EVALUATION OF A SYSTEMATIC, MULTICHEMICAL PROGRAM APPROACH FOR WHEAT PEST MANAGEMENT AND EVALUATION OF A NEW FUNGICDE FOR TAN SPOT IN SPRING WHEAT (*TRITICUM AESTIVUM. L.*)

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Title

Evaluation of a Systematic, Multichemical Program Approach for Wheat Pest Management and Evaluation of a New Fungicide for Tan Spot in Spring Wheat (Triticum aestivum.L.)

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Experiments were conducted to evaluate Proceed Plus (prothioconazole & tebuconazole & metalaxyl & clothianidin), bixafen, Prosaro (prothioconazole & tebuconazole), Baythroid XL (beta-cyfluthrin), with 'Glenn' and 'Oklee' hard red spring wheat cultivars in a systematic, multichemical program approach for management of tan spot disease and fusarium head blight, both fungal diseases of wheat. Grain yield was lowest with the control treatment (3900 kg ha^{-1}) and highest with the treatments including seed treatment, herbicide, early fungicide, late fungicide, and late insecticide (4400 kg ha^{-1}). Additional experiments were conducted to evaluate early tan spot control in 'Alsen', hard red spring wheat, with bixafen fungicide. Grain yield was highest with fenoxaprop-p-ethyl & pyrasulfotole & bromoxynil & mefenpyr safener plus pyraclostrobin (3710 kg ha^{-1}) and lowest with propoxycarbazone-sodium & mesosulfuron-methyl plus 30g ai/ha^{-1} of bixafen (3400 kg ha^{-1}). Although objectives were met in both studies, the research pointed the way toward necessary future research.

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INTRODUCTION

Spring wheat (*Triticum aestivum L.*) production in North Dakota totaled 2.22 million ha in 2011 (Ransom et. al 2011). North Dakota, which is number one in production of spring wheat, produces an average of 60.1 metric tons per year. Several diseases, such as fusarium head blight and tan spot, have a negative effect on yield if not managed. In addition, weeds and insects also negatively impact wheat yields in North Dakota. A systematic, multichemical program approach, which consists of seed treatments, herbicides, insecticides, and fungicides, would potentially be an effective tool for managing wheat pests. Research to evaluate the use of combinations of pesticides will show whether there is value in using them in conjunction to produce a spring wheat crop that is high yielding and quality. The purpose of this research project is to look at combinations of pesticides that can be used by spring wheat growers under weed, disease, and insect pressure. This research is important because the grain industry demands a high yielding crop as well as a high quality crop to meet the needs of consumers.

LITERATURE REVIEW

North Dakota has led the nation in spring wheat (*Triticum aestivum L.*) production for decades. Never the less, several weed, insect, and disease species may adversely affect the production of spring wheat, and different control methods are widely used. There is a need to create a systematic, multichemical program approach for spring wheat production to ensure that we have a high yielding as well as a high quality crop.

Integrated pest management (IPM) is one of the more important areas to arise out of agricultural sciences in the second half of the twentieth century (Kogan 1998). The definition of IPM from the National IPM network is "IPM is a sustainable approach to managing pests by combining biological, cultural, physical and chemical tools in a way that minimizes economic, health, and environmental risks" (McMullen and Knodel 2002). Basic tactics of IPM were proposed and used long before the term IPM became recognized (Kogan 1998). It was not until 1970 that the phrase "integrated pest management" and its acronym IPM were incorporated into the English literature and accepted by the scientific community. Although some consider IPM to involve only insects, most scientists consider IPM to include weeds, pathogens, and nonarthropod animals. Even before the term IPM came to be, there have been efforts to combat the negative effects of pests in agricultural fields.

There are five basic steps in IPM and they include: scouting or monitoring, identification, pest situation assessment, implementation of management options and evaluation (McMullen and Knodel 2002). Scouting is important because it is used to detect the presence, concentration and type of pests. Scouting is implemented on a regular scheduled basis to collect information to make appropriate management decisions during the growing season and also to assist in future decisions. Identification of pests is also an important component. Properly identifying pests in the environment allows the producer to make sound decisions when it comes time to selecting a treatment. Pest situation assessment is when the information collected from the scouting efforts is analyzed and the decision regarding whether or not to apply an appropriate treatment is made. Implementation is the step where, if the decision is to apply a treatment, appropriate method and type of application are selected. The final step to IPM is the evaluation. Evaluating is necessary to see if the implemented control method was effective or ineffective and what can be done in the future to better control pests. IPM has several benefits such as new products and innovative methods, reduced crop loss through improved timing and efficiency of IPM strategies, judicious use of pesticides, decreased environmental impacts, and increased partnership (McMullen and Knodel 2002).

Cultivars

Cultivar selection is an important part of a program approach. Proper cultivar selection involves choosing the cultivar that best suits the needs of the producer in a given area. High yielding cultivars are the focal point when selecting a cultivar, but other qualities such as disease resistance, agronomic characteristics, and grain quality are also important factors to consider.

North Dakota harvested 2.22 million ha of hard red spring wheat (HRSW) in 2011 (Ransom et. al 2011). The state's average yield was estimated at 41 kg ha^{-1}. North Dakota grows several HRSW varieties with Glenn being the most popular in 2011, occupying 25% of the total ha^{-1} planted (Ransom et. al 2011). Glenn was released in 2005 and is resistant to stem rust (*Puccinia graminis*) and leaf rust (*Puccinia reconditi*), intermediately resistant to leaf spot (*Pyrenophora tritici-repentis),* and moderately resistant to fusarium head blight (*Fusarium graminearum)*. Oklee occupied 0.2% of the total ha planted in 2011 Oklee is resistant to stem rust, moderately resistant or moderately susceptible leaf rust, moderately resistant to leaf spot, and moderately resistant or moderately susceptible to fusarium head blight (Wiersma et al.2006). Glenn and Oklee were chosen for the program approach study to evaluate two different varieties with varying levels of leaf spot and head blight resistance

Alsen occupied 3% of the total ha planted in 2011(Ransom et al. 2011). Alsen is resistant to stem rust, moderately resistant or moderately susceptible to leaf rust, susceptible to leaf spot, and moderately resistant to fusarium head blight. Alsen was chosen for the tan spot study because it is susceptible to leaf spot diseases, which allowed for treatment evaluation.

Insects

Several insects in North Dakota have varying levels of impact on the production of spring wheat. Aphids, such as the greenbug (*Schizaphis graminum*), english grain aphid (*Macrosiphum avenae)*, and bird cherry oat aphid (*Rhopalosiphum padi)* cause problems in North Dakota wheat (Knodel 2012). The Greenbug is the most injurious out of the three because it injects a toxin while it is feeding. These aphids do not overwinter in the region and migrate from the south in late spring . The threshold for chemical application is 85% of the stems with more than one aphid present, or 12-15 aphids per stem, prior to complete heading. Barley yellow dwarf virus is transmitted by these insects as well (Knodel 2012).

Wheat stem maggot (*Meromyza americana*) also is a concern for North Dakota wheat producers. It causes the head of the wheat plant to turn prematurely white and produce no seed (Knodel 2012). Infestations rarely exceed 2%. The insect overwinters in wheat stems in the larval stage and pupate in the spring. No economic threshold has been developed for this insect.

Baythroid XL (beta-cyfluthrin), an insecticide produced by Bayer CropScience, can be used to treat these insects (Waldstein 2010). However, North Dakota State University data show that although Baythroid XL treatments generally reduce the number of aphids, the reduction is generally not statistically lower (Waldstein 2010). North Dakota State University studies also have shown that Baythroid XL resulted in not statistically lower but numerically lower wheat stem maggot populations compared to untreated checks (Waldstein 2010).

Diseases

Many diseases have the potential to affect spring wheat crop production in North Dakota. Two important fungal diseases that affect spring wheat production are fusarium head blight caused by *Fusarium graminearum* and tan spot caused by *Pyrenophora tritici-repentis.* These two diseases consistently affect crop production and can severely affect yield and quality if not properly controlled (McMullen et al. 1997, Dewolfe et al. 1998).

Fusarium Head Blight

Fusarium head blight (FHB), also known as scab, can be caused by several *Fusarium* species, especially *Fusarium graminearum*, and can be a devastating disease affecting wheat and other small grain crops. McMullen et al.(1997) stated "Since the early 1990s, FHB has been one of the greatest impediments to economic small-grain production in the Red River Valley". The onset for this disease is relatively quick and occurs when the crop is flowering to the kernel soft dough stage. The pathogen thrives when there are frequent rainfalls, heavy dews, and also high humidities (McMullen et al. 1997).

Direct and indirect economic losses due to FHB infection of hard red spring wheat, durum wheat, soft red winter wheat, and barley in the U.S. for a three year period (1998 through 2000) was estimated at $2.7 billion (Nganje et al. 2001). Direct losses included grain yield reductions, and indirect losses included the presence of mycotoxins in the harvested grain. Almost one-half of the economic losses were in North Dakota.

The inoculum for FHB comes from the overwintering fungus, surviving as chlamydospores or mycelium in crop debris and residue. The fungus colonizes remaining crop residues such as wheat and corn stover (Champeil et al. 2004). The fungus produces perithecia in the growing season on the crop residues when moisture and moderate temperatures occur. The perithecia then release ascospores into the air, which in turn infect the flowering plant when they land on susceptible wheat spikes. High relative humidities are necessary for spores to infect the wheat crop.

Early symptoms of FHB are usually observed as small water soaked spots at the base of the glumes (Mathre, 1982). The symptoms then spread causing a blighted appearance. The infection spreads to other spikelets via the vascular tissue. Infected florets either do not produce a kernel or produce shriveled kernels. Thus, infected kernels are smaller, more shriveled, and white to pale pink in color.

The FHB pathogen also produces mycotoxins such as deoxynivalenol. Deoxynivalenol (DON, vomitoxin) creates health issues for humans and livestock when it is ingested. Consuming vomitoxin contaminated grain can damage cells in the gastrointestinal tract and alter neurochemicals in the brain, which results in vomiting and anorexia (Hollingsworth et al. 2008). Currently, the U.S. Food and Drug Administration guidelines advise that toxin concentrations should not exceed 1 ppm in finished wheat products used for food (flour, germ, and/or bran), 5 ppm in feed for swine with a 20% limit for total feed rations, and 10 ppm in feed for cattle (at least 4 months old) and chickens, with a 50% limit for total feed ration (Hollingsworth et al. 2008).

Management strategies can be implemented to reduce the severity of FHB (McMullen et al 2008). Complete resistance in cultivar selection is not an option at this point in time, but there are varieties showing partial resistance to the disease. The use of high quality seed and the removal of seed containing FHB prior to planting will improve the crop stand in the field. Tillage practices can be used to bury plant residue that the perithecia colonize, and crop rotation can be used to reduce the amount of crop residue in which the fungus overwinters to infect the crop the following year. In addition to limiting inoculum, pathogen infection and growth can be reduced with fungicide applications during flowering in spring wheat, thereby reducing FHB damage and dockage.

Tan Spot

Tan spot caused by, *Pyrenophora tritici-repentis*, is a constraint on yields in wheat growing areas of the world (Bhathal et al. 2003). Under moist conditions tan spot survives on wheat stubble under moist conditions produces pseudothecia, ascospores from the pseudothecia, and initiates the disease on wheat leaves after rain (Bhathal et al. 2003). The fungus produces wind-borne asexual conidia on the dead leaf tissue, which then spread to the new crop. The use of reduced or no-till systems leave large amounts of residue from the previous crop and favors higher levels of leaf and spike diseases (Caignano et al. 2008). An important determinant of the disease severity during the growing season is the amount of primary inoculum that is present. Under severe epidemics, tan spot has been reported to reduce wheat yields 10 to 50% (Ali et al. 2007).

Wheat on wheat and no-till practices are common in the central United States including Texas, Colorado, Oklahoma, Kansas, Nebraska, South Dakota and North Dakota. Crop sequences of soybean (*Glycine max*), corn (*Zea mays*), barley (*Hordeum vulgare L*), and alfalfa (*Medicago sativa*), each after mixed oats and barley were shown to reduce tan spot in a subsequent wheat crop (Bockus and Claassen 1992). Wheat management practices such as proper nitrogen management, selecting wheat cultivars that are resistant to leaf diseases, and the use of foliar fungicides have been shown to reduce the impact of tan spot on wheat yields. Attributing yield loss to tan spot can be difficult to determine as other leaf diseases could be responsible. Reasonable estimates of yield loss can be made if tan spot is the primary disease present. Estimations of yield loss from field experiments vary with wheat class, cultivar, and method of control (De Wolf et al. 1998). Yield losses as high as 48% have been observed when conditions favored disease development. Yield of a susceptible cultivar may be reduced by 13% as a result of early disease, 35% as a result of late disease, and 48% from disease throughout the growing season (De Wolf et al. 1998). Fungicide applications may be used to combat the disease. Fungicides used to control plant diseases are either a protectant or a systemic product. Protectant fungicides remain on the surface of the plant and prevent infection by the inhibition of pathogen growth prior to penetration. Systemic fungicides penetrate the plant tissue and are redistributed throughout the plant with the ability to eliminate the pathogen in existing lesions.

Chemicals

The use of chemicals is an important component of a systematic, multichemical program approach toward pest management. Several characteristics of the chemical might predict the usefulness of any chemical in a program approach toward pest management. These characteristics would include the ability to tank mix (or be available prepackaged as a combination of chemicals) and to control a wide-spectrum of species within a pest class (multiple weeds, diseases, or insects.). In addition, the use of chemicals with multiple modes of action would also be important to prevent or delay the onset of resistance.

Seed Treatment

Proceed Plus™ (Proceed; Material Safety Data Sheet) manufactured by Bayer CropScience, is a seed treatment product with the active ingredients prothioconazole, tebuconazole, clothianidin, and metalaxyl. The mode of action for prothioconazole and tebuconazole is a sterol biosynthesis in membrane inhibitor. The mode of action for clothianidin is nicotinic acetylcholine receptor disruptor and the mode of action for metalaxyl is a nucleic acids synthesis inhibitor. Proceed is active on loose smut (*Ustilago tritici*), seedling blight (*Fusarium graminearum*), and common root rot (*Cochiobolus sativus*) (McMullen and Markell 2011). An equivalent product to Proceed is Raxil MD (tebuconazole + metalaxyl) and was used to treat over 683,000 ha almost 11% of the total ha in North Dakota in 2008 (Zollinger et al 2008).

Herbicides

Wolverine® (Wolverine; Material Safety Data Sheet), manufactured by Bayer CropScience, is a prepackaged mix of several herbicides (fenoxaprop-p-ethyl, pyrasulfotole, bromoxynil, and mefenpyr safener) that would meet most of the chemical characteristics preferred in a program approach due to having a multi-weed spectrum. Wolverine was used to treat about 19,000 ha, accounting for 0.1% of the total ha, in North Dakota in 2008 (Zollinger et al 2009). Wolverine was a relatively new product in 2008, so a relatively low use in 2008 would not be unexpected. However, fenoxaprop-p-ethyl, one of the components of Wolverine, was used to treat 1.38 million ha in 2008. Fenoxaprop-p-ethyl is a grass product, and rarely is it not tank mixed with a broadleaf herbicide. Thus, it is not surprising that Wolverine is replacing much of the fenoxaprop-p-ethyl use. Fenoxaprop-p-ethyl controls a wide-spectrum of grass weeds by ACC-ase inhibition. Wolverine also contains pyrasulfotole, which controls grass weeds acting as an HPPD (4-hydoxyphenylpyruvate dioxygenase) inhibitor. Another component of Wolverine is bromoxynil which controls broadleaf weeds by Photosystem II inhibition (PSII). Thus, Wolverine controls a broad spectrum of annual grass and broadleaf weeds using multiple modes of action. In addition, Wolverine is able to be tank mixed with several fungicides; one exception is tebuconazole (Wolverine; Label).

Rimfire Max®(Rimfire Max; Material Safety Data Sheet), manufactured by Bayer CropScience, is a prepackaged mix of mesosulfuron, propoxycarbazone, and mefenpyr safener that provides an option for producers that have ACC-ase (acetyl-CoA carboxylase) resistant wild oat. The two active ingredients are both ALS enzyme inhibitors (acetolactate synthase inhibitor). Rimfire Max has good to excellent control of wild oat (Zollinger 2012). Rimfire Max was a relatively new product in 2008 which would explain the low usage of the product covering almost 84,000 ha in that year accounting for 0.5% of the total ha (Zollinger et. Al 2009).The usage has more than doubled to 172,000 ha treated in 2011 (Haugland 2012). Rimfire Max also has the ability to be tank mixed with several fungicides with the exception of tebuconazole (Rimfire Max; Label).

Insecticides

Baythroid XL® (Baythroid XL; Material Safety Data Sheet), manufactured by Bayer CropScience, is a product with a single active ingredient, beta-cyfluthrin. The mode of action is a sodium channel modulator. Baythroid XL is a broad spectrum product controlling aphids (*Aphidinae*), cereal leaf beetles (*Oulema melanopus*), grasshoppers (*Caelifera*), and wheat stem maggot (*Meromyza americana).* Baythroid XL was used to treat 81,730 ha in North Dakota in 2008 (Zollinger et al 2009).

Fungicides

Headline® (Headline; Safety Data Sheet), manufactured by BASF, is a product with a single active ingredient, pyraclostrobin. The mode of action is respiration inhibition. Headline is a broad spectrum fungicide with activity on leaf spot (*Pyrenophora tritici-repentis*), leaf rust (*Puccinia triticina*), stem rust (*Puccinia graminis),* and powdery mildew (*Blumeria graminis*) (McMullen and Markell 2011). Headline was used to treat 438,784 ha accounting for 11.8% of the total ha in North Dakota in 2008 (Zollinger et al 2009).

Tilt® (Tilt; Material Safety Data Sheet), manufactured by Syngenta, is a product with a single active ingredient, propiconazole. The mode of action is inhibition of sterol biosynthesis in membranes. Tilt has activity on tan spot (*Pyrenophora tritici-repentis*), leaf rust (*Puccinia triticina*), stem rust (*Puccinia graminis)*, powdery mildew (*Blumeria graminis*), and fusarium head blight (*Fusarium graminearum*) (McMullen and Markell 2011). Tilt was used to treat 502,738 ha accounting for 13.5% of the total ha in 2008 (Zollinger et al 2009).

Stratego® (Stratego; Material Safety Data Sheet), manufactured by Bayer CropScience, has two active ingredients: propiconazole and trifloxystrobin, which have different modes of action. Propiconazole is a sterol biosynthesis in membrane inhibitor and trifloxystrobin is a respiration inhibitor. Stratego has activity on leaf spot (*Pyrenophora tritici-repentis*), leaf rust (*Puccinia triticina*), stem rust (*Puccinia graminis),* and powdery mildew (*Blumeria graminis*) (McMullen and Markell 2011). Stratego was used to treat 98,536 ha accounting for 2.6% of the total ha in North Dakota in 2008 (Zollinger et al 2009).

Prosaro™ (Prosaro; Material Safety Data Sheet), manufactured by Bayer CropScience, has two active ingredients: prothioconazole and tebuconazole. The mode of action for prothioconazole and tebuconazole is a sterol biosynthesis in membrane inhibitor. Prosaro has activity on leaf spot (*Pyrenophora tritici-repentis*), stem rust (*Puccinia graminis)*, powdery mildew (*Blumeria graminis*) and fusarium head blight (*Fusarium graminearum*) (McMullen and Markell 2011). Prosaro was a relatively new product in 2008 and was used to treat 3,919 ha in North Dakota in 2008 (Zollinger et al 2009). However, the two active ingredients were applied either as a tank mix or applied separately. Prothioconazole was used to treat 163,822 ha accounting for 4.4% of the total ha in 2008, and tebuconazole was used to treat 409,656 ha accounting for 11.0% of the total ha treated in North Dakota in 2008 (Zollinger et al 2009).

Bixafen™ (bixafen; Pesticide Peer Review), manufactured by Bayer CropScience, is an early season and mid-season experimental fungicide currently not labeled for use in the United States. It is currently sold in United Kingdom as a pre-mix with prothioconazole under the name Aviator™. Its mode of action is a respiration inhibitor. Aviator has activity on leaf diseases such as stripe rust (*Puccinia striiformis*), brown rust (*Puccinia recondita*) and septoria leaf spot (*Septoria tritici*) (Aviator; Label).

OBJECTIVES

This thesis is primarily focused on the chemical methods of pest management, and does not include treatments involving the use of biological, cultural, and physical methods of controlling pests. A systematic, multichemical program approach as used in this thesis describes the integration of chemicals and cultivars on pest management. The major emphasis is on pesticide use to reduce pest problems and increase yield and quality such as test weight, protein and DON. A secondary focus involved a second experiment designed to evaluate a new novel fungicide for control of leaf diseases in wheat.

Two objectives of this study were 1) to evaluate Proceed Plus (prothioconazole & tebuconazole & metalaxyl & clothianidin), Wolverine (fenoxaprop-p-ethyl & pyrasulfotole & bromoxynil & mefenpyr), bixafen, Prosaro (prothioconazole & tebuconazole), and Baythroid XL (beta-cyfluthrin), with ‘Glenn’ and ‘Oklee’ hard red spring wheat cultivars in a systematic, multichemical program approach for management of tan spot, leaf diseases and fusarium head blight, and 2) to evaluate early season tan spot control in ‘Alsen’, hard red spring wheat variety, with bixafen fungicide compared to industry standard products applied at the tillering stage of wheat.

MATERIALS AND METHODS

Systematic, Multichemical Program Approach Study

Four experiments were established in fields on land that previously was planted to soybean, to simulate a typical eastern North Dakota crop rotation. Locations were two field plots at the Bayer CropScience Northern Field Technology Station near Sabin, MN (Environment 1, 2010 and Environment 3, 2011) and two field plots in a cooperator field located 8 km north of Valley City, ND (Environment 2, 2010 and Environment 4, 2011). The soil series for environments 1 and 3 (Sabin, 2010 and 2011) were a Wheatville silt loam (Coarse-silty over clayey, mixed over smectitic, superactive, frigid Aeric Calciaquolls) (Web Soil Survey 2012). The soil series for environment 2 (Valley City 2010) was a Hamerly-Wyard (Hamerly: Fine-loamy, mixed, superactive, frigid Aeric Calciaquolls; Wyard: Fine-loamy, mixed, superactive, frigid Typic Endoaquolls). The soil series for environment 4 (Valley City 2011) was a Gardena silt loam (Coarse-silty, mixed, superactive, frigid Pachic Hapludolls). The experimental sites in Sabin, MN were broadcast fertilized in the spring before seeding with 56 kg ha^{-1} of nitrogen (46-0-0) and 11.2 kg ha^{-1} of phosphorus (0-20-0) in both 2010 and 2011. The sites in Valley City were fertilized with 123 kg ha^{-1} of anhydrous ammonia (82-0-0) and 140 kg ha^{-1} of phosphorus (0-20-0) in both 2010 and 2011. All sites used field cultivation as a fertilizer incorporation method. Soil samples were randomly taken using a soil probe 10 to 14 days after crop emergence throughout the research area. Samples were taken between plots, 0 to 15cm deep, and 20 samples were taken at each experimental site in both years (Table 1).

Table 1. Soil sample results for the systematic, multichemical program approach study in Sabin, MN and Valley City, ND in 2010 and 2011.

Location	Nitrogen	Phosphorus	Potassium	pH	Cation exchange capacity[a]
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}		
2010 Sabin	67	11	235	8.0	22.2
2010 Valley City	90	13	207	7.2	22.0
2011 Sabin	60	16	302	8.0	20.7
2011 Valley City	65	24	605	6.6	20.7

[a]Quantity of negative charges in soil existing on the surfaces of clay and organic matter

All four experiments were designed as a randomized complete block split plot arrangement (four replicates), variety as the main plot and treatment as the sub plot. Plot size was 2.0 by 6.1 m. Treatments included two HRSW varieties, Glenn and Oklee. Both varieties were seeded at 120 kg ha^{-1} to a depth of 3.8 cm. Both sites were seeded with a Tye grain drill with 13 rows and 15 cm row spacing on dates shown in Table 2.

Table 2. Seeding dates for systematic, multichemical program approach studies in Sabin, MN and Valley City, ND in 2010 and 2011.

	2010	2011
Sabin, MN	April 8	May 1
Valley City, ND	April 8	May 18

Herbicide and fungicide applications were made with a CO_2 – pressurized hand sprayer with four nozzles or a bike sprayer with four nozzles depending on weather conditions. The entire plot was sprayed using 110015 nozzles (TeeJet, Wheaton, IL) at 241 kPa applying 93.5 L ha^{-1} of solution. Late fungicide applications were made using 110015 nozzles (TeeJet, Wheaton, IL) at 241 kPa applying 187 L ha^{-1} of solution. Herbicide and early fungicide applications were made with straight down nozzles. Late fungicide applications were made with two nozzles angled at 45 degrees from the horizontal. The sequential products applied included: seed treatment applied prior to planting, herbicide applied over all plots at Feekes 3, early fungicide applied at Feeks 3, early insecticide applied at Feekes 3, late insecticide at Feekes 10.51, and late fungicide at Feeks 10.51. Chemical treatments, growth stages at application and rate information for the systematic, multichemical program approach study are listed in Table 3. Application timing, treatment date, weather information, wheat variety and wheat staging for the systematic multichemical program approach studies are provided in Table 4.

Table 3. Treatment, growth stage and chemical rate information for the systematic, multichemical program approach study in Sabin, MN and Valley City, ND.

Treatment	Growth Stage	Rate (g ai ha^{-1})
Control		
ST (Proceed Plus) [a]	Pre-Plant	13
ST + EF (bixafen)[b]	Pre-Plant + FKS 3	13 + 30
ST + EF + EI (Baythroid)[c]	Pre-Plant + FKS 3 + FKS 3	13 + 30 + 14
ST + LF (Prosaro)[de]	Pre-Plant + FKS 10.51	13 + 203
ST + EF + LF	Pre-Plant + FKS 3 + FKS 10.51	13 + 30 + 203
ST + EF + LF + LI[c]	Pre-Plant + FKS 3 + FKS 10.51 + FKS 10.51	13 + 30 + 203 + 14

[a] (ST) prothioconazole & tebuconazole &clothianidin & metalaxyl = Proceed Plus Seed Treatment

[b] (Early Fungicide = EF) bixafen = BAY Fungicide; FKS 3 = Tillers formed

[c] (Early Insecticide = EI) (Late Insecticide = LI) beta-cyfluthrin = Baythroid XL EC Insecticide

[d] (Late Fungicide = LF) prothioconazole & tebuconazole = Prosaro SC Fungicide; FKS 10.51 = Flowering

[e] All treatments containing prothioconazole & tebuconazole received NIS at 0.25% v/v

Table 4. Application timing, treatment date, weather information, wheat variety and wheat staging for the systematic, multichemical program approach experiments at Valley City, ND and Sabin, MN in 2010 and 2011.

Application timing	Treatment date	Air temp	Soil temp	RH	Wheat variety	Wheat stage
		C	C	%		
			Sabin 2010			
Early[a]	May 20	18	15	65	Oklee	4/3[c]
					Glenn	4/2
Late[b]	June 19	22	17	56	Oklee	20[d]
					Glenn	30
			Valley City 2010			
Early	May 26	21	9	27	Oklee	4/2
					Glenn	4/2
Late	June 22	27	11	50	Oklee	15
					Glenn	25
			Sabin 2011			
Early	June 9	11	14	80	Oklee	4/3
					Glenn	3/2
Late	July 6	25	22	56	Oklee	25
					Glenn	35
			Valley City 2011			
Early	June 20	19	10	67	Oklee	4/3
					Glenn	3/3
Late	July 11	20	13	74	Oklee	15
					Glenn	30

[a] Treatment components are seed treatment, herbicide, early fungicide, and/or early insecticide
[b] Treatment components are late fungicide and/or late insecticide
[c] Wheat stage for early application = number of leaves/number of tillers
[d] Wheat stage for late application = percent of flowering spikes

Parameters measured included stand counts, 21 to 28 days after planting; crop injury 7 to 10 days after treatment, 21 to 28 days after treatment, and pre-harvest; plant height; foliar disease severity; severity and incidence ratings for head diseases; yield; and quality parameters protein, 1000 kernel weight, test weight, and DON (if DON was present in untreated checks).

Stand counts were taken from the front and back of each plot by selecting the second row from the left and placing one meter stick 30 cm from start and end of the row. Plants that fell within the meter length were counted. The two numbers were averaged. Crop injury was evaluated visually by a rating scale of zero to one hundred percent (zero meaning no crop injury and one hundred meaning total crop loss). Only the first rating at 7 to 10 days after treatment is presented in the results section because no visual injury occurred at the 21 to 28 days after treatment or pre-harvest. Plant height was determined by measuring the height of the plants from the soil surface to the tip of the spike both in the front and back of each plot. The two numbers were averaged. Tan spot disease ratings were evaluated by taking 10 random flag leafs from the middle of both sides of each plot (20 total leaves per plot). These leaves were given a visual rating on percent infection from 0 to one 100 (0 meaning no infection apparent and 100 meaning completely infected). Fusarium head blight disease ratings were taken by selecting 20 random heads from the middle of both sides of each plot (40 heads per plot). Heads were rated on a scale from 0 to 100 percent (0 meaning no infection and 100 meaning complete infection). Thousand kernel weight was calculated by weighing 100 random kernels per plot and multiplying by 10. Grain yield and test weight were calculated by the harvesting equipment. Protein (whole kernel analysis) and DON mycotoxins (deoxynivalenol = DON) (Enzyme Linked Immunosorbent Assay) were determined by North Dakota Grain Inspectors in Fargo, ND. Wheat was harvested with a Wintersteiger Nursery Master small plot combine that had a harvest width of 1.5 m. The harvested area was the center of each plot and the total length of the plot. Harvest dates are shown in Table 5.

Table 5. Harvest dates for systematic, multichemical program approach study in Sabin, MN and Valley City, ND in 2010 and 2011

	2010	2011
Sabin, MN	July 30	August 15
Valley City, ND	August 8	August 24

Data Analyses were completed with SAS ANOVA (Statistical Analysis Software 2003). F-test results were considered significant at $P \leq 0.05$ and treatment means were separated using an F-protected least significant difference at $P \leq 0.05$

Tan Spot and Bixafen Fungicide Study

Tan spot management with bixafen and several other fungicides were evaluated separately from the systematic multichemical program approach study. This was done to evaluate the efficacy of bixafen, a new SDHI (succinate dehydrogenase inhibitors) fungicide, compared to products that are currently registered for use in spring wheat for controlling tan spot. There was also a desire to see how bixafen performed with the lower 30 g ai/ha compared to the 60 g ai/ha and any possible adverse effects when tank mixed with Wolverine and Rimfire Max. These tank mixed fungicide and herbicide treatments were compared to split applications of Wolverine and bixafen (30g ai/ha) where bixafen was applied first and Wolverine was applies 5 days after.

Four field trials were established on land that previously was planted to grow spring wheat, in order to promote the development of tan spot. The sites, plant nutrients, and seedbed preparation described next were similar as described for the systematic, multichemical program approach study. Two trials were at the Bayer CropScience Northern Field Technology Station near Sabin, MN (Environment 1, 2010 and Environment 3, 2011) and two in a cooperator field north of Valley City, ND (Environment 2, 2010 and Environment 4, 2011). The soil series for environments 1and 3 (Sabin, 2010 and 2011) were a Wheatville silt loam (Coarse-silty over clayey, mixed over smectitic, superactive, frigid Aeric Calciaquolls). The soil series for environment 2 was a Hamerly-Wyard (Hamerly: Fine-loamy, mixed, superactive, frigid Aeric Calciaquolls; Wyard: Fine-loamy, mixed, superactive, frigid Typic Endoaquolls). The soil series for environment 4 was a Gardena silt loam (Coarse-silty, mixed, superactive, frigid Pachic Hapludolls). The sites in Sabin, MN were broadcast fertilized in the spring before seeding with 56 kg ha^{-1} of nitrogen (46-0-0) and 11.2 kg ha^{-1} of phosphorus (0-20-0) in both 2010 and 2011. The sites in Valley City were fertilized with 123 kg ha^{-1} of anhydrous ammonia (82-0-0) and 140 kg ha^{-1} of phosphorus (0-20-0) in both 2010 and 2011. All sites used field cultivation as a fertilizer incorporation method. Soil sample results are in Table 6. Soil samples to a 15 cm depth using soil probe were randomly taken 10 to 14 days after crop emergence throughout the research area in each experimental site.

Table 6. Soil sample results for the tan spot and bixafen experiments in Sabin, MN and Valley City, ND in 2010 and 2011

Location	Nitrogen	Phosphorus	Potassium	pH	Cation exchange capacity[a]
	--------------------kg ha^{-1}--------------------				Cmol(+) kg^{-1}
2010 Sabin	73	10	258	8.2	21.8
2010 Valley City	75	22	269	6.5	23.2
2011 Sabin	65	10	252	8.2	17.4
2011 Valley City	83	24	560	6.5	19.4

[a]Quantity of negative charges in soil existing on the surfaces of clay and organic matter

All four experiments were designed as randomized complete block (RCBD) with four replicates. Plot size was 1.98 m wide by 7.6 m long (13 rows and 15 cm row spacing). All plots were seeded with Alsen HRSW at 120 kg ha^{-1} at a depth of 3.8 cm. These sites were seeded with a Tye grain drill. Seeding dates are shown in Table 7.

Table 7. Seeding dates for the tan spot and bixafen study in Sabin, MN and Valley City, ND in 2010 and 2011.

Location	2010	2011
Sabin, MN	April 14	May 4
Valley City, ND	April 15	May 19

Plots were sprayed with a CO_2 – pressurized hand sprayer with four nozzles or a bike sprayer with four nozzles depending on weather conditions. The entire plot was sprayed using 110015 nozzles (TeeJet) at 241 kPa applying 93.5 L ha^{-1} of solution. Both herbicide and fungicides were sprayed with straight down nozzles. Chemical treatments, growth stages at application and application rates are shown in Table 8.

Table 8. Chemical treatments, growth stages, and chemical rates for the tan spot and bixafen study in Sabin, MN and Valley City, ND in 2010 and 2011.

Treatment	Growth Stage	Rate (g ai ha^{-1})
Fenoxaprop[a]	FKS 3[i]	318
Fenoxaprop + Bixafen[b]	FKS 3	318 + 30
Fenoxaprop + Bixafen	FKS 3	318 + 60
Fenoxaprop + Propiconazole[c] & Trifloxystrobin	FKS 3	318 + 73
Fenoxaprop + Pyraclostrobin[d]	FKS 3	318 + 55
Fenoxaprop + Propiconazole[e]	FKS 3	318 + 58
Propoxycarbazone[fg]	FKS 3	44
Propoxycarbazone + Bixafen	FKS 3	44 + 30
Propoxycarbazone + Bixafen	FKS 3	44 + 60
Fenoxaprop[h] + Bixafen	FKS 3	318 + 30

[a] (Fenoxaprop) Fenoxaprop-p-ethyl & pyrasulfotole & bromoxynil & mefenpyr safener = Wolverine EC herbicide
[b] Bixafen = BAY Fungicide
[c] Propiconazole & trifloxystrobin = Stratego EC fungicide
[d] Pyraclostrobin = Headline SC fungicide
[e] Propiconazole = Tilt EC fungicide
[f] (propoxycarbazone) propoxycarbazone-sodium & mesosulfuron-methyl = Rimfire Max WG herbicide
[g] Propoxycarbazone-sodium & mesosulfuron-methyl includes a labeled rate of Quad 7 at 1% v/v
[h] Applied 4 to 6 days after bixafen
[i] FKS 3 = Feekes 3 = Tillers formed

Application timing, treatment date, weather information, wheat variety, and wheat staging for 2010 and 2011 tan spot experiments at Valley City and Sabin are shown in Table 9.

Table 9. Application timing, treatment date, weather information, wheat variety and wheat staging for the tan spot and bixafen study at Valley City, ND and Sabin, MN in 2010 and 2011.

Application timing	Treatment date	Air	Soil	RH	Wheat stage
		----------C----------		%	
		Sabin 2010			
A[a]	May 27	28	22	29	4/3[c]
B[b]	June 1	14	17	85	5/3
		Valley City 2010			
A	May 28	20	22	43	4/3
B	June 1	14	18	46	5/3
		Sabin 2011			
A	June 2	16	9	49	4/2
B	June 6	19	16	73	5/2
		Valley City 2011			
A	June 24	20	19	51	4/3
B	June 30	24	25	77	5/3

[a] All treatments except for fenoxaprop in the split application of Wolverine and bixafen

[b] Date for fenoxaprop in the split application of Wolverine and bixafen

[c] Wheat stage = number of leaves/number of tillers

Parameters measured included crop injury 7 to 10 days after treatment, 21 to 28 days after treatment; and pre-harvest; disease severity for foliar diseases; yield; and quality parameters protein and test weight. Crop injury was evaluated visually by a rating scale of zero to 100% (0 meaning no crop injury and 100 meaning total crop loss). Only the first rating at 7 to 10 days after treatment is presented in the results section because no visual injury was observed at either the 21 to 28 days after treatment or pre-harvest. Tan spot disease ratings were evaluated by taking 10 random flag leaves from the middle of both sides of each plot (20 total leaves per plot). These leaves were given a visual rating on percent infected from zero to 100 (0 meaning no infection and 100 meaning completely infected). Grain yield and test weight were calculated by the harvesting equipment. Protein analysis (whole kernel analysis) and DON (Enzyme Linked Immunosorbent Assay) were determined by the North Dakota Grain Inspectors in Fargo, ND.

Wheat was harvested with a Wintersteiger Nursery Master small plot combine that had a harvest width of 1.5 m. The harvested area was the center of each plot and the total length of the plot. Harvest dates are shown in Table 10.

Table 10. Harvest dates for the tan spot and bixafen study in Valley City, ND and Sabin, MN in 2010 and 2011.

Location	2010	2011
Sabin, MN	August 6	August 15
Valley City, ND	August 8	August 24

Data analyses were completed with SAS ANOVA (Statistical Analysis Software 2003). F-test results were considered significant at $P \leq 0.05$ and treatment means were separated using an F-protected least significant difference at $P \leq 0.05$.

RESULTS AND DISCUSSION

Weather

Weather data for the two years and two locations are presented in Table 11 (NDAWN 2012). Monthly mean temperatures for both years were generally about the same as the long-term averages. An exception was at both locations for April, 2010, where the monthly average temperatures were about 5 C above average. Monthly mean rainfall values for all locations were generally similar to the long-term averages, although there were exceptions. For example, compared to monthly averages, June had less rainfall at both locations in 2010, and July was a wetter month at both locations in 2010. In 2011, July was a wetter month than the average at both locations; June also was wetter than the average in Valley City and August was wetter at Sabin.

Averaged over the April to August growing season, all environments received greater rainfall compared to an average year. Sabin, 2011, exhibited the greatest rainfall increase over the crop growing season, 43% more rainfall than in an average growing season, and Valley City, 2010, exhibited the least increase (15%).

Weed Control

Weed control was considered good to excellent in all locations. Locations were placed on land that had a history of good weed management practices. These practices included: tillage and use of both conventional and glyphosate resistant crops.

Table 11. Monthly temperature and rainfall means for Sabin, MN and Valley City, ND in 2010 and 2011.

	Sabin, MN				Valley City, ND			
Year/Month	Monthly mean temp	Normal mean temp	Monthly mean rainfall	Normal mean rainfall	Monthly mean temp	Normal mean temp	Monthly mean rainfall	Normal mean rainfall
2010	-----C-----		-----mm-----		-----C-----		-----mm-----	
April	10.6	5.6	47.2	34.8	9.3	5.4	18.5	33.5
May	14.2	13.3	68.8	66.3	12.5	13.0	166	65.5
June	18.9	18.1	64.8	89.2	18.0	17.8	44.5	84.1
July	21.8	20.9	145	73.2	20.8	20.3	105.2	78.5
August	21.8	19.8	74.2	64.0	20.4	19.3	41.1	65.3
2011								
April	5.8	5.6	46.2	34.8	3.9	5.4	26.7	33.5
May	12.6	13.3	80.3	66.3	10.8	13.0	54.9	65.5
June	19.1	18.1	95.0	89.2	17.7	17.8	162	84.1
July	23.4	20.9	143	73.2	22.5	20.3	122	78.5
August	21.0	19.8	102	64.0	20.8	19.3	61.7	65.3

Systematic, Multichemical Program Approach Study

Stand Count, Crop Injury, and Disease Ratings

The stand count, crop injury, and disease ratings are discussed in a combined analysis because the experimental errors were homogenous (Table 12). Stand count was influenced by the environment and variety but not by treatment. The Valley City environment in 2011 provided higher (2 more plants per plot) stand counts than the other environments (data not shown). The variety effect was due to Glenn having higher stand counts (about 9% higher) than Oklee across environments (data not shown).

All treatments provided a similar level of crop injury, because the injury was due to the herbicide which was common to all treatments (Table 12). Never the less, there was an interaction with environment and variety, which was predominately due to Oklee exhibiting greater injury than Glenn (14.7% vs. 10.3%) only at Valley City in 2011 (data not shown). Crop injury was greatest at Valley City 2011 (average 12.6% injury) and lowest at Valley City 2010 (average 8.6% injury).

Table 12. Partial analysis of variation for stand count, crop injury and disease ratings table for the systematic, multichemical program approach study in Sabin, MN and Valley City, ND in 2010 and 2011.

Source of variation	df[a]	Stand count	Crop injury	Tan spot	Head blight incidence	Head blight severity	Head blight index
Environment	3	*[b]	**[c]	**	**	NS[d]	**
Treatment	6	NS	NS	**	*	NS	**
Variety	1	*	NS	NS	*	NS	*
Environment X Treatment	18	NS	NS	*	*	NS	NS
Environment X Variety	3	NS	**	*	*	NS	NS
Variety X Treatment	6	NS	NS	NS	*	*	*
Environment X Variety X Trt.	18	NS	NS	NS	*	*	NS

[a]df = degrees of freedom
[b] * = Significant at P<0.05
[c] ** = Significant at P<0.01
[d]NS = Non-significant

The effect of the treatments on tan spot was influenced by the environment (Table 12). The addition of the late fungicide lowered tan spot percentage at all environments except at Sabin 2011 (Table 13). The lack of a treatment response at Sabin in 2011 was surprising, especially with the relatively high moisture conditions during June and July at this location. Tan spot ratings were carried out at the same time as head blight ratings at each environment. It is possible that earlier ratings might have provided different results, but the influence of later ratings should have been similar at all environments. Thus, the reason for the lack of a treatment response at Sabin in 2011 remains unknown.

The effect of variety on tan spot symptoms was influenced by the environment (Table 12). Glenn had higher tan spot compared to Oklee in Sabin both years (Table 14). This finding was not surprising as Glenn is intermediate in regards to resistance, whereas Oklee is listed as being moderately resistant (Ransom et al 2010 and Wiersma et al 2006). Surprisingly, Glenn and Oklee did respond the same in Valley City in both 2010 and 2011 (Table 14).

Table 13. Tan spot effect from environment and treatment for the systematic, multichemical program approach study in Sabin, MN and Valley City, ND in 2010 and 2011.

	Sabin, MN		Valley City, ND		
Treatment	2010	2011	2010	2011	Mean
	-----------------------------	------	-------%-------	------	-------------------
Control	24.6	18.3	19.3	23.3	21.4
ST (Proceed Plus) [a]	24.3	18.1	19.5	23.0	21.2
ST + EF (bixafen)[b]	26.6	16.1	17.8	20.5	20.3
ST + EF + EI (Baythroid)[c]	25.9	19.0	17.5	20.9	20.8
ST + LF (Prosaro)[de]	17.7	15.3	9.6	14.3	14.2
ST + EF + LF	19.1	18.3	8.4	12.8	14.7
ST + EF + LF + LI[c]	19.2	15.0	9.8	14.7	14.7
Mean	22.5	17.2	14.6	18.5	
LSD 0.05 Environment x Treatment = 3.5					

[a] (ST) prothioconazole & tebuconazole & clothianidin & metalaxyl = Proceed Seed Treatment
[b] (Early Fungicide = EF) bixafen = BAY Fungicide
[c] (Early Insecticide = EI) (Late Insecticide = LI) beta-cyfluthrin = Baythroid XL EC Insecticide
[d] (Late Fungicide = LF) prothioconazole & tebuconazole = Prosaro SC Fungicide
[e] All treatments containing prothioconazole & tebuconazole received NIS at 0.25% v/v

Table 14. Tan spot effects from environment and variety for the systematic, multichemical program approach study in Sabin, MN and Valley City, ND in 2010 and 2011

	Variety		
Location	Oklee	Glenn	Mean
Sabin 2010	17.4	27.5	22.5
Sabin 2011	13.0	21.3	17.2
Valley City 2010	13.2	15.9	14.6
Valley City 2011	18.0	18.7	18.6
Mean	15.5	20.9	
LSD 0.05 Variety x Env. = 3.5			

Head blight incidence data are presented as the percent of the spikelets showing symptoms of this disease. These data are shown in Table 15 with only 2011 represented due to the lack of disease in 2010. Head blight incidence was affected by the treatments, although the extent of the effect was influenced by both the environment and the variety (Table 12). Head blight incidence was lower in Sabin compared to Valley City in 2011. The Sabin location showed no difference among the treatments or the varieties. In Valley City, Oklee was not affected by any of the treatments, but percent head blight incidence for Glenn was reduced with the addition of the late fungicide application. Head blight incidence of Glenn was higher than Oklee at Valley City for treatments not including the late fungicide and the head blight incidence of Glenn was similar to that of Oklee when the late fungicide was applied.

Table 15. Percent head blight incidence for the systematic, multichemical program approach experiment in Sabin, MN and Valley City, ND in 2011

	Sabin, MN		Valley City, ND	
Treatment	Oklee	Glenn	Oklee	Glenn
	------------------------%------------------------			
Control	9.4	8.1	31.3	40.0
ST (Proceed Plus) [a]	8.8	8.8	27.5	45.0
ST + EF (bixafen)[b]	7.5	8.1	30.6	45.0
ST + EF + EI (Baythroid)[c]	7.5	6.9	31.3	42.5
ST + LF (Prosaro)[de]	6.9	8.1	26.3	30.6
ST + EF + LF	5.6	4.4	31.3	26.9
ST + EF + LF + LI[c]	5.0	4.3	26.9	20.6
LSD 0.05 Env. x Trt. x Variety = 7.6				

[a] (ST) prothioconazole & tebuconazole & clothianidin & metalaxyl = Proceed Plus Seed Treatment
[b] (Early Fungicide = EF) bixafen = BAY Fungicide
[c] (Early Insecticide = EI) (Late Insecticide = LI) beta-cyfluthrin = Baythroid XL EC Insecticide
[d] (Late Fungicide = LF) prothioconazole & tebuconazole = Prosaro SC Fungicide
[e] All treatments containing prothioconazole & tebuconazole received NIS at 0.25% v/v

Fusarium head blight severity is the percent of the head area that is showing symptoms of disease. Fusarium head blight severity in 2011 was affected by treatments, although the extent of the effect was influenced by environment and variety (Table 12). Fusarium head blight data are shown only for 2011 due to lack of disease in 2010 (Table 16). Head blight severity was not affected by treatments in Valley City, whereas specific treatments did affect severity in Sabin. The Sabin location had two treatments that were not typical. Treatment ST + EF + LF in Oklee and treatment ST + EF + LF + LI in Glenn showed higher percent head blight severity compared to the other treatments with the late fungicide and all treatments without the late fungicide. Although these two treatments had low head blight incidence, the affected spikes were more severely affected than other treatments. These two treatments associated with higher severity values appear to be outliers, and cannot be explained.

Table 16. Percent head blight severity affected by environment, treatment, and variety for the systematic, multichemical program approach experiments in Sabin, MN, and Valley City, ND, in 2011.

	Sabin, MN		Valley City, ND	
Treatment	Oklee	Glenn	Oklee	Glenn
	--------------------------%-----------------------			
Control	10.4	10.9	8.2	9.8
ST (Proceed Plus) [a]	9.5	13.0	10.2	8.7
ST + EF (bixafen)[b]	7.0	10.8	9.4	9.2
ST + EF + EI (Baythroid)[c]	8.0	9.2	8.9	9.2
ST + LF (Prosaro)[de]	5.3	7.0	8.9	8.9
ST + EF + LF	16.9	5.3	8.4	9.0
ST + EF + LF + LI[c]	7.6	15.7	8.1	8.3
LSD 0.05 Env. x Trt. x Variety = 5.6				

[a] (ST) prothioconazole & tebuconazole & clothianidin & metalaxyl = Proceed Plus Seed Treatment
[b] (Early Fungicide = EF) Bixafen = BAY Fungicide
[c] (Early Insecticide = EI) (Late Insecticide = LI) beta-cyfluthrin = Baythroid XL EC Insecticide
[d] (Late Fungicide = LF)prothioconazole & tebuconazole = Prosaro SC Fungicide
[e] All treatments containing prothioconazole & tebuconazole received NIS at 0.25% v/v

Fusarium head blight index is the incidence multiplied by severity and divided by one hundred. These values were averaged across two locations in 2011 (Table 17). The two varieties Glenn and Oklee did not respond the same to the various treatments in regards to head blight index. Head blight index was higher in Glenn compared to Oklee until the addition of the late fungicide. Head blight index of Oklee was not affected by any of the treatments. The general trend was lower head blight index percentage with the addition of late fungicide in Oklee except for the ST + EF + LF but these differences were not significant. In contrast, head blight index was lower for Glenn when the late fungicide was applied, except for the ST + LF treatment.

Table 17. Percent head blight index for the systematic, multichemical program approach experiment in Sabin, MN, and Valley City, ND, in 2011.

Treatment	Oklee	Glenn
	------------------%-----------------	
Control	1.8	2.4
ST (Proceed Plus) [a]	1.8	2.6
ST + EF (bixafen)[b]	1.7	2.6
ST + EF + EI (Baythroid)[c]	1.7	2.3
ST + LF (Prosaro)[de]	1.4	1.7
ST + EF + LF	1.8	1.3
ST + EF + LF + LI[c]	1.3	1.2
LSD 0.05 Treatment x Variety = 0.9		

[a] (ST) prothioconazole & tebuconazole & clothianidin & metalaxyl = Proceed Plus Seed Treatment
[b] (Early Fungicide = EF) bixafen = BAY Fungicide
[c] (Early Insecticide = EI) (Late Insecticide = LI) beta-cyfluthrin = Baythroid XL EC Insecticide
[d] (Late Fungicide = LF)prothioconazole & tebuconazole = Prosaro SC Fungicide
[e] All treatments containing prothioconazole & tebuconazole received NIS at 0.25% v/v

Agronomic and Quality Traits

The agronomic and quality traits are discussed in a combined analysis because the experimental errors were homogenous (Table 18). Plant height was influenced only by the variety and the environment. Plant height was greater for Glenn compared to Oklee across all environments (93 cm vs. 84 cm), and plant height was higher in 2010 compared to 2011 for both varieties (data not shown).

Table 18. Partial analysis of variance for agronomic and quality traits table for the systematic, multichemical program approach study in Sabin, MN and Valley City, ND in 2010 and 2011

Source of variation	df[a]	Plant height	Grain yield	Test weight	Grain protein percent	Kernel weight	DON[b]
Environment	3	**[c]	**	**	**	**	**
Treatment	6	NS[d]	**	*[e]	**	NS	NS
Variety	1	**	NS	NS	NS	NS	NS
Environment X Treatment	18	NS	NS	NS	NS	NS	**
Environment X Variety	3	NS	**	**	NS	**	NS
Variety X Treatment	6	NS	NS	NS	NS	NS	NS
Environment X Variety X Trt.	18	NS	NS	NS	NS	NS	NS

[a]df = degrees of freedom
[b]DON = Deoxynivalenol
[c] ** = Significant at P<0.01
[d]NS = Non-significant
[e] * = Significant at P<0.05

Grain yield was affected by treatment, and the treatment effect was similar across environments and varieties (Table 18). The control treatment alone resulted in the lowest grain yield and the highest yielding treatment was the ST + EF + LF + LI (Table 19). The addition of an early fungicide did not increase yield compared to the seed treatment followed by herbicide treatment. Adding an early insecticide increased yield compared to the treatment that included ST + EF. There were no visible insects at the time of application to account for the yield increase. One possible cause for the increased yield was the decrease in barley yellow dwarf. Barley yellow dwarf virus (BYDV) is a worldwide virus disease that affects wheat and is transmitted aphids (D'Arcy and Domier 2000). Assessments were not made on the occurrence of BYD in experiments. Thus, it is unknown if this is the cause for the yield difference. Seed treatment + late fungicide yielded higher than the previous treatments. Grain yield with the treatment ST + EF + LF was not significantly higher than the treatment without the early fungicide but it was comparable to the herbicide alone treatment. The complete treatment of

ST + EF + LF + LI was the overall best treatment with an increase of 500 kg ha^{-1} over the control (Table 19).

Grain yield was affected by both environment and variety shown in Table 20. There were lower grain yields in 2011 compared to 2010 for both Oklee and Glenn except for at Glenn the Sabin location.

Table 19. Treatment effects on grain yield, test weight, and protein content for the systematic, multichemical program approach study in Sabin, MN and Valley City, ND in 2010 and 2011.

Treatment	Grain yield	Test weight	Protein content
	-kg ha^{-1}-	-g L^{-1}-	-%-
Control	3900	786	15.0
ST (Proceed Plus) [a]	4050	792	14.7
ST + EF (Bixafen)[b]	4050	791	14.8
ST + EF + EI (Baythroid)[c]	4150	793	14.7
ST + LF (Prosaro)[de]	4250	796	14.5
ST + EF + LF	4200	793	14.5
ST + EF + LF + LI[c]	4400	801	14.4
Mean	4100	793	14.7
LSD 0.05	75.0	9.1	0.3

[a] (ST) Prothioconazole & tebuconazole & clothianidin & metalaxyl = Proceed Plus Seed Treatment
[b] (Early Fungicide = EF) Bixafen = BAY Fungicide
[c] (Early Insecticide = EI) (Late Insecticide = LI) Beta-cyfluthrin = Baythroid XL EC Insecticide
[d] (Late Fungicide = LF)Prothioconazole & Tebuconazole = Prosaro SC Fungicide
[e] All treatments containing Prothioconazole & Tebuconazole received NIS at 0.25% v/v

Test weight was affected by treatment, and the treatment effect was similar across environments and varieties (Table 18). The control treatment had the numerically lowest test weight (786 g/L) and the ST + EF + LF + LI had the highest test weight (801 g/L) (Table 19). Although not always significant, there appeared to be a trend toward higher test weight by adding an early fungicide and a further increase when a late fungicide was added. Adding an early or a late insecticide appeared to provide a further increase. All increases in test weight were relatively small in this study (Table 19).

Grain protein percentage was affected by treatment, and the treatment effect was similar across environments and varieties (Table 18). Protein percentage was numerically the highest with the control treatment and generally lower with the remaining treatments, especially when a late fungicide was included (Table 19). This was not surprising as there is generally a negative relationship between yield and protein percentage, and these treatments increased yield. Treatments that would tend to improve the health of the plant during the grain fill period (post-anthesis) would generally improve yield and decrease grain protein percentage (Deckard et al 1985).

Thousand kernel weight was dependent on the environment and the variety (Table 18). In 2010, Oklee had higher thousand kernel weights compared to Glenn in both environments (34g vs. 31g). Oklee also had higher thousand kernel weight compared to Glenn (28g vs. 26g) at Sabin in 2011. However, the two varieties responded similarly in regard to kernel weight in 2011 at Valley City (data not shown).

Table 20. Grain yield influenced by environment and variety for the systematic, multichemical program approach study in Sabin, MN and Valley City, ND in 2010 and 2011.

	Variety		
Location	Oklee	Glenn	Mean
	------------------------kg ha^{-1}------------------------		
Sabin 2010	5470	4430	4950
Sabin 2011	3370	3280	3320
Valley City 2010	5890	4990	5440
Valley City 2011	2910	2750	2830
Mean	4411	3860	
LSD 0.05 Env. x Variety = 1460			

Deoxynivalenol (DON) was higher in Valley City compared to Sabin (Table 21). The addition of a late fungicide did not decrease DON in Sabin, whereas the late fungicide application generally lowered DON in Valley City. The DON values were relatively low for both varieties at all environments.

Table 21. Deoxynivalenol as influenced by environment and treatment for the systematic, multichemical program approach experiment in 2011.

Treatment	Sabin, MN	Valley City, ND
	------------PPM-----------	
Control	0.6	3.5
ST (Proceed Plus) [a]	0.7	3.5
ST + EF (bixafen)[b]	0.6	3.6
ST + EF + EI (Baythroid)[c]	0.6	3.4
ST + LF (Prosaro)[de]	0.5	2.7
ST + EF + LF	0.5	2.5
ST + EF + LF + LI[c]	0.5	2.5
Mean	0.6	3.1
LSD 0.05 Env. x Trt. Interaction = 0.8		

[a] (ST) prothioconazole & tebuconazole & clothianidin & metalaxyl = Proceed Plus Seed Treatment
[b] (Early Fungicide = EF) bixafen = BAY Fungicide
[c] (Early Insecticide = EI) (Late Insecticide = LI) Beta-cyfluthrin = Baythroid XL EC Insecticide
[d] (Late Fungicide = LF) prothioconazole & tebuconazole = Prosaro SC Fungicide
[e] All treatments containing prothioconazole & tebuconazole received NIS at 0.25% v/v

Tan Spot and Bixafen Fungicide Study

The agronomic and quality traits are discussed in a combined analysis because the experimental errors were homogenous (Table 22).

Table 22. Partial analysis of variance for crop injury, disease and agronomic traits for the tan and bixafen fungicide study in Sabin, MN and Valley City, ND in 2010 and 2011

	df[a]	Crop injury	Tan spot severity	Grain yield	Test weight	Percent protein
Source of variation						
Environment	3	**[b]	**	**	**	**
Treatment	9	NS[c]	NS	**	**	NS
Environment/Treatment	27	**	NS	NS	NS	NS

[a]df = Degrees of freedom
[b]** = Significant at P> 0.01
[c]NS = Non-significant

Crop injury was noticed as a result of the chemical treatments in 2011, and injury was influenced by the environment (Table 22). The crop injury results shown in Table 23 are from

2011 only, as there were no visual injury symptoms in 2010. The environment X treatment interaction apparently resulted from three of the treatments: propoxycarbazone + bixafen @ 30g ai/ha, propoxycarbazone + bixafen @ 60g ai/ha, and the bixafen followed by fenoxaprop five days later. Sabin had higher injury compared to Valley City with both of the propoxycarbazone + bixafen treatments (Table 23). History has shown that there will be an increased risk of crop injury from propoxycarbazone plus mesosulfuron when temperatures are elevated and/or a fungicide is added to this herbicide (Thorsness 2012). The air temperature at Sabin at time of application was 16 C with an average maximum air temperature five days after application of 28.4 C (NDAWN 2012). The air temperature at Valley City at the time of application was 20 degrees Celsius with an average maximum air temperature of 22.1 C five days following application. The higher maximum temperatures following application likely contributed to the greater injury at Sabin. Injury symptoms associated with the split application of bixafen @ 30g ai/ha at Sabin and Valley City were also different. Valley City showed more crop injury compared to Sabin (14.3 vs. 9.0). Weather conditions at the time of application is a probable cause for this difference. The air temperature was higher in Valley City compared to Sabin (24 C vs. 19 C).

Tan spot severity was influenced by the environment and was higher in 2010 at both Sabin and Valley City compared to 2011. The mean percent severity in Valley City in 2010 was 22% compared to 14% in 2011. The mean percent severity in Sabin in 2010 was 23% compared to 10% in 2011. The increased rainfall in 2010 at the tillering stage of the crop would promote higher tan spot severity.

Table 23. Crop injury ratings influenced by treatment and environment for the tan spot and Bixafen fungicide experiment in 2011.

Treatment	Sabin, MN	Valley City, ND
	---------------%	---------------
Fenoxaprop[a]	10.5	12.5
Fenoxaprop + Bixafen[b] @ 30 g ai/ha^{-1}	12.0	12.5
Fenoxaprop + Bixafen @ 60 g ai/ha^{-1}	12.3	13.5
Fenoxaprop + Propiconazole[c] & Trifloxystrobin	15.0	15.8
Fenoxaprop + Pyraclostrobin[d]	14.3	14.3
Fenoxaprop + Propiconazole[e]	11.5	12.5
Propoxycarbazone[fg]	16.5	13.5
Propoxycarbazone + Bixafen @ 30 g ai/ha^{-1}	17.5	13.5
Propoxycarbazone + Bixafen @ 60 g ai/ha^{-1}	18.0	11.8
Bixafen @ 30 g ai/ha^{-1} fb Fenoxaprop[h]	9.0	14.3
Mean	13.7	13.4
LSD 0.05 Env. x Trt. interaction = 3.7		

[a] (Fenoxaprop) Fenoxaprop-p-ethyl & pyrasulfotole & bromoxynil & mefenpyr safener = Wolverine EC herbicide
[b]Bixafen = BAY Fungicide
[c] Propiconazole & trifloxystrobin = Stratego EC fungicide
[d]Pyraclostrobin = Headline SC fungicide
[e]Propiconazole = Tilt EC fungicide
[f] (Propoxycarbazone) Propoxycarbazone-sodium & mesosulfuron-methyl = Rimfire Max WG herbicide
[g]Propoxycarbazone-sodium & mesosulfuron-methyl includes a labeled rate of Quad 7 at 1% v/v
[h]Applied 5 days after bixafen

Grain yield for the tan spot study in Sabin and Valley City in 2010 and 2011 was influenced by treatments and environments (Table 22). Grain yield was numerically highest with the fenoxaprop + pyraclostrobin treatment and lowest with the propoxycarbazone + bixafen (30g ai/ha) (Table 24). Although the fenoxaprop + pyraclostrobin treatment resulted in higher yield than several other treatments, it was not significantly higher than Fenoxaprop alone. Grain yield was likely influenced in different ways, including the presence of the tan spot disease and from crop injury as a result of the chemical treatments. The chemical treatments did not influence tan spot severity (Table 22), so the interaction should not be a significant factor. In general, those treatments that caused crop injury also resulted in a decreased yield (Table 24), although it is far from a perfect association and crop injury was only noted in 2011.

Test weight for the tan spot study in Sabin and Valley City in 2010 and 2011 was influenced by treatments and environments (Table 22). However the differences among the treatments are relatively small. Fenoxaprop alone resulted in numerically the highest test weight, which was significantly greater than several of the treatments, but, again, the differences are relatively small.

Protein percentage was evaluated at all the locations except in Sabin in 2010. This is due to missing data in that year. Valley City in 2011 had the highest average mean percent protein content of 17% compared to 16.1% at Sabin in 2011 and 14.6% at Valley City in 2010.

Table 24. Grain yield and test weight for tan spot and bixafen fungicide study in Sabin, MN, and Valley City, ND, in 2010 and 2011.

Treatment	Grain Yield kg ha^{-1}	Test Weight g L^{-1}
Fenoxaprop[a]	3610	778
Fenoxaprop + Bixafen[b] @ 30 g ai/ha^{-1}	3520	774
Fenoxaprop + Bixafen @ 60 g ai/ha^{-1}	3600	776
Fenoxaprop + Propiconazole[c] & Trifloxystrobin	3580	775
Fenoxaprop + Pyraclostrobin[d]	3710	776
Fenoxaprop + Propiconazole[e]	3500	767
Propoxycarbazone[fg]	3550	775
Propoxycarbazone + Bixafen @ 30 g ai/ha^{-1}	3400	769
Propoxycarbazone + Bixafen @ 60 g ai/ha^{-1}	3430	769
Bixafen @ 30 g ai/ha^{-1} fb Fenoxaprop[h]	3580	769
Mean	3548	773
LSD 0.05	158	2.4

[a] (Fenoxaprop) Fenoxaprop-p-ethyl & pyrasulfotole & bromoxynil & mefenpyr safener = Wolverine EC herbicide

[b]Bixafen = BAY Fungicide

[c] Propiconazole & trifloxystrobin = Stratego EC fungicide

[d]Pyraclostrobin = Headline SC fungicide

[e]Propiconazole = Tilt EC fungicide

[f] (Propoxycarbazone) Propoxycarbazone-sodium & mesosulfuron-methyl = Rimfire Max WG herbicide

[g]Propoxycarbazone-sodium & mesosulfuron-methyl includes a labeled rate of Quad 7 at 1% v/v

[h]Applied 5 days after bixafen

SUMMARY

Two objectives of this study were 1) to evaluate Proceed Plus (prothioconazole & tebuconazole & metalaxyl & clothianidin), Wolverine (fenoxaprop-p-ethyl & pyrasulfotole & bromoxynil & mefenpyr), bixafen, Prosaro (prothioconazole & tebuconazole), and Baythroid XL (beta-cyfluthrin), with ‘Glenn’ and ‘Oklee’ hard red spring wheat cultivars in a systematic, multichemical program approach for management of tan spot, leaf diseases and fusarium head blight, and 2) to evaluate early season tan spot control in ‘Alsen’, hard red spring wheat variety, with bixafen fungicide compared to industry standard products applied at the tillering stage of wheat.

These objectives were studied by establishing two studies. The first study (objective 1) used a systematic, multichemical program approach at two locations in each of two years. The second study (objective 2) involved evaluating a novel fungicide, bixafen, for managing tan spot at the same two locations and the same years as the first study. In both studies, data were combined across experiments (locations and years).

Systematic, Multichemical Program Approach Study

Crop injury was affected by an interaction of environment and variety. This interaction was due to Oklee exhibiting greater injury compared to Glenn (14.7% v. 10.3%). Overall, crop injury was greatest at Valley City in 2011 and lowest at Valley City in 2010. All the chemical treatments provided similar levels of crop injury. That is, all chemical additions to the herbicide did not result in greater crop injury.

Treatment effects on tan spot were influenced by the environment. The addition of a late fungicide lowered tan spot percentage in all environments except at Sabin in 2011. Early fungicide treatments did not influence tan spot, but these findings could have been different had the plots been evaluated shortly after early fungicide application instead of later in the season. Tan spot ratings were affected by an interaction of varieties and environment. Glenn had a higher tan spot percentage compared to Oklee at only one location, Sabin.

Head blight index was influenced by variety as Glenn generally exhibited higher index values than Oklee. The head blight index of Oklee was not affected by any of the treatments, but there was a general trend towards lower head blight index with the addition the late fungicide, with the exception of the seed treatment, early fungicide, and late fungicide treatment. Glenn exhibited lower head blight index when the late fungicide was applied with the exception of the seed treatment and late fungicide treatment.

Grain yield was affected by treatment. The herbicide alone treatment (control) resulted in the lowest grain yield (3900 kg ha^{-1}), chemical combinations with the late fungicide generally resulted in higher yields. The treatment including seed treatment, early fungicide, late fungicide, and late insecticide resulted in the highest yield (4400 kg ha^{-1}).

Test weight was also affected by treatment. Herbicide alone had the lowest test weight (786 g/L) and the seed treatment, early fungicide, late fungicide, and late insecticide had the highest test weight of (801 g/L). All the increases in test weight were relatively small.

Grain protein percentage was generally the highest with the herbicide alone treatment. The lowest grain protein percentage was with the treatment that included seed treatment, early fungicide, late fungicide, and late insecticide. Lower grain protein percentages were especially evident when the late fungicide was used.

Deoxynivalenol (DON) was affected by an interaction of environment and treatment. DON was higher in grain from Valley City compared to Sabin. The addition of the late fungicide application did not decrease DON in Sabin, whereas it generally did in Valley City. DON levels were relatively low for both varieties at all locations.

The objectives of this study were to evaluate Proceed Plus (prothioconazole & tebuconazole & metalaxyl & clothianidin), bixafen, Prosaro (prothioconazole & tebuconazole), and Baythroid XL (beta-cyfluthrin), with ‘Glenn’ and ‘Oklee’ hard red spring wheat cultivars in a systematic, multichemical program approach for management of tan spot, leaf disease, and fusarium head blight. The overall finding of this study was that the implementation of a systematic, multichemical program approach would be beneficial for growers. The complete treatment of seed treatment, herbicide, early fungicide, late fungicide, and late insecticide proved to give the most return to the grower. This is true taking into account today’s commodity prices along with today’s input costs which are subject to change in the future.

Tan Spot and Bixafen Fungicide Study

Crop injury was noticed in 2011 as a result of chemical treatments, and injury was influenced by environment. There were no crop injury symptoms in 2010. The environment by variety interaction seems to have resulted from the two treatments containing propoxycarbazone and bixafen at Sabin and the bixafen followed by fenoxaprop five days later treatment at Valley City.

Grain yield was influenced by treatments and environments. Grain yield was highest numerically with the fenoxaprop plus pyraclostrobin treatment although it was not significantly higher than the fenoxaprop alone treatment, grain yield was lowest with the propoxycarbazone plus bixafen treatment.

Test weight for both location and both years was influenced by treatments and environments. Fenoxaprop alone resulted in numerically the highest test weight and was significantly greater than several of the treatments.

The objectives of this study were to evaluate early season tan spot control in ‘Alsen’, hard red spring wheat variety, with bixafen compared to industry standard products applied at the tillering stage of wheat. The objective was accomplished by conducting field experiments at four locations over a two year time period.

The findings of this study was that bixafen was very competitive with today’s commonly used early season fungicides. This product has potential to be beneficial for growers to implement in their disease control program in spring wheat. Bixafen also is able to be applied to control midseason plant diseases which provide growers with alternative options when selecting a product.

The overall findings between the two studies was that the implementation of a systematic, multichemical program approach is beneficial for growers and that bixafen performance shows good potential for tan spot management compared to industry standards. Although these studies were conducted at four locations over two years, there is a need for further research. The influence of environment in each of the two studies shows that experiments involving more locations and years would provide more complete data for making recommendations. New chemicals and constantly changing commodity prices and input prices also means it is necessary to continue working on a systematic, multichemical program approach.

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