Soft Red and White Winter Wheat Response to Input-Intensive Management

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ABSTRACT

Record grain yields and increased awareness of climate variability have more producers considering intensive (i.e., high-input) wheat (*Triticum aestivum* L.) management. This study investigated soft winter wheat response to several agronomic inputs across intensive and traditional (i.e., low-input) management systems. A four site-year trial was established at Richville and Lansing, MI during 2015 and 2016 to evaluate the following inputs: increased rates of nitrogen (N) fertilizer, urease inhibitor (UI), nitrification inhibitor (NI), fungicide, plant growth regulator (PGR), and foliar micronutrients. Across four site-years, intensive management did not increase yield compared to traditional management. In addition, traditional management increased average economic net return by \$221 ha^{-1}. At the reduced N rate, Richville 2016 yield decreased 0.94 Mg ha^{-1} within the intensive system suggesting greater N demand with intensive management. Due to significant stripe rust (*Puccinia striiformis* f. sp. *tritici*) occurrence, at 2016 Lansing, yield increased 0.75 Mg ha^{-1} when fungicide was added to the traditional system. Lansing 2017 yield decreased 0.52 Mg ha^{-1} when UI was removed from the intensive system, yet decreased 0.51 Mg ha^{-1} when UI was added to the traditional system. Heavy rainfall, lack of urea hydrolysis, and N rate likely contributed to the inconsistent UI response. The 2016 and 2017 growing seasons produced an overall absence of adverse environmental conditions which influenced negligible input responses. Although yield increases were observed, no single input increased net return. Results suggest intensive management benefits are unlikely at current wheat prices and without the presence of yield-limiting factors.

Core Ideas

- Prophylactic input applications failed to consistently increase wheat yield and net return without the presence of yield-limiting factors.
- Traditional management significantly increased economic net return in three of four site-years.
- Producers may wish to consider integrated pest management strategies for justification of input applications.

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Interest in maximizing wheat grain yield continues to increase due to consecutive record yield averages of 5.44 and 5.98 Mg ha^{-1} produced during the 2015 and 2016 Michigan growing seasons, respectively (NASS, 2017). Additionally, increased awareness of climate variability (i.e., increased rainfall intensities, greater length of time between rainfall events, and prolonged periods of greater than normal air temperatures) combined with soil spatial inconsistencies has motivated producers to maximize grain yield by adopting more intensive wheat management systems (Rosenzweig et al., 2001; Kravchenko et al., 2005; Crane et al., 2011; Swoish and Steinke, 2017). Intensive management commonly involves prophylactic applications of multiple inputs as a form of risk insurance (Mourtzinis et al., 2016). In contrast, traditional management involves minimal input applications often based on university-recommended integrated pest management (IPM) and nutrient management guidelines (Marburger et al., 2016; Mourtzinis et al., 2016). Recent studies have examined wheat response to commonly marketed inputs including additional N fertilizer, urease inhibitor, nitrification inhibitor, plant growth regulator, foliar micronutrients, and fungicide (Paul et al., 2010; Wang et al., 2015; Knott et al., 2016; Mohammed et al., 2016; Swoish and Steinke, 2017). However, few studies exist investigating wheat grain yield and profitability in response to multiple inputs applied individually and in combination across intensive and traditional management systems.

Over time, N fertilizer application rates have risen simultaneously with gains in grain yield (Swoish and Steinke, 2017). Michigan growers continue to report significant grain yield increases with 25 to 50% more applied N than recommended despite multiple university trials observing a lack of increased grain yield and N use efficiency from greater N application rates (Kanampiu et al., 1997; Knott et al., 2016; Mourtzinis et al., 2017; Swoish and Steinke, 2017). Nitrogen fertilizer was identified as the single most important input to maximize wheat yield (Nielsen and Halvorson, 1991; White and Edwards, 2008) with growers often perceiving yield loss from underapplication as a greater risk than the cost of overapplication (Mourtzinis et al., 2017; Rutan and Steinke, 2017). However, excessive N applications have been shown to increase disease pressure, plant lodging,

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Abbreviations: B, boron; DON, deoxynivalenol; FHB, fusarium head blight; IPM, integrated pest management; Mn, Managanese; N, nitrogen; NBPT, N-(n-butyl)-thiophosphoric triamide; NI, nitrification inhibitor; PGR, plant growth regulator; SRWW, soft red winter wheat; SWWW, soft white winter wheat; UAN, urea ammonium nitrate; UI, urease inhibitor; TE, trinexapac-ethyl; Zn, Zinc.

and significant N losses deteriorating environmental quality (Kanampiu et al., 1997; Warncke et al., 2009; Brinkman et al., 2014). Producers continue to increase N rates for maximum wheat yield and in doing so may further increase the need for additional inputs to mitigate otherwise preventable risks from greater N application rates (Knapp and Harms, 1988; Knott et al., 2016; Salgado et al., 2017; Swoish and Steinke, 2017).

Mitigation of potential N losses is essential for maximizing wheat grain yield and nutrient efficiency (Raun and Johnson, 1999; Mohammed et al., 2016). Michigan growers often utilize spring (i.e., March– April) top-dress applications of N using surface-applied urea or urea ammonia nitrate (UAN), which can enhance NH_3–N volatilization losses, further reducing N availability and uptake (Terman, 1980; Warncke et al., 2009; Warncke and Nagelkirk, 2010). Urease inhibitors [e.g., N-(n-butyl)-thiophosphoric triamide (NBPT)] are often applied with top-dressed urea or UAN to delay urea hydrolysis and reduce NH_3–N volatilization for improved functionality of urea-based fertilizers (Manunza et al., 1999; Mohammed et al., 2016; Thapa et al., 2016). Early spring urea + NBPT applied to winter wheat has shown nearly a 66% reduction in NH_3–N losses and a 3.1% increase in grain yield when compared with urea without NBPT (Engel et al., 2011; Slaton et al., 2011). However, NBPT can also be detrimental to wheat growth due to increased incidence of urea leaching and NH_4–N toxicity (Joo et al., 1991; Britto and Kronzucker, 2002; Dawar et al., 2011). Positive NBPT yield responses are often inconsistent and not widely reported due to cool soil temperatures, increased precipitation frequency during peak wheat growth, or lack of NH_3–N volatilization conditions during winter wheat spring N application timings (Mckenzie et al., 2010; Grant, 2014; Mohammed et al., 2016; Rajkovich et al., 2017).

In addition to N loss from NH_3–N volatilization, soil bacterial oxidation of NH_4–N to NO_3–N can result in leaching and/or denitrification N losses (Mohammed et al., 2016; Franzen, 2017). Winter wheat spring N applications in Michigan have greater risk of leaching and/or denitrification due to spring weather volatility (Warncke et al., 2009; Steinke and Bauer, 2017). Nitrification inhibitors {e.g., nitrapyrin [2-chloro-6-(trichloromethyl) pyridine]} can be added with urea or UAN to inhibit the conversion of NH_4–N to NO_3–N, thereby reducing the risk of leaching and/or denitrification and allowing larger quantities of N to remain in the root zone (Warncke et al., 2009; Trenkel, 2010). In Canada, spring urea-based fertilizer applications containing nitrapyrin resulted in larger pools of NH_4–N for at least eight weeks after treatment and increased total N by 25% as compared with untreated N fertilizer (Degenhardt et al., 2016). Rao (1996) and Mohammed et al. (2016) observed a 7 to 24% and 5 to 17% increase in wheat yield, respectively, following incorporation of nitrapyrin onto urea-based fertilizers. However like NBPT, yield responses are often inconsistent as yield increases from nitrapyrin applications are only expected in the presence of climatic N loss conditions (Liu et al., 1984; Barker and Sawyer, 2017; Franzen, 2017; Steinke and Bauer, 2017; Sassman et al., 2018).

Greater than recommended N fertilizer rates (often associated with intensive management) combined with high wind speeds and frequency from spring weather volatility can increase the incidence of plant lodging prior to harvest (Brinkman et al., 2014; Knott et al., 2016; Swoish and Steinke, 2017; Kleczewski and Whaley, 2018). Plant lodging can interfere with plant water and nutrient uptake, increase mechanical harvest difficulties, and reduce grain fill and yield. (Knapp et al., 1987; Knapp and Harms, 1988; Van Sanford et al., 1989). Plant growth regulators have proven successful in the shortening of plant height resulting in reduced lodging incidence and crop loss (Knapp and Harms, 1988; Van Sanford et al., 1989). Trinexapac-ethyl (TE) {ethyl 4-[cyclopropyl (hydroxyl) methylene]-3, 5-dioxocyclohexane-1-carboxylate} is a PGR labeled to decrease plant height and therefore reduce lodging susceptibility caused by wind damage (Rademacher, 2000; Swoish and Steinke, 2017). Trinexapac-ethyl inhibits the formation of active gibberellins resulting in decreased stem elongation and stronger stem tissues (Rademacher, 2000; Matysiak, 2006). In Michigan, TE applications decreased lodging 50 to 83% and increased grain yield by 5%, suggesting TE may be a beneficial risk management tool for high yielding, intensively managed wheat (Swoish and Steinke, 2017). In contrast, Kleczewski and Whaley (2018) observed no significant yield response to TE application due to the absence of lodging. Recent literature suggests wheat response to PGR application may be dependent on lodging occurrence, environmental conditions, and varietal characteristics including plant height and stem strength (Brinkman et al., 2014; Knott et al., 2016; Kleczewski and Whaley, 2018).

Perceived increased occurrence of plant tissue micronutrient deficiencies has raised grower interest in foliar micronutrient applications for intensively managed systems (Sutradhar et al., 2017). The increased use of synthetic fertilizers, new and greater yielding crop genetics, and liming to increase soil pH have all been suggested to decrease soil micronutrient concentrations and availability (Alloway, 2008). Michigan micronutrient recommendations are based on soil test, soil pH, and crop responsiveness at low micronutrient availability (Vitosh et al., 1995; Warncke et al., 2009). Greater emphasis has been placed on boron (B), manganese (Mn), and zinc (Zn) deficiencies throughout Michigan field crops generating grower interest in foliar applications of these specific nutrients to correct perceived deficiencies (Vitosh et al., 1995; Warncke et al., 2009). In B–, Mn–, and Zn–deficient New Zealand soils, wheat grain yield was increased following Mn application but not Zn or B (Curtin et al., 2008). Wheat grain yield was not increased in China or Canada following Zn or B application to soils deficient in each nutrient (Gupta et al., 1976; Lu et al., 2012; Wang et al., 2015). University guidelines suggest wheat as responsive to Mn but non-responsive to B and Zn suggesting that only a Mn application may be warranted on deficient soils (Vitosh et al., 1995; Warncke et al., 2009). Local Midwest research documenting wheat response to applications of B, Mn, and Zn is scarce, suggesting further research is needed to understand wheat response to micronutrient applications.

Intensive management practices often incorporate fungicide application to control disease and prevent yield loss (Beuerlein et al., 1989; Mourtzinis et al., 2017). Fusarium head blight (FHB) (*Fusarium graminearum*) affects wheat yield potential and grain quality across both soft red and soft white winter wheat production in Michigan (McMullen et al., 1997; Jones, 2000; Nagelkirk and Chilvers, 2016). Environmental conditions including frequent rainfall, high relative humidity, or heavy dew coinciding with anthesis and grain fill favors disease development (McMullen et al., 1997). Fusarium head blight infection can result in grain yield reductions through discolored and/or shriveled kernels and reduced marketability when deoxynivalenol (DON) mycotoxin concentrations exceed 1 mg kg^{-1} and 2 mg kg^{-1} for Michigan soft white and soft red winter wheat, respectively (McMullen et al., 1997; Jones and Mirocha, 1999; Jones, 2000; Nagelkirk and Chilvers, 2016). Previous research from more than 100 fungicide efficacy trials determined triazole-based fungicide applications including prothioconazole {2-[2-(1-chlorocyclopropyl)0–3-(2-chlorophenyl)-2-hydroxypropyl]-1, 2-dihydro-3H-1, 2, 4-triazole-3-thione} and tebuconazole {α-[2-(4-chlorophenyl)ethyl]-α-(1,1-dimethylethyl)-1H-1, 2, 4-triazole-1-ethanol} significantly reduced FHB severity, increased grain yield, and reduced DON contamination when applied directly to the grain head during anthesis (Paul et al., 2008). Deoxynivalenol reductions near 57% and 18 to 23% increases in grain yield have been observed following triazole fungicide applications (Beyer et al., 2006; Blandino et al., 2006; Paul et al., 2010). However, frequency of positive fungicide response will depend on varietal resistance, climatic conditions, and pathogen presence during wheat heading through kernel ripening (Blandino et al., 2006; Paul et al., 2010).

The objectives of this trial were to investigate soft red and soft white winter wheat grain yield and economic net return in response to increased N fertilizer, urease inhibitor, nitrification inhibitor, plant growth regulator, fungicide, and foliar micronutrient applications across intensive (i.e., high-input) and traditional (i.e., low-input) production systems. An omission trial design, previously used in Midwest corn (*Zea mays* L.) and soybean research to evaluate specific intensive management factors (Bluck et al., 2015; Ruffo et al., 2015), was used to determine whether the elimination of a specific input from an intensive management system or the introduction of a specific input into a traditional management system significantly affected grain yield or economic return.

MATERIALS AND METHODS

Soft Red Winter Wheat (SRWW) field trials were conducted at the South Campus Research Farm in Lansing, MI. (42°42′37.0″ N lat., 84°28′14.6″ W long.) on a Capac loam soil (fine-loamy, mixed, active, mesic Aquic Glossudalfs). Pre-plant soil characteristics (0–20 cm) included 6.4 to 7.0 pH (1:1 soil/water) (Peters et al., 2015), 27 to 47 mg kg^{-1} P (Bray-P1) (Frank et al., 2015), 85 to 94 mg kg^{-1} K (ammonium acetate method) (Warncke and Brown, 1998), 27 to 32 g kg^{-1} soil organic matter (loss-on-ignition) (Combs and Nathan, 2015), 0.6 to 2 mg kg^{-1} B (hot-water extraction) (Watson, 1998), 36 to 37 mg kg^{-1} Mn (0.1 M HCl) (Whitney, 1998), and 0.4- 2.1 mg kg^{-1} Zn (0.1 M HCl) (Whitney, 1998). Calcium sulfate (0–0–0–16 N–P–K–S) was broadcast at a rate of 18 kg S ha^{-1} in 2016 and 2017 while muriate of potash (0–0–62 N–P–K) was broadcast at a rate of 70 kg K ha^{-1} in 2017 based on soil test. Fields were previously cropped to silage corn and tilled prior to planting. Soft White Winter Wheat (SWWW) trials were conducted at the Saginaw Valley Research and Extension Center in Richville, MI (43°23′57.3″ N lat., 83°41′49.7″ W long.) on a Tappan-Londo loam soil (fine-loamy, mixed, active, calcareous, mesic Typic Enduaquolls). Pre-plant soil characteristics (0–20 cm) included 6.6 to 7.8 pH, 23 to 46 mg kg^{-1} P, 124 to 150 mg kg^{-1} K, 24 to 27 g kg^{-1} soil organic matter (loss-on-ignition), 0.5 to 6 mg kg^{-1} B, 16 to 43 mg kg^{-1} Mn, and 1.2 to 3.6 mg kg^{-1} Zn. Fields received broadcast applied calcium sulfate (0–0–0–16 N–P–K–S) at a rate of 18 kg S ha^{-1} in 2016 and 2017. Fields were previously cropped to dry bean (*Phaseolus vulgaris* L.) and soybean in 2016 and 2017, respectively, and tilled prior to planting. Both locations were non-irrigated and tile-drained.

Locations included twelve-row plots measuring 2.5 m in width by 7.6 m in length with 19.1 cm row spacing. Plots were planted with a Gandy Orbit-Air Seeder coupled with John Deere double disk openers at a plant population of 4.4 million seeds ha^{-1} and arranged in a randomized complete block design with four replications. Soft red winter wheat variety 'Sunburst' (Michigan Crop Improvement Assoc., Okemos, MI), a short-strawed, high-yielding variety was planted at Lansing on 29 Sept. 2015 and 23 Sept. 2016. Soft white winter wheat variety 'Jupiter' (Michigan Crop Improvement Assoc., Okemos, MI), a short-strawed high-yielding variety was planted at Richville on 1 Oct. 2015 and 10 Oct. 2016.

Nitrogen was applied as UAN (28–0–0) utilizing a backpack sprayer equipped with streamer bars (Chafer Machinery Ltd, Upton, UK) at the Feekes 3 growth stage (29 Mar. 2016 and 3 Apr. 2017, Lansing; 30 Mar. 2016 and 12 Apr. 2017, Richville). Traditional management system N rates were based on Michigan State University recommendations for the Lansing and Richville locations. Traditional N rate treatments consisted of 100.9 kg N ha^{-1} and 134.5 kg N ha^{-1} for SRWW and SWWW, respectively. Intensive N rate treatments consisted of a 20% increase from traditional N rates (121.1 kg N ha^{-1} and 161.4 kg N ha^{-1} for SRWW and SWWW, respectively). Urease inhibitor [Agrotain Advanced, N-(n-butyl)-thiophosphoric triamide (NBPT) (1.04 mL kg^{-1} UAN); Koch Agronomic Services LLC, Wichita, KS] and nitrification inhibitor [Instinct II, nitrapyrin (2-chloro-6-(trichloromethyl) pyridine) (2.7 L ha^{-1}); Dow Agrosciences, Indianapolis, IN] were applied with UAN at Feekes 3. Foliar micronutrient fertilizer [Max-In Ultra ZMB, 4% Zn (EDTA), 3% Mn (EDTA), 0.1% B (boric acid) [4.7 L ha^{-1}]; Winfield United LLC, St. Paul, MN] and plant growth regulator (Palisade EC, Trinexapac-ethyl [0.8 L ha^{-1}]; Syngenta Crop Protection, Cambridge, UK) were applied at Feekes 6 (29 Apr. 2016 and 24 Apr. 2017, Lansing; 3 May 2016 and 3 May 2017, Richville) using a backpack sprayer calibrated at 140.3 L ha^{-1} with Teejet XR8002 nozzles (Teejet Technologies, Wheaton, IL). Fungicide (Prosaro 421 SC, prothioconazole {2-[2-(1-chlorocyclopropyl0–3-(2-chlorophenyl)-2-hydroxypropyl]-1, 2-dihydro-3H-1, 2, 4-triazole-3-thione} and tebuconazole {α-[2-(4-chlorophenyl) ethyl]-α-(1,1-dimethylethyl)-1H-1, 2, 4-triazole-1-ethanol}[0.6 L ha^{-1}]; Bayer CropScience Research Triangle Park, NC) was applied at Feekes 10.5.1 (31 May 2016 and 28 May 2017, Lansing; 1 June 2016 and 2 June 2017, Richville) using a backpack sprayer calibrated at 140.3 L ha^{-1} with Teejet tt11002 nozzles (Teejet Technologies, Wheaton, IL). Inputs applied simultaneously at the same growth stage were tank-mixed.

Omission treatment design was used to determine specific input responses (Table 1). The omission design utilized two treatment controls, one containing all applied inputs (i.e., intensive treatment) and one containing none of the applied inputs (i.e., traditional treatment) (Bluck et al., 2015; Ruffo et al., 2015). To evaluate individual input effects, inputs removed from

Table 1. Overview of omission treatment design, treatment names, and inputs applied, 2016 to 2017.

		Agronomic inputs applied						
Treatment	Treatment name	UI†	NI‡	PGR§	Fungicide¶	Micro#	High-N††	Low-N‡‡
1	Intensive (I)	Yes	Yes	Yes	Yes	Yes	Yes	No
2	I- UI	No	Yes	Yes	Yes	Yes	Yes	No
3	I- NI	Yes	No	Yes	Yes	Yes	Yes	No
4	I- PGR	Yes	Yes	No	Yes	Yes	Yes	No
5	I- Fungicide	Yes	Yes	Yes	No	Yes	Yes	No
6	I- Micro	Yes	Yes	Yes	Yes	No	Yes	No
7	I- High-N	Yes	Yes	Yes	Yes	Yes	No	Yes
8	Traditional (T)	No	No	No	No	No	No	Yes
9	T + UI	Yes	No	No	No	No	No	Yes
10	T + NI	No	Yes	No	No	No	No	Yes
11	T + PGR	No	No	Yes	No	No	No	Yes
12	T + Fungicide	No	No	No	Yes	No	No	Yes
13	T + Micro	No	No	No	No	Yes	No	Yes
14	T + High-N	No	No	No	No	No	Yes	No
15	Check	No	No	No	No	No	No	No

† Urease inhibitor (UI) applied at a rate of 1.04 ml kg^{-1} UAN at F3 growth stage.

‡ Nitrification inhibitor (NI) applied at a rate of 2.71 L ha^{-1} at F3 growth stage.

§ Plant growth regulator (PGR) applied at a rate of 0.8 L ha^{-1} at F6 growth stage.

¶ Fungicide applied at a rate of 0.6 L ha^{-1} at F10.5.1 growth stage.

Foliar micronutrient fertilizer containing Zn, Mn, and B applied at a rate of 4.7 L ha^{-1} at F6 growth stage.

†† High-nitrogen applied at a rate of 121.1 and 161.4 kg ha^{-1} for Lansing and Richville locations, respectively.

‡‡ University-recommended N rate applied at 100.9 kg N ha^{-1} and 134.5 kg N ha^{-1} for Lansing and Richville locations, respectively.

the intensive management system were compared only with the intensive treatment and inputs added into the traditional management system were only compared with the traditional treatment (Bluck et al., 2015; Ruffo et al., 2015).

Average monthly temperature and total cumulative precipitation were recorded throughout the growing season using the Michigan State University Enviro-weather (https://www.enviroweather.msu.edu/, Michigan State University, East Lansing, MI). Temperature and precipitation 30-yr means were obtained from the National Oceanic and Atmospheric Administration (NOAA, 2017). Flag leaf tissue samples for Zn, Mn, and B concentrations and mean plant height were collected at Feekes 9 and Feekes 10.5.4, respectively. Visual estimates of percent flag leaf area affected by foliar disease and/or percent grain heads affected by FHB were taken two and three weeks after fungicide application, respectively.

Grain yield was harvested from the center 1.2 m of each plot utilizing a small-plot combine (Almaco, Nevada, IA) on 11 July 2016 and 9 July 2017 at Lansing and 12 July 2016 and 17 July 2017 at Richville and adjusted to 135 g kg^{-1} moisture. Grain subsamples were collected from each plot and sent to the U.S. Wheat and Barley Scab Initiative mycotoxin testing laboratory (University of Minnesota, St. Paul, MN) and evaluated for DON quantification. Due to the susceptibility of SWWW variety 'Jupiter' to pre-harvest sprouting (Brown et al., 2017), additional grain samples were taken from SWWW plots and evaluated for α-amylase activity and pre-harvest sprouting incidence. Falling number procedure (Perten Instruments, Springfield, IL) was used to determine α-amylase activity of SWWW flour and determine sprout damage.

Data Analysis

Economic profitability was assessed using input cost estimates of US\$0.94 kg^{-1}, \$13.34 to \$27.70, \$28.91, \$39.14, \$34.60, and \$44.33 ha^{-1} in 2016 and \$0.90 kg^{-1}, \$12.60 to \$20.16, \$29.62, \$32.79, \$31.51, and \$43.27 ha^{-1} in 2017 for N fertilizer, urease inhibitor, nitrification inhibitor, plant growth regulator, foliar micronutrient, and fungicide, respectively. Cost estimate varied for urease inhibitor due to application rates depending on total N rates which varied by treatment and location. An additional cost of \$18.53 and \$17.30 ha^{-1} for 2016 and 2017, respectively, was incorporated as an application cost for N fertilizer, plant growth regulator, foliar micronutrient, and fungicide. Net returns were calculated by multiplying harvest grain price estimates of \$1.71 and \$1.87 kg^{-1} in 2016 and \$1.86 and \$2.08 kg^{-1} in 2017 for soft red and soft white winter wheat, respectively, by grain yield and subtracting total treatment cost. Product, application, and harvest grain price estimates were taken from local agriculture retailers and grain elevators.

Site years were analyzed separately due to a significant treatment by year interaction. Locations were analyzed separately due to different SRWW and SWWW wheat varieties and locally recommended N rates. Statistical analyses were performed using the GLIMMIX procedure in SAS (SAS Institute, 2012) at $\alpha = 0.10$. Replication was considered a random factor in all experiments with all other factors considered fixed. Single degree of freedom contrasts were used to determine treatment mean separations. Authors could not contrast input responses across both the intensive and traditional management systems due to unequal comparisons regarding treatments containing a specific input and treatments without that input.

RESULTS AND DISCUSSION

Environmental Conditions

Growing season (March–July) precipitation differed by –27 and 4% and −9 and 14% from the 30-yr mean during 2016 to 2017 at Richville and Lansing, respectively (Table 2). May and June 2016 cumulative rainfall was 68 and 60% below the 30-yr

Table 2. Mean monthly precipitation and temperature† for the winter wheat growing season, Richville. and Lansing, MI, 2016 to 2017.

Site	Year	Mar.	Apr.	May	June	July	Total
				cm			
Richville	2016	10.1	3.3	1.6	4.0	8.8	27.9
	2017	4.8	14.7	5.0	12.3	2.8	39.6
	30-yr‡ avg.	4.9	8.1	8.4	9.0	7.9	38.2
Lansing	2016	10.1	7.5	5.2	1.8	9.6	34.2
	2017	7.6	13.2	6.5	8.4	6.7	42.5
	30-yr avg.	5.2	7.7	8.5	8.8	7.2	37.4
				°C			
Richville	2016	3.6	5.6	14.8	19.7	22.6	–
	2017	0.7	10.3	13.7	20.4	21.1	–
	30-yr avg.	0.4	7.4	13.2	18.7	20.9	–
Lansing	2016	5.6	7.5	14.8	20.3	23.0	–
	2017	1.1	11.1	13.5	19.9	21.8	–
	30-yr avg.	1.7	8.6	14.3	19.8	21.9	–

† Precipitation and air temperature data were 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. Wheat grain yield for Richville and Lansing, MI, 2016 to 2017. Mean grain yield of intensive and traditional control treatments displayed. All other treatments display change in grain yield from respective intensive or traditional treatment using single degree of freedom contrasts.

	2016		2017	
Treatment†	Richville	Lansing	Richville	Lansing
		Mg		
Intensive (I)	7.02	5.25	4.34	6.69
I - UI‡	–0.39	+0.40	+1.09	–0.52*
I - NI	–0.32	+0.15	+1.54	+0.35
I - PGR	–0.57	–0.08	+1.11	+0.32
I - Fungicide	–0.56	0.0	–0.63	+0.05
I - Micro	–0.17	+0.65	+1.01	+0.20
I - High-N	–0.94*	–0.58	+1.16	–0.15
Traditional (T)	6.85	5.43	4.34	6.73
T + UI§	+0.40	–0.18	+0.03	–0.51*
T + NI	–0.32	+0.23	+0.10	–0.20
T + PGR	+0.30	+0.10	–1.22	–0.29
T + Fungicide	–0.05	+0.75*	+0.18	+0.07
T + Micro	0.0	+0.50	+0.13	–0.41
T + High-N	–0.05	+0.23	–0.67	+0.06
Check¶	4.25	4.52	2.79	3.21
I vs. T#	ns ††	ns	ns	ns
CV %	11.25	17.51	42.25	10.19

* Significantly different at $\alpha = 0.1$ using single degree of freedom contrasts.

† UI, N-(n-butyl)-thiophosphoric triamide urease inhibitor; NI, nitrapyrin nitrification inhibitor; PGR, trinexapac-ethyl plant growth regulator; High-N, 20% increase in nitrogen fertilizer rate.

‡ Values in I – input rows indicate a yield (Mg ha^{-1}) change from respective intensive (I) treatment.

§ Values in T + input rows indicate a yield (Mg ha^{-1}) change from respective traditional (T) treatment.

¶ Non-treated check containing no fertilizer or additional inputs was not included in statistical analysis.

Comparison between the intensive and traditional treatment utilizing single degree of freedom contrasts.

†† Nonsignificant $\alpha = 0.1$ using single degree of freedom contrasts.

mean for Richville and Lansing, respectively, likely reducing wheat grain yield potential. April 2017 rainfall was 72 to 82% above 30-yr means at both locations likely resulting in the potential for N loss (e.g., leaching and/or denitrification). March 2016 air temperatures were 3.2 and 4.9 °C above average and Apr. 2017 air temperatures were 2.9 and 2.5 °C above average at Richville and Lansing, respectively (Table 2). May through July mean air temperatures were within 10% of the 30-yr mean across all site-years. Delayed autumn planting, site-specific soil spatial variability, and winter injury caused by cool February and March air temperatures with minimal snow cover contributed to the below average grain yields observed at Richville during 2017 (Table 3).

Intensive vs. Traditional Management Systems

Across site-years, locations, and both SRWW and SWWW varieties, grain yield was not significantly different between the intensive treatment containing all inputs and the traditional treatment containing a recommended rate of N fertilizer (Table 3). Intensively-managed wheat resulted in grain yields of 7.02 and 4.34 Mg ha^{-1} at Richville and 5.25 and 6.69 Mg ha^{-1} at Lansing, as compared to 6.85 and 4.34 Mg ha^{-1} at Richville and 5.43 and 6.73 Mg ha^{-1} at Lansing for traditionally-managed wheat during 2016 and 2017, respectively. An overall lack of N loss conditions, micronutrient deficiency symptoms, plant lodging, and disease pressure resulted in minimal and inconsistent input responses across site-years. Additionally, SRWW and SWWW grain DON concentration and SWWW falling number are not presented due to a lack of FHB and pre-harvest sprouting incidence across all site-years. Richville 2017 site-specific variability caused a yield coefficient of variation (CV) of 42% and likely contributed to the lack of significant input responses during this single site-year. However, no additional N loss, micronutrient deficiency symptoms, disease, or plant lodging were observed. Results from the current study are consistent with previous research that support university recommended IPM principles and suggest positive grain yield responses are not associated with specific input applications without the presence of yield-limiting factors (e.g., disease presence, nutrient-loss conditions, and plant lodging) (Paul et al., 2010; Wegulo et al., 2012; Knott et al., 2016; Barker and Sawyer, 2017; Rajkovich et al., 2017; Swoish and Steinke, 2017).

Economic Net Return

Across all four site-years, the intensive treatment averaged a \$346 ha^{-1} treatment cost with an average break-even yield of 2.3 Mg ha^{-1} as compared with the \$127 ha^{-1} treatment cost and break-even yield of 0.8 Mg ha^{-1} for the traditional treatment. Compared with the intensive treatment, the traditional treatment containing only a university recommended N rate resulted in a significantly greater net return per hectare in three of four site-years and averaged \$221 ha^{-1} greater across all four site-years (Table 4). The 20% greater N rate was the only individual input to significantly increase net return per hectare in 1 of 4 site-years. Positive economic gains were only observed with additional N within the intensive management system. Intensive management containing 20% greater N produced an average net return of \$686 ha^{-1} compared with \$891 ha^{-1} for the traditional treatment at Richville in 2016 (Table 4). Data suggest that although increased N rates positively impacted net return in an intensive system, utilization of a traditional management system was still

Table 4. Wheat economic profitability for Richville and Lansing, MI, 2016 to 2017. Mean net return of intensive and traditional control treatments displayed. All other treatments display change in net return from respective intensive or traditional treatment using single degree of freedom contrasts.

	2016		2017	
Treatment†	Richville	Lansing	Richville	Lansing
	US\$ ha^{-1}			
Intensive (I)	686.14	385.31	374.74	694.06
I - UI‡	–38.88	+68.63	+203.79	–63.98
I - NI	–24.79	+49.99	+289.65	+81.96*
I - PGR	–46.13	+35.20	+220.09	+80.51*
I - Fungicide	–38.05	+67.39	–43.69	+69.53
I - Micro	+4.81	+124.35*	+200.83	+59.55
I - High-N	–118.48*	–55.83	+222.57	–1.40
Traditional (T)	891.41	635.91	592.25	905.86
T + UI§	+45.85	–39.98	–11.99	–88.79*
T + NI	–81.60	+2.13	–45.76	–60.33
T + PGR	–15.44	–48.77	–255.94	–94.68*
T + Fungicide	–73.57	+35.70	–31.57	–51.68
T + Micro	–54.91	+13.82	–27.02	–110.12*
T + High-N	–31.08	+17.76	–136.59	–8.69
Check¶	643.16	620.38	469.67	483.49
I vs. T#	*	*	ns ††	*
CV %	14.99	10.20	61.11	12.84

* Significantly different at $\alpha = 0.1$ using single degree of freedom contrasts.

† N-(n-butyl)-thiophosphoric triamide urease inhibitor (UI), nitrapyrin nitrification inhibitor (NI), trinexapac-ethyl plant growth regulator (PGR), 20% increase in nitrogen fertilizer rate (High-N).

‡Values in I - input rows indicate a net return (US\$ ha^{-1}) change from respective intensive (I) treatment.

§Values in T + input rows indicate a net return (US\$ ha^{-1}) change from respective traditional (T) treatment.

¶ Non-treated check containing no fertilizer or additional inputs was not included in statistical analysis.

Comparison between the intensive and traditional treatment utilizing single degree of freedom contrasts.

†† Nonsignificant $\alpha = 0.1$ using single degree of freedom contrasts.

more profitable. July 2016 and 2017 wheat commodity prices were the lowest over the last 8 yr (NASS, 2017). Producers continue to perceive yield loss as a greater risk than profit loss (Rutan and Steinke, 2017). However, at current year wheat prices, results suggest producers may want to consider greater emphasis on increasing profitability rather than protecting yield loss when choosing to incorporate additional inputs.

Nitrogen Rate

A 20% greater N rate did not significantly affect yield in any site-year within the traditional management system (Table 3). Previous research from both Michigan and Wisconsin concluded optimal wheat yields were produced with N rates between 52 and 84 kg N ha^{-1} (Bauer, 2016; Mourtzinis et al., 2017). Results from this trial concur with previous traditional management findings that suggested negligible grain yield increases occurred with above-recommended N rates when utilizing minimal input management systems (Vaughan et al., 1990, Bauer, 2016; Knott et al., 2016; Mourtzinis et al., 2017; Swoish and Steinke, 2017).

In contrast to the traditional system, a significant grain yield decrease of 0.94 Mg ha^{-1} occurred at Richville in 2016 when the 20% increase in N rate was removed within the intensive management system (Table 3). A similar albeit nonsignificant observation occurred at Lansing within the intensive system where yield decreased 0.58 Mg ha^{-1} and 0.15 Mg ha^{-1} in 2016 and 2017, respectively, at the lower N rate. No visual differences of N deficiency as measured by chlorophyll meter values and green canopy cover occurred between standard and high-N treatments at any location throughout the study (data not shown). Data from this trial suggested potential greater N fertilizer demand with intensive management (Ruffo et al., 2015) or a potential synergistic effect between additional inputs and the greater intensive N rate (161.4 kg N ha^{-1}) associated with SWWW as compared to the lower intensive N rate (121.1 kg N ha^{-1}) associated with SRWW. However, no other input resulted in a significant yield decrease when removed from the Richville 2016 intensive system causing difficulty in understanding which specific input(s) interacted with the increased N rate. Previous research observed significant interactions between fungicide application and increased N rates (140 kg N ha^{-1}– 240 kg N ha^{-1}) regardless of disease presence, presumably due to the extended photosynthetic period associated with fungicide application (Kelley, 1993; Dimmock and Gooding, 2002; Brinkman et al., 2014; Mourtzinis et al., 2017; Salgado et al., 2017). Application of multiple inputs can enhance the green flag leaf area and extend grain fill resulting in increased plant N requirement (Mourtzinis et al., 2017; Salgado et al., 2017).

Previous reports of greater individual input responses using intensive rather than traditional management suggests synergy may exist, depending on the various intensive input technologies utilized (Brinkman et al., 2014; Bluck et al., 2015; Ruffo et al., 2015). University-recommended N rates are based off the assumption that N response is independent of agronomic factors other than yield (Warncke et al., 2009; Brinkman et al., 2014). Results suggest recommended N rates proposed by Warncke et al. (2009) have the potential to supply sufficient available N to optimize wheat yield when utilizing a low-input, traditional management system. However, a greater N demand may occasionally be needed for an intensive management system due to sufficient N being the primary source for significant input interactions (Mourtzinis et al., 2017). Significant N rate responses were inconsistent across both site-years at Richville, with site-specific variability potentially hindering a similar 2017 response as observed in 2016. Further research is likely needed to investigate potential synergisms between inputs and N fertilizer as a source for interactions across additional site-years to determine whether recommended wheat N rates require adjustment based on specific agronomic inputs and management practices.

Urease Inhibitor

Utilizing a urease inhibitor resulted in a significant grain yield response in one of four site-years across both management systems (Table 3). Lansing 2017 grain yield significantly decreased 0.52 Mg ha^{-1} when UI was removed from the intensive system and significantly decreased 0.51 Mg ha^{-1} when UI was added to the traditional system. In all four site-years, UAN was applied to minimal-residue, cool, spring soils with rainfall occurring within 7 d following N fertilizer application (Table 5). Environmental conditions encountered across all site-years of this study suggest a response to UI application should not have been expected due to a lack of volatilization N loss conditions (Ma et al., 2010; Franzen, 2017). Urease inhibitor effects may also be less likely when utilizing UAN due to only 50% urea composition (Hendrickson, 1992).

The 2017 growing season produced April rainfall totals 82 and 72% greater than the 30-yr mean in Richville and Lansing, respectively (Table 2) with Lansing experiencing the greatest cumulative rainfall (5.3 cm) within one week of N application (Table 5). Significant rainfall following N application at Lansing in 2017 may suggest that N fertilizer was transported beneath the soil surface, decreasing the risk of volatilization. In addition, although nonsignificant, the high-N treatment was the only other input to give a negative yield response of 0.15 Mg ha^{-1} when removed from the intensive system at Lansing in 2017 (Table 3). Yield reduction observed from UI removal following significant rainfall within the intensive system suggests a potential synergistic effect occurred between application of both UI and the SRWW intensive N rate of 121 kg N ha^{-1}. Urea is an uncharged, mobile form of N that can readily move downward through the soil profile under high moisture conditions (Fenn and Miyamoto, 1981; Dawar et al., 2011). Adding a UI while also receiving significant rainfall may delay urea hydrolysis and promote leaching through the soil profile beyond the wheat rooting zone (Dawar et al., 2011). However, current results suggest the combination of a UI with the SRWW intensive N rate inhibited N transformation and may have accounted for potential N losses by supplying additional N to the root zone (Dawar et al., 2011; Mohammed et al., 2016).

In contrast to a positive yield response within the intensive management system, UI application significantly decreased grain yield and tissue N (data not shown) within the traditional management system at 2017 Lansing (Table 3). The traditional system base-N rate of 100.9 kg N ha^{-1} was the lowest among all SRWW and SWWW treatments allowing for smaller N losses to have a greater percentage reduction of plant available N. Similar yield reductions from UI additions have been observed in corn where UAN plus UI applications were followed with 2.9 cm rainfall within four days of N application (Murphy and Ferguson, 1997). Joo et al. (1991) observed decreased recovery of plant and soil urea-derived N in turfgrass with the addition of a UI due to a combination of delayed hydrolysis and 13 cm rainfall within 7 d of N application. Due to the increased frequency of Michigan's spring rainfall events often coinciding with wheat N application timings, UI application is unlikely to provide a yield benefit when applied individually under traditional management and may result in additional risk of N loss when fertilizing within recommended N guidelines or significant rainfall occurs soon after application. However, intensive management practices including a UI application with a 20% greater N rate may improve N availability by offsetting some degree of N loss (Hou et al., 2006; Dawar et al., 2011; Mohammed et al., 2016).

Nitrification Inhibitor

Nitrification inhibitor did not significantly impact wheat grain yield across any of the four site-years (Table 3). Lack of significant grain yield response in 2016 was likely due to negligible risk of N leaching and/or denitrification from below 30-yr average April rainfall at both locations (Table 2). Results were consistent with previous research indicating yield gains from NI application are not expected when below average rainfall follows N application (Nelson and Huber, 1980; Barker and Sawyer, 2017; Franzen, 2017; Steinke and Bauer, 2017).

Table 5. Weekly precipitation† and soil temperatures following wheat N fertilizer applications, Richville and Lansing, MI, 2016 to 2017.

Site	Year	Day 1–7	Day 8–14	Day 15–21	Day 22–28
			cm		
Richville	2016	2.8	0.7	0.0	1.5
	2017	2.5	3.2	0.0	1.9
Lansing	2016	2.5	3.2	0.0	1.9
	2017	5.3	0.5	2.9	3.9
			°C		
Richville	2016	3.4	3.3	9.6	9.8
	2017	10.2	11.0	8.9	10.0
Lansing	2016	7.3	4.5	10.0	12.3
	2017	8.9	13.3	14.8	12.7

† Precipitation and soil temperature (0–5 cm) data were collected from Michigan State University Enviro-weather (https://enviroweather.msu.edu/).

April 2017 rainfall following N fertilizer application was 82% and 72% greater than the 30-yr average at Richville and Lansing, respectively, suggesting a potential for N-loss (Table 2). Lansing received significant rainfall (5.3 cm) within one week of N application (Table 5). Despite significant rainfall following N application, NI application did not affect grain yield at either 2017 location. In spite of above average rainfall, insignificant responses to NI application following N fertilization have been observed in recent literature (Barker and Sawyer, 2017; Franzen, 2017; Maharjan et al., 2017; Sassman et al., 2018). Barker and Sawyer (2017) observed no soil NO_3–N or corn grain yield benefits from NI application on fine-textured, poorly drained soils receiving 10.7 cm rainfall within one week of N application. Authors attributed the lack of NI response to cool soil temperatures following N application, resulting in delayed bacterial conversion of NH_4–N to NO_3–N (Barker and Sawyer, 2017). Nitrification rates significantly decrease at soil temperatures less than 15 °C (Shammas, 1986). Both Richville and Lansing average soil temperatures one week following N application were less than 9 °C and less than 11 °C in 2017, respectively (Table 5), and may provide evidence that bacterial conversion of NH_4–N to NO_3–N may have been slowed or delayed thus reducing the risk for N loss.

In addition to cool soil temperatures, the specific formulation of nitrapyrin (Instinct II; Dow Agrosciences, Indianapolis, IN) used in the current study may have contributed to the lack of response (Ferrel, 2012; Franzen, 2017; Maharjan et al., 2017). Instinct is a polymer-encapsulated form of nitrapyrin that is ineffective until nitrapyrin is released from the microcapsule (Ferrel, 2012). Ferrel (2012) observed a 300% increase in soil NH_4–N concentration when utilizing the NI dicyandiamide (DCD) as compared to Instinct. Maharjan et al. (2017) observed no corn yield benefits to Instinct application despite significant rainfall occurring the day of N application and in the two weeks following N application. Previous research has observed poor Instinct performance across various cropping systems and environmental conditions (Ferrel, 2012; Franzen, 2017; Maharjan et al., 2017; Sassman et al., 2018) with authors attributing poor performance to inadequate nitrapyrin availability from microencapsulation (Ferrel, 2012; Franzen, 2017; Maharjan et al., 2017). Instinct has been suggested to delay release and reduce concentration of nitrapyrin during N applications and may require greater application rates than labeled to inhibit nitrification (Ferrel, 2012; Franzen, 2017; Maharjan et al., 2017).

Table 6. Site year and soil descriptions, soil chemical properties, and mean P, K, B, Mn, and Zn soil test (0– 20 cm) nutrient concentrations obtained prior to winter wheat planting, Richville and Lansing, MI, 2016 to 2017.

Site	Year	Soil description	Soil test† P	K	B	Mn	Zn	pH	CEC
			mg kg^{-1}						cmolc kg^{-1}
Richville	2016	Tappan-Londo Loam	23	150	6	43	1.2	7.8	16.7
	2017	Tappan-Londo Loam	46	124	0.5	16	3.6	6.6	5.6
Lansing	2016	Capac Loam	27	94	2	35.5	0.4	6.4	9.1
	2017	Capac Loam	47	85	0.6	37	2.1	7.0	10.4

† P, phosphorus (Bray–P1); K, potassium (ammonium acetate extractable K); Zn, zinc (0.1 M HCl); Mn, manganese (0.1 M HCl); B, boron (hot-water extraction).

Foliar Zn, Mn, and B

Foliar application of Zn, Mn, and B did not affect grain yield (Table 3). Pre-plant soil test data showed B deficiencies (< 0.7 mg kg^{-1}) in two of four site-years, Zn deficiencies {Zn requirement = [(5.0 × pH)– (0.4 × soil test Zn mg kg^{-1})]– 32} in three of four site-years, and no Mn deficiencies {Mn requirement = [(6.2 × pH)– (0.35 × soil test Mn mg kg^{-1})]– 36} in any site-year (Table 6) (Warncke et al., 2009). Tissue samples from the uppermost leaf at Feekes 9 showed deficiencies in B (< 6 mg kg^{-1}) in three of four site-years, Zn deficiency (< 21 mg kg^{-1}) in four of four site-years, and no Mn deficiency (< 16 mg kg^{-1}) in any site-year (Table 7). Soil and tissue nutrient analyses suggested a potential response to foliar application of B and Zn (Vitosh et al., 1995). However despite soil and tissue deficiencies of B and Zn, no visual plant deficiency symptoms were observed across any site-year and thus a response to application was not expected.

University micronutrient recommendations are not solely based on soil or tissue test levels but also incorporate crop sensitivity to low micronutrient availability (Vitosh et al., 1995; Warncke et al., 2009). Crops categorized as sensitive to specific micronutrients have a high likelihood of response to application once soil and tissue nutrient levels drop below sufficiency ranges, while crops categorized as non-sensitive may not respond (Vitosh et al., 1995; Warncke et al., 2009). Previous literature and university guidelines suggest wheat as non-sensitive to B and Zn, yet highly sensitive to Mn (Vitosh et al., 1995; Warncke et al., 2009; Havlin et al., 2014). Therefore, yield increases from a combined foliar application of Zn, Mn, and B to wheat may only occur in the presence of a Mn deficiency, which was not present in any site-year. Results are supported by Curtin et al. (2008) who only observed a significant wheat yield response to Mn and not B or Zn on soils identified as deficient in all three nutrients. Additionally, in Chinese and Canadian soils categorized as deficient in Zn (0.5 to 0.7 mg kg^{-1}) and B (0.6 mg kg^{-1}), respectively, wheat grain yield was not increased following Zn or B application (Gupta et al., 1976; Lu et al., 2012; Wang et al., 2015). Current results suggest a crop response to micronutrient applications may only be expected once crop-sensitive micronutrients decrease below sufficiency levels and/or where visual plant deficiency symptoms are observed. Soil and tissue testing in conjunction with university fertilizer guidelines and crop scouting may be important prior to incorporating a micronutrient application.

Table 7. Winter wheat flag leaf B, Mn, and Zn tissue nutrient concentrations taken from non-treated plots at Feekes 9 growth stage, Richville and Lansing, MI, 2016 to 2017.

Site	Year	Tissue micronutrient concentration† B	Mn	Zn
		mg kg^{-1}		
Richville	2016	2	20	16.5
	2017	3.3	21.8	19.8
Lansing	2016	5	44	19.5
	2017	9.3	22	15

† B, boron (ICP mass spectroscopy); Mn, manganese (ICP mass spectroscopy); Zn, zinc (ICP mass spectroscopy).

Plant Growth Regulator

Plant growth regulator application did not affect grain yield in any site-year (Table 3). Plant height reductions were inconsistent when PGR was applied individually in the traditional system resulting in one significant height reduction (5.8 cm) at Lansing in 2017 (Table 8). Inconsistent height reductions following PGR application has also been reported by Knott et al. (2016). Results contradict Matysiak (2006) and Wiersma et al. (2011) who observed 27 and 6% height reductions, respectively, following PGR application. When the PGR was removed from the intensive system, significant plant height increases were observed in two of four site-years. Additionally, when the foliar micronutrient was removed from the intensive system, significant plant height increases were observed in three of four site-years, suggesting a potential synergism between the tank-mixed application of the PGR and foliar micronutrient. Foliar micronutrient (Max-IN ZMB; Winfield United, St. Paul, MN) used in this trial contains a monosaccharide adjuvant utilized to increase plant uptake of foliar-applied Zn, Mn, and B (Boring, 2013). Results suggest the addition of this specific adjuvant may have increased plant uptake of the PGR resulting in a greater PGR-induced plant height reduction.

Plant lodging did not occur in any of the four site-years across both SRWW and SWWW varieties and management systems including N rates of up to 161.4 kg N ha^{-1}. Both SWWW and SRWW varieties used in this study consisted of short-strawed, high-stem-strength physical characteristics (Siler et al., 2017; Michigan Crop Improvement Assoc., Okemos, MI) which likely contributed to the lack of lodging and grain yield response to PGR application. Results corresponded with recent research by Swoish and Steinke (2017), who observed yield increases from PGR application only in the presence of lodging, which was more consistent of a taller, weaker structured cultivar rather than adoption of greater N rates. Results suggest motives for applying a PGR may depend more on cultivar structure, susceptibility to lodging, and average plant height data which are evaluated and accessible through university variety trials (Siler et al., 2017), rather than management intensification (Knott et al., 2016; Swoish and Steinke, 2017).

Fungicide

Adding a fungicide to the traditional management system increased yield 0.75 Mg ha^{-1} in one of four site-years

Table 8. Plant growth regulator (PGR) and foliar micronutrient effects on Feekes 10.5.4 mean winter wheat plant height, Richville and Lansing, MI, 2016 to 2017.

		Treatment					
Site	Year	Intensive (I)	I - PGR†	I - Micro	Traditional (T)	T + PGR‡	T + Micro
		cm					
Richville	2016	71.9	+1.3	+1.2	73.8	+3.8	+1.6
	2017	63.9	+11.6*	+8.8*	70.1	–4.3	+3.5
Lansing	2016	70.5	+4.6	+8.7*	77.4	–1.3	+0.6
	2017	71.8	+10.5*	+7.1*	81.2	–5.8*	+0.3

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

† Values in I - input column indicate a plant height (cm) change from respective intensive (I) treatment.

‡ Values in T + column indicate a plant height (cm) change from respective traditional (T) treatment.

(Table 3). Fungicide removal from the intensive system did not significantly affect grain yield at either location in 2016 or 2017. Fusarium head blight did not occur in any of the four site-years. Below average May rainfall occurred across all site-years (Table 2). When rainfall is deficient during the period of wheat anthesis or growth stage Feekes 10.5.1, decreased risks of FHB infection and subsequent DON accumulation occur. Lansing 2016 was the only site-year to experience significant foliar disease pressure, predominantly caused by stripe rust (Table 9). Stripe rust, rarely prevalent in Michigan, was identified as the most significant wheat yield reducing factor in 2016 due to strong winds out of the western and southern United States, aiding fungal spore dispersal (Chen, 2005; Siler et al., 2016). Additionally, local areas received adequate temperature, rainfall, and humidity for disease growth (Chen, 2005; Siler et al., 2016). Lansing received 5.6 cm greater April through June rainfall than Richville in 2016, likely creating an advantageous environment for stripe rust development.

Visual assessment of flag leaf infection showed removal of fungicide from the intensive system at Lansing 2016 increased disease presence by 11.3% (Table 9). Addition of the fungicide to the traditional management system reduced flag leaf disease presence by 15%. Data are supported by Chen (2014) who reported controlling wheat stripe rust incidence 42 to 100% with triazole fungicide applications, resulting in 22 to 878% grain yield increases compared with non-fungicide treated plots. Additionally, Salgado et al. (2017) observed triazole fungicide treatments applied at Feekes 10 or 10.5.1 reduced wheat leaf rust (*Puccinia triticina*) in Ohio from 72 to 99%. Explanation for the nonsignificant yield response to fungicide in the presence of disease despite significant visual control within the intensive system at Lansing remains unclear. Disease suppression from inputs other than fungicide including foliar applied Mn and B have occurred and been shown to decrease rust (*Puccinia* spp.) incidence in wheat (Huber and Wilhelm, 1988; Datnoff et al., 2007). Results support previous findings by Paul et al. (2010) and Wegulo et al. (2012), suggesting greatest fungicide impact occurs in a high disease environment. In addition, producers should also look to incorporate disease resistant varieties to reduce fungicide applications in a low disease environment and maximize fungicide efficacy and response in a high disease environment (Mesterházy et al., 2003; Wegulo et al., 2011)

CONCLUSIONS

Trial results demonstrated a lack of evidence that an intensive management system utilizing prophylactic applications of multiple inputs benefits wheat yield and/or producer economic profitability without the presence of adverse conditions driving specific input responses (e.g., disease presence, nutrient-loss conditions, and plant lodging). The 2016 and 2017 growing seasons produced negligible and inconsistent responses from applications of UI, NI, PGR, foliar micronutrients, fungicide, and high N management on SRWW and SWWW grain yield. Although positive yield responses from an increase in N rate, UI, and fungicide were observed, economic net return was not greater than a traditional management system utilizing only a university recommended N rate at current wheat grain prices. Results appear to provide continued support for the use of university IPM programs which emphasize both grain yield and profitability. To capitalize on proven benefits associated with inputs applied in this trial, producers should look to incorporate a management system that utilizes specific techniques (i.e., crop scouting, prediction models, varietal resistance, nutrient recommendations) to justify input applications and match specific crop requirements. Further research involving similar treatments and additional varieties across multiple production environments will further develop many of the ideas presented in this study.

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Table 9. Effect of Feekes 10.5.1 fungicide on wheat flag leaf (uppermost leaf) disease presence three weeks after application, Richville and Lansing, MI, 2016 to 2017.

		Treatment			
Site	Year	Intensive (I)	I - Fungicide†	Traditional (T)	T + Fungicide‡
		% flag leaf area affected			
Richville	2016	0.0§	0.0	0.0	0.0
	2017	0.0	0.0	0.0	0.0
Lansing	2016	6.8	+11.3*	21.8	–15.0*
	2017	0.0	0.0	0.0	0.0

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

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

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

§ Years and locations containing all values of 0.0 indicate years and locations that did not receive foliar disease pressure.

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