Targeting Input Responses and Returns on Intensively-Managed Soft Red Winter Wheat

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ABSTRACT

Consecutive years of record wheat (*Triticum aestivum* L.) yield (81 and 89 bu A^{-1} in 2015 and 2016, respectively), climate variability, and continued demand from Michigan's milling and cereal industry have increased interest in intensively-managed (i.e. multiple-input) soft red winter wheat production systems. The objective of this study was to investigate the grain yield and economic profitability of several agronomic inputs across intensive (i.e., multiple-input) and traditional (i.e., individual-input) management systems. A two-year omission field trial was established in Lansing, MI to evaluate the following inputs: two nitrogen (N) rates (90 lbs N A^{-1} and 108 lbs N A^{-1}), urease inhibitor, nitrification inhibitor, fungicide, plant growth regulator, and foliar micronutrients. Due to significant stripe rust (*Puccinia striiformis* f. sp. *tritici*) disease pressure in 2016, addition of the fungicide within the traditional system resulted in a significant yield increase of 10.7 bu A^{-1}. Urease inhibitor (UI) significantly increased grain yield by 7.7 bu A^{-1} within the intensive system but significantly decreased grain yield by 7.6 bu A^{-1} within the traditional system in 2017. Above average April rainfall following N fertilizer application, N rate, and UI tank-mixed with or without nitrification inhibitor likely contributed to the inconsistent UI responses across different management systems. Overall minimal and inconsistent input responses were observed across the 2016 and 2017 growing seasons. Despite some observed yield increases, no single input resulted in a positive return on investment in 2016 or 2017. Traditional management consistently resulted in comparable grain yields and significantly greater net returns when compared to intensive management suggesting the limited potential for improved yield or profitability from prophylactic input applications in these studies.

INTRODUCTION

Michigan wheat producers continue to rank in the top five nationally with recent state record yield averages of 81 and 89 bu A^{-1} produced during the 2015 and 2016 growing seasons, respectively (USDA-NASS, 2017). Grower apprehension towards and increased awareness of climate variability has further motivated producers seeking maximum wheat yield to switch to an intensively managed wheat system (Rosenzweig et al., 2001; Crane et al., 2011; Swoish and Steinke, 2017). Intensive wheat management systems most commonly involve prophylactic applications of multiple inputs recommended as risk insurance (Rosenzweig et al., 2001; Crane et al., 2011; Mourtzinis et al., 2016). In contrast, traditional management systems justify input applications utilizing university recommended integrated pest management (IPM) strategies (Mourtzinis et al., 2016). Previous research has examined wheat response to commonly marketed inputs such as additional nitrogen (N) fertilizer, urease inhibitor, nitrification inhibitor, plant growth regulator, and fungicide (Rao, 1996; Paul et al., 2010; Mohammed et al., 2016; Knott et al., 2016; Swoish and Steinke et al., 2017). However few studies have examined wheat yield and profitability response to multiple inputs individually and in combination across traditional and intensive management systems.

The objective of this study was to investigate soft red winter wheat grain yield and economic profitability response to high-N fertilizer management, urease inhibitor, nitrification inhibitor, plant growth regulator, fungicide, and foliar micronutrient applications across intensive (i.e. multiple-input) and traditional (i.e. individual-input) production systems. An omission trial design was utilized to determine if a significant yield and/or profitability response occurred from the elimination of a specific input from an intensive management system, or from the introduction of a specific input into a traditional management system.

MATERIALS AND METHODS

Trials investigating soft red winter wheat response to two nitrogen rates (90 lbs. N A^{-1} and 108 lbs. N A^{-1}), urease inhibitor, nitrification inhibitor, plant growth regulator, fungicide, and foliar micronutrients were conducted in Lansing, MI. Pre-plant soil characteristics (0-8 in) included 6.4 to 7.0 pH, 27 to 47 ppm P, 85 to 94 ppm K, 0.6 to 2 ppm B, 36 to 37 ppm Mn, and 0.4 to 2.1 ppm Zn. Fields were previously cropped to corn (*Zea mays* L.) and tilled prior to planting. Individual twelve row plots measured 8 ft. in width by 25 ft. in length with a 7.5 in. row spacing. Plots were planted at a population of 1.8 million seeds A^{-1} and arranged in a randomized complete block design with four replications. Soft red winter wheat variety 'Sunburst' (Michigan Crop Improvement Assoc.), a short strawed, high yielding, intensively-managed variety was planted on 29 Sept. 2015 and 23 Sept. 2016.

An omission treatment design was used to determine specific input responses (Table 1). An omission design utilizes two treatment controls, one containing all studied inputs (intensive management control) and one containing none of the studied inputs (traditional management control) (Bluck et al., 2015). In order to evaluate treatment effects, inputs removed from the intensive management system are compared only to the intensive management control and inputs added into the traditional management system are compared only with the traditional management control (Bluck et al., 2015).

Grain yield was harvested from the center 3.75 ft. of each plot utilizing a small-plot combine (Almaco, Nevada, IA) on 11 July 2016 and 9 July 2017 and adjusted to 13.5% moisture. Economic profitability was assessed from input cost estimates of US$39-47.00, $5.40-6.40, $11.70, $15.84, $14.00, and $17.94 A^{-1} in 2016 and $36.81-44.17, $5.10-6.10, $11.99, $13.27, $12.75, and $17.51 A^{-1} in 2017 for nitrogen fertilizer, urease inhibitor, nitrification inhibitor, plant growth regulator, foliar micronutrient, and fungicide, respectively. An additional cost of $7.50 and $7.00 A^{-1} for 2016 and 2017, respectively was added as an application cost for nitrogen fertilizer, plant growth regulator, foliar micronutrient, and fungicide. Net returns were calculated by multiplying commodity grain price estimates of $3.75 bu^{-1} in 2016 and $4.10 bu^{-1}

in 2017 by grain yield and subtracting total treatment cost. Product, application, and harvest grain price estimates were taken from local agriculture retailers and grain elevators.

Statistical analyses were performed using the PROC GLIMMIX procedure of SAS (SAS Institute, 2012) at $\alpha=0.1$. Single degree of freedom contrasts were used to determine treatment mean separations. To evaluate treatment effects within the omission design, a factor removed from the intensive management system was contrasted to only the intensive management control and a factor added into the traditional management system was contrasted to only the traditional management control (Bluck et al., 2015).

RESULTS AND DISCUSSION

Nitrification inhibitor (NI), plant growth regulator (PGR), foliar micronutrients, and a 20% increase in N fertilizer did not significantly affect grain yield across both site-years (Table 3). Below-average April 2016 rainfall following N fertilizer application likely contributed to the non-significant response to NI application as minimal N leaching or denitrification events occurred (Franzen, 2017) (Table 2). In 2017, April rainfall was 55% higher than the 30-yr mean suggesting potential for N loss. However NI application did not positively influence grain yield. Non-significant response was likely caused by low soil temperatures (<40°F) following N fertilizer application (data not shown). Low soil temperatures delay bacterial conversion of NH_4 to NO_3, minimizing the risk of N loss caused by leaching from above average rainfall. Similar results have been observed by Barker and Sawyer (2017) in corn, where low soil temperatures within 4 weeks following N application inhibited positive influence from NI application.

Non-significant PGR response was likely attributed to the absence of lodging during the 2016 and 2017 growing seasons. SRWW variety 'Sunburst' utilized in this trial contains varietal characteristics important for the protection against plant lodging including: short plant height and high stem strength (Michigan Crop Improvement Assoc.). Results correspond to recent Michigan research by Swoish and Steinke (2017) who determined yield increases from PGR application only occurred in the presence of lodging which was more likely to occur in taller, more weakly structured cultivars. In addition, results support previous conclusions, suggesting producer motive for applying a PGR should depend on cultivar structure, susceptibility to lodging, and average plant height rather than management intensification (Knott et al., 2016; Swoish and Steinke, 2017).

Pre-plant soil test data and tissue analysis taken from the uppermost leaf at F9 showed at least one Zn and/or B deficiency and no Mn deficiencies across both site-years (data not shown). University recommendations for micronutrient applications are not solely based on soil or tissue test levels but also incorporate crop responsiveness (Vitosh et al., 1994; Warncke et al., 2009). Previous literature and university plant nutrient guidelines define wheat as being non-responsive to B and Zn, yet highly responsive to Mn (Vitosh et al., 1994; Warncke et al., 2009). Therefore, positive response from foliar application of Zn, Mn, and B on wheat should only occur in the presence of a Mn deficiency. Similar observations were published by Curtin et al. (2008) where a significant wheat yield response only occurred following Mn application, and not B and Zn on nutrient deficient soils. Trial results suggest application of foliar micronutrients may only be warranted once specific crop-responsive micronutrients drop below sufficiency ranges.

Adequate and timely rainfall, combined with low soil temperatures following N fertilizer application likely decreased the potential for N loss caused by volatilization, leaching, and/or denitrification. Lack of N loss conditions suggest a university recommended N rate of 90 lbs N A^{-1} was sufficient to meet plant N demands and a 20% increase in N rate was not beneficial during the 2016 and 2017 growing seasons. Results correspond to previous research by Knott et al. (2016) and Swoish and Steinke (2017).

Urease inhibitor (UI) application significantly influenced grain yield in 2017 (Table 3). Grain yield was significantly decreased by 7.7 bu A^{-1} when removed from the intensive system and significantly decreased by 7.6 bu A^{-1} when added to the traditional system. In both site-years, UAN was applied to conventionally tilled, minimal residue, low temperature soils, with rainfall occurring within 5 days following N fertilizer application. Previous conclusions regarding similar environmental conditions suggest minimal N loss from volatilization occurred, contributing to the non-significant UI response in 2016 (Warncke et al., 2009; Franzen, 2017). The 2017 growing season produced April rainfall totals near double of the 30-yr mean (Table 2), resulting in risk of N loss from leaching and/or denitrification. Inconsistent responses observed from UI application across varying management systems in 2017 was likely a function of N fertilizer rate and UI application combined with or without nitrification inhibitor. Previous research has shown during a wet growing season, top winter wheat grain yields were produced from a combined application of both a UI and NI (Mohammed et al., 2016). Results suggest combined inhibitor application within intensive management provided greatest reduction of multiple N-loss risks through slow release of N, thus synchronizing fertilizer N availability with crop N demand and increasing grain yield (Mohammed et al., 2016). In contrast, UI application significantly decreased grain yield within the traditional management system in 2017. April 2017 produced above average rainfall following N fertilizer application, with high cumulative rainfall (2.62 in.) occurring within 1 week following N application (data not shown). April 2017 produced high potential for fertilizer N to be completely transported below the soil surface and beyond the root zone. UAN+UI once transported below the soil surface due to above average rainfall may have reduced the rate of urea hydrolysis to the point that urea could not be transformed into NH_4 to allow plant uptake, thus increasing the risk of N translocation beyond the root zone and decreasing plant availability. In addition, traditional N rates are 20% lower than intensive N rates, resulting in theoretically less soil N availability following an N loss event. Results correspond to previous research involving corn where application of UAN+UI was concluded to reduce the rate of urea hydrolysis to the point of inadequate plant N uptake and resulted in decreased ear-leaf N concentration and grain yield (Fox and Piekielek 1993; Murphy and Ferguson, 1997).

Addition of the fungicide to the traditional management system resulted in a significant yield increase of 10.8 bu A^{-1} in 2016 (Table 3). Fusarium head blight (FHB) incidence did not occur across site-years. Below average May rainfall was observed in 2016 and 2017, specifically during anthesis (F10.5.1) thus decreasing risk of FHB infection. Despite the lack of FHB incidence, 2016 experienced significant foliar disease pressure, predominantly caused by the pathogen stripe rust (*Puccinia striiformis* f. sp. *tritici*.). Stripe rust infection was attributed to strong winds out of the western and southern United States aiding fungal spore movement, complimented with local areas receiving adequate temperature, rainfall, and humidity for disease growth (Pennington, 2016). Visual assessment of percent leaf area affected showed removal of fungicide from the intensive system in 2016 resulted in an 11.3 % increase in foliar disease presence (Table 4). Conversely, addition of the fungicide to the traditional management system reduced foliar disease presence by 15%. Results are supported by Chen (2005), who reported stripe rust control ranging between 42 - 100% with triazole fungicide application resulting in grain yield increases of 22 - 878%. The reason for the non-significant yield response to fungicide in the presence of disease, despite significant visual control within the intensive system is unclear. However, response may be attributed to 3.7% less disease within the intensive system without fungicide than the traditional system without fungicide. In addition, non-significant yield response within the intensive system suggests potential disease suppression from inputs other than fungicide, such as foliar applied Mn and B, both previously shown to decrease rust (*Puccinia* spp.) incidence in wheat (Datnoff et al., 2007).

Despite positive grain yield responses observed, no single input resulted in a significant increase in return on investment following the 2016 and 2017 growing seasons (Table 3). Wheat 2016 and 2017 commodity prices hit an 8-year low (USDA-NASS, 2017) signifying that even in the presence of adverse conditions warranting positive yield responses, input application still may not be profitable to the producer at current commodity prices. In addition, the traditional management system produced comparable grain yields and significantly increased per acre net return by an average of \$93 A^{-1} across both site-years when compared to the intensive management system. Producers perceive yield loss as a greater risk than profit loss; however, based on results observed producers should place greater emphasis on profitability rather than yield loss when choosing to incorporate additional inputs. Results suggested little potential for improved grain yields and/or net returns from integrating an intensive management system even in the presence of adverse climactic conditions warranting input applications. Trial results support the importance of incorporating a university recommended IPM program to justify input applications to optimize grain yields and net returns rather than applying multiple inputs as risk insurance.

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Table 1. Overview of omission treatment design, treatment names, and inputs applied in 2016 and 2017 (Bluck et al., 2015).

		Agronomic Input Applied					
Treatment	Treatment Name	UI†	NI‡	PGR§	Fungicide¶	Micro#	High-N††
1	Intensive (I)	Yes	Yes	Yes	Yes	Yes	Yes
2	I without UI	No	Yes	Yes	Yes	Yes	Yes
3	I without NI	Yes	No	Yes	Yes	Yes	Yes
4	I without PGR	Yes	Yes	No	Yes	Yes	Yes
5	I without Fungicide	Yes	Yes	Yes	No	Yes	Yes
6	I without Micro	Yes	Yes	Yes	Yes	No	Yes
7	I without High-N	Yes	Yes	Yes	Yes	Yes	No
8	Traditional (T)	No	No	No	No	No	No
9	T with UI	Yes	No	No	No	No	No
10	T with NI	No	Yes	No	No	No	No
11	T with PGR	No	No	Yes	No	No	No
12	T with Fungicide	No	No	No	Yes	No	No
13	T with Micro	No	No	No	No	Yes	No
14	T with High-N	No	No	No	No	No	Yes
15	Check	No	No	No	No	No	No

† Urease inhibitor applied at a rate of 1 qt ton^{-1} UAN at F3 growth stage.
‡ Nitrification inhibitor applied at a rate of 37 oz A^{-1} at F3 growth stage.
§ Plant growth regulator applied at a rate of 12 oz A^{-1} at F6 growth stage.
¶ Fungicide applied at a rate of 8.2 oz A^{-1} at F10.5.1 growth stage.
†† Foliar micronutrient fertilizer containing Zn, Mn, B applied at a rate of 64 oz A^{-1} at F6 growth stage.
# High-nitrogen applied at a rate of 108 lbs N A^{-1} at F3 growth stage.

Table 2. Monthly cumulative precipitation totals for SRWW spring growing season in Lansing, MI, 2016-2017.

Year	Location	March	April	May	June	July	Total
		-------------------------------	in	-------------------------------			
2016	Lansing	3.98	2.94	2.06	0.71	3.78	13.47
2017	Lansing	2.98	5.22	2.59	3.29	2.65	16.73
30-yr avg.	Lansing	2.06	3.36	8.53	3.45	2.84	14.74

† Precipitation data was collected from Michigan State University Enviro-weather (https://enviroweather.msu.edu/). 30-yr means were obtained from the National Oceanic and Atmospheric Administration (https://www.ncdc.noaa.gov/cdo-web/datatools/normals).

Table 3. Grain yield and net return values for 2016 and 2017. Shown is average grain yield and net return of intensive and traditional control treatments. All other treatments show change in grain yield or net return from respective intensive or traditional control.

Treatment	Year			
	2016	2017	2016	2017
	------------------bu A^{-1}-----------------		------------------US$ A^{-1}----------------	
Intensive (I)	77.88	99.56	156.13	280.88
I w/o UI†	+5.70	-7.80*	+27.78	-25.89
I w/o NI	+2.28	+5.17	+20.23	+33.16*
I w/o PGR	-0.42	+4.71	+14.25	+32.58*
I w/o Fungicide	+0.35	+0.76	+27.27	+28.13
I w/o Micro	+9.83	+2.90	+50.32*	+24.10*
I w/o High-N	-8.43	-2.18	-22.59	-0.57
Traditional (T)	81.03	100.10	257.34	366.59
T w/ UI‡	-2.88	-7.52*	-16.18	-35.93*
T w/ NI	+3.35	-3.03	+0.86	-24.41
T w/ PGR	+1.10	-4.26	-19.73	-38.31*
T w/ Fungicide	+10.78*	+1.00	+14.45	-20.91
T w/ Micro	+7.23	-6.05	+5.59	-44.57*
T w/ High-N	+4.05	+0.94	+7.19	-3.51
I vs. T	ns§	ns	*	*
Check¶	66.95	47.73	251.06	195.66

***** Significantly different at α=0.1 using single degree of freedom contrasts.

† Values in I w/o input rows indicate a yield (bu A^{-1}) or net return (US$ A^{-1}) change from respective intensive (I) treatment.

‡ Values in T w/ input rows indicate a yield (bu A^{-1}) or net return (US$ A^{-1}) change from respective traditional (T) treatment.

§ Non-significant

¶ Untreated check containing no fertilizer or additional inputs was not included in statistical analysis.

Table 4. Influence of Feekes 10.5.1 fungicide on foliar disease presence, 3 weeks after application in 2016 and 2017.

		Treatment			
Location	Year	Intensive (I)	I w/o Fungicide†	Traditional (T)	T w/ Fungicide‡
		----------------------------- % leaf area affected -------------------------------			
Lansing	2016	6.78	+11.34*	21.75	-14.98*
Lansing	2017	0.0§	0.0	0.0	0.0

* Significantly different at α=0.1 using single degree of freedom contrasts

† Values in I w/o fungicide column indicate a leaf area affected (%) change from respective intensive (I) treatment.

‡ Values in T w/ fungicide column indicate a leaf area affected (%) change from respective traditional (T) treatment.

§ Years containing all values of 0.0 did not receive foliar disease pressure.