increased mean grain yield and when combined, improved straw yield. In absence of autumn starter, mean straw yield declined regardless of late-season N application. Autumn starter reduced grain nutrients and protein content implying partitioned photosynthates were diluted because of higher yield. Conversely, late-season applied N had a positive influence on grain protein. The lack of influence of fungicide indicates disease control was not necessary due to a low-disease pressure environment. Overall, autumn starter increased grain and straw yields while late-season applied N improved grain nutrients and protein content.

MATERIALS AND METHODS

Soft red winter wheat field trials were established on a non-irrigated wheat field following silage corn (*Zea mays* L.). Experiment was conducted on Conover loam soils (Fine-loamy, mixed, active, mesic *Aquic Hapludalfs*). The experimental site consisted of twelve-row plots measuring 8 ft × 25 ft. Plots were planted with an Orbit-Air Granular Applicator with Disc Furrow Opener (Gandy Company Manufacturing, Owatonna, MN) at a rate of 1.8 million seeds A^{-1}. The short-statured, high-yielding variety of soft red winter wheat ‘Wharf’ (Michigan Crop Improvement Association, Okemos, MI) was planted on 20 September 2021.

Treatments were arranged as a full-factorial 2×5×2, randomized complete block design, with four replicates. Experimental factors included two levels of autumn starter (0 and 250 lbs. A^{-1}), five fungicide application timings (none, Feekes 7 and 10.5.1, Feekes 9 and 10.5.1, Feekes 10.5.1 individually, and Feekes 7, 9 and 10.5.1) and two levels of late-season applied nitrogen (0 and 30 lbs. A^{-1}) applied at Feekes 7. On 27 September 2021, autumn starter (12-40-0-10-1, N-P-K-S-Zn) (MicroEssentials® SZ® (MESZ) (Mosaic CO., Plymouth, MN) fertilizer was applied at a rate of 250 lbs. A^{-1} and topdressed using a handheld spreader. Blanket spring N was applied at 100 lbs N A^{-1} during Feekes 4 growth stage. Late N fertilizer was applied at a rate of 30 lbs N A^{-1} as UAN at Feekes 7. The five fungicide application timings evaluated included control (no fungicides applied), Feekes 10.5.1 individually (one spray), Feekes 5 – 7 and 10.5.1 (two-spray), Feekes 9 and 10.5.1 (two-spray), and Feekes 5 – 7, 9, and 10.5.1 (three-spray). Fungicide applications included 0.125% v/v of non-ionic surfactant and anti-foaming agent to improve fungicide coverage and efficacy. Fungicide was applied using a modified plot sprayer attachment (LeeAgra, Inc., Lubbock, TX; Kincaid Equipment Manufacturing Corporation, Haven, KS; Juniper Systems Inc., Logan, UT).

On 9 July 2022, plots were end-trimmed prior to harvest. Grain and straw yields were harvested from the central 3.9 ft of each plot utilizing a research combine (Kincaid Manufacturing, Haven, KS). Preliminary plot grain weight (lb), moisture (%), and test weight (lb bu^{-1}) data were collected and used to calculate grain yield expressed as bu A^{-1} and Mg ha^{-1} at a 13.5% moisture basis. Grain subsamples were acquired from each plot for nutrient concentration and nutritive quality. Straw yield was determined from the weights of total residue generated by combine output. The combine was set to 5.0" and weights were adjusted from total moisture content of gross harvest weight.

Data were analyzed with R using Analysis of Variance (α=0.10). Least square means were separated using Tukey's Honest Significant Difference (HSD) when ANOVA indicated a significant interaction. Means separation was calculated utilizing a single degree of freedom contrasts. Pearson correlation coefficient analyses were performed on the means of grain nutrients and protein content with grain and straw yields in SAS 9.4 (SAS Institute, 2012) using the PROC CORR procedure.

RESULTS AND DISCUSSION

Influence of weather on fungal disease development and fungicide effectivity.

Cumulative rainfall for May and June 2022 was 35% and 56% below average, respectively (data not shown). Mean temperature of April 2022 was also 5% lower than the 30-yr average which may have delayed the spring plant development and green-up (data not shown). In this study, the continuous cold and dry early- and mid-season months (March-May) eliminated the favorable environment for fungal disease development. Moist, cool conditions are most conducive for early fungal diseases such as Septoria leaf spot (*Zymoseptoria tritici*) and powdery mildew (*Blumeria graminis f. sp. tritici*) (Kelley, 2001). The absence of significant differences in grain yield (Table 1) and straw production (Fig. 1) across fungicide treatments indicates disease control was not necessary in a low-disease pressure environment.

Effects of autumn starter on grain yield, nutritive quality, and straw production.

The application of 250 lbs. A^{-1} of autumn starter increased the average grain yield 33 bu A^{-1} (Table 1). The positive correlation between grain yield, plant height, head count, and head length offers evidence for why autumn starter positively influenced grain production (Table 2). Increased yield through plant height, head count, and head length driven by autumn starter are justified by N fertilizer that exposes wheat to grow vigorously and increase tiller initiation (Zhang et al., 2020). Tiller population, a component of yield, determines potential head count. This aligns with Quinn and Steinke, (2019) study that both tiller production and head production increased from application of autumn starter in a low-input management system. Moreover, autumn starter supplied N and Zn, which may have increased the survival rate of productive tillers and developed into mature heads. Das et al., (2019), reported that the maximum number of tillers, grain, and straw yields was observed from 160 kg ha^{-1} N and 2 kg ha^{-1} Zn nutrient combination.

Head development is most rapid during stem elongation. When the wheat stem elongates, the “heading stage” is initiated (Simmons et al., 1985). This suggests that as stem extends, it offers greater opportunity for the head to stretch—producing a longer head. With longer head length comes more spikelets that will be filled with grains. According to Broeske et al., (2018), the number of spikes per head is determined at Feekes 5. Since autumn starter was applied in the early season, it provided more elongated stems relative to plants that did not receive autumn starter.

Grain yield was negatively correlated with grain nutrient concentrations (Table 2). Waldren and Flowerday (1979) found the translocation of dry matter from leaves to grain starts at the beginning of anthesis (Feekes 10.5.1) up to the grain-filling stage (Feekes 10.5.4). This aligns with the sufficient ranges of flag leaf nutrient concentrations at Feekes 9; since translocation has not yet started (data not shown). With the exception of grain K and Ca, autumn starter reduced grain N, P, and Mg by 13.1%, 5.0%, and 5.1%, respectively, and increased grain S by 9.6% (Table 1). At maturity, Waldren and Flowerday (1979) added that 70-75% of N and P are translocated when only 15% of K is present in grains. In this study, grain N, P, and Mg were reduced in autumn starter-treated plots (Table 1) suggesting that translocated grain N, P, and Mg were diluted from higher yield.

The application of autumn starter provided the highest mean straw yield when late-season N was not applied (1 ton A^{-1}) (Fig. 1). Conversely, the absence of autumn starter resulted in reduced straw yields, regardless of late-season applied N. The positive correlation between straw yield with plant height demonstrates the contribution of stem elongation during straw accumulation (Table 2). The active growing stage of wheat starts at Feekes 5 when leaf sheaths are fully elongated and pseudostems are strongly erected up to Feekes 10 when head is visible in the leaf sheath (Broeske et al., 2020). Rapid N uptake begins at Feekes 5 to 7 (Waldren & Flowerday, 1979). Since autumn starter was applied early in the season, it increased N uptake, which translated to improved stem elongation. Autumn starter increased plant height by 9.8% (data not shown). This demonstrates the potential for autumn starter to provide an advantageous start for mid-season environment, translating to improved straw production (Fig. 1).

Effects of late-season applied N in grain yield, nutrients, and protein content.

Late-season N at Feekes 7 increased grain yield, nutrient concentration, and protein content (Table 1). Late-season applied N improved grain yield by 5.0 bu. A^{-1}, as well as protein content, grain N, and P. Grain protein content was positively correlated with grain N (0.94) (Table 2). Previous studies have variable observations about the influence of late-season applied N on grain yield, nutrient concentration and quality. Topdressed spring N applications before stem elongation (Feekes 4 – 9) improved fertilizer N recovery, grain yield, and protein content (Sowers et al., 1994). This conflicts with De Oliveira Silva et al., (2021) who reported N applications at beginning of stem elongation (Feekes 5) did not increase the yield and nutrient uptake but enhanced the grain and vegetative components—an indicator of luxury consumption According to Waldren and Flowerday (1979), the N accumulation peaks at grain filling stage with 70% of N uptake goes into grains. It is possible that the late-season applied N underwent translocation into grains thereby promoting yield and increasing nutrient concentration.

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Table 1. Mean grain yield, protein content, and nutrient concentrations as influenced by autumn starter, fungicide timing, and late-season applied nitrogen in non-irrigated following silage corn, Lansing, MI, 2021-2022†.

Treatment	Yield	Protein Content‡	N	P	K	Ca	Mg	S
			Grain nutrient concentration§					
	--(bu A^{-1})--	--%--	--%--					
Autumn Starter								
0 lb A^{-1}	91.6 b	10.98 a	1.780 a	0.354 a	0.425	0.030	0.143 a	0.114 b
250 lb A^{-1}	124.6 a	9.70 b	1.574 b	0.337 b	0.421	0.030	0.136 b	0.125 a
p-value < 0.10	***	***	***	***	NS	NS	***	***
Fungicide Timing								
No fungicide	107.4	10.59 a	1.712	0.343	0.417	0.030	0.138 ab	0.115
Feekes 5-7, 10.5.1	107.8	10.15 ab	1.653	0.345	0.42	0.030	0.138 ab	0.121
Feekes 10.5.1	110.2	10.11 b	1.631	0.339	0.419	0.030	0.136 b	0.119
Feekes 9, 10.5.1	105.8	10.44 ab	1.684	0.346	0.429	0.030	0.139 ab	0.120
Feekes 5-7, 9, 10.5.1	109.2	10.42 ab	1.704	0.354	0.43	0.030	0.144 a	0.122
p-value < 0.10	NS	*	NS	NS	NS	NS	**	NS
Late-season Nitrogen								
0 lb A^{-1}	105.5 b	9.98 b	1.608 b	0.342 b	0.422	0.030	0.138	0.119
30 lb A^{-1}	110.6 a	10.71 a	1.745 a	0.349 a	0.424	0.030	0.141	0.120
p-value < 0.10	**	*	***	**	NS	NS	NS	NS
Nontreated check ††	45.9	9.66	1.505	0.36	0.453	0.03	0.145	0.123

† Treatments were compared per environment at 0.10 probability level, Tukey's HSD, where significant values * = 0.10, ** = 0.05, ***0.001.
†† Nontreated check, no fertilizer or fungicide applied.
‡ For nutrient concentration, 150 g. of grains was weighed and sent to the A&L Great Lakes Laboratories, Inc (Fort Wayne, Indiana).
§ For nutritive quality, near-infrared transmission (NIRS™ DS2500 L; FOSS Analytical, Hillerød, DK) was used.

Table 2. Correlations between agronomic and nutrient concentration with yield components and grain protein content in in non-irrigated following silage corn (SC), Lansing, MI, 2021-2022. †

	Agronomic ‡				Grain nutrient concentration					
	T	**PH**	**HC**	**HL**	**N**	**P**	**K**	**Ca**	**Mg**	**S**
Yield	0.19	0.84 ***	0.83 ***	0.67 ***	-0.34 **	-0.44 ***	-0.33 **	-0.06	-0.44 ***	0.48 ***
Straw	0.02	0.63 ***	0.6 ***	0.37 **	-0.28 *	-0.39 **	-0.16	0.06	-0.4 **	0.27
Grain Protein	-0.1	-0.16	-0.47 ***	-0.005	0.94 ***	0.46 ***	-0.04	-0.05	0.46 ***	-0.49 ***

† Peason correlation coefficient analysis using PROC CORR procedure, α = 0.05, where significant values * = 0.05, ** = 0.001, * < 0.001.**
‡ Agronomic parameters: T – tiller population, PH – plant height, HC – head count, HL – head length.

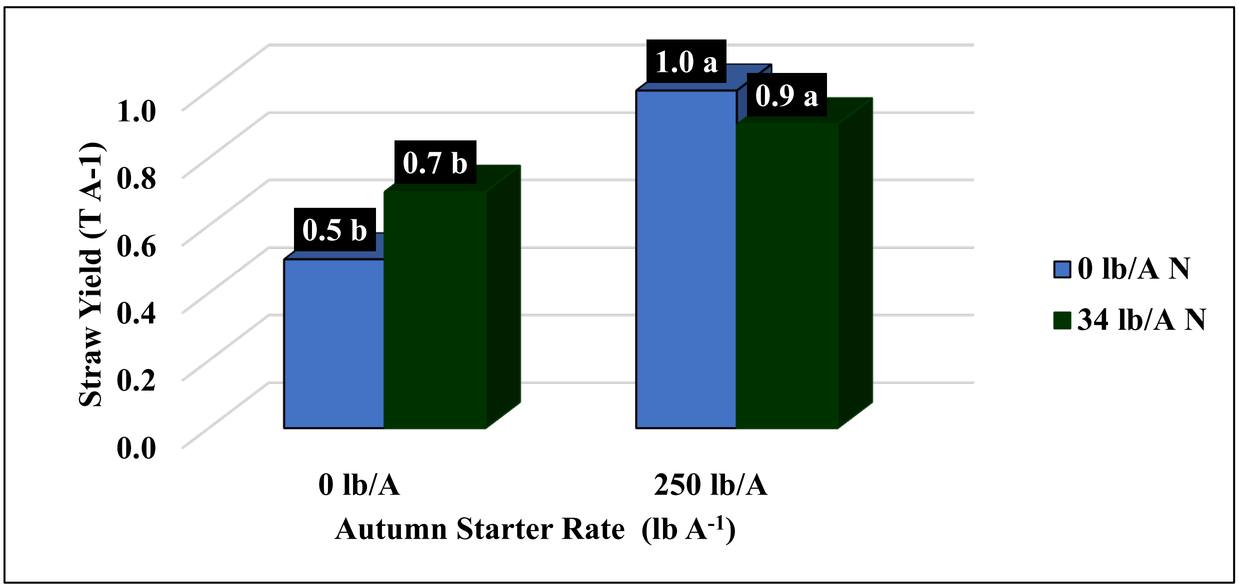

Figure 1. Interaction of autumn starter and late-season applied nitrogen on straw yield (T A^{-1}) in non-irrigated following silage corn (SC), Lansing, MI, 2021-2022. †
† Treatments were compared at 0.10 probability level, Tukey's HSD.