H13 EFFICACY AS A SPRING CEREAL CROP HERBICIDE

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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

H13 is an experimental herbicide that has activity on both broadleaf and grass weeds. This project evaluated H13 efficacy as a spring cereal herbicide by determining H13 site of entry into plants, tolerance of hard red spring wheat, durum wheat, and barley to H13, and H13 efficacy to wild oat and wild buckwheat. H13 caused substantial response when applied to wild oat and wild buckwheat foliage only and negligible response when applied to soil only, indicating H13 is primarily absorbed through foliage. All crops were sensitive to H13 applied preemergence. Hard red spring wheat was tolerant to H13 applied post emergence while durum wheat and barley have potential to manifest injury. H13 gave less control of wild oat and wild buckwheat than three industry standard herbicides. H13 was not an effective spring cereal herbicide for wild oat and wild buckwheat control under conditions observed in this project.

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INTRODUCTION

Wild oat (*Avena fatua* L.) and wild buckwheat (*Polygonum convolvulus* L.) continue to be among the top ten most damaging weeds to cereal crop production in North Dakota (Zollinger et al. 2003). A North Dakota weed survey conducted in 2000 estimated spring wheat (*Triticum aestivum*) yield loss of 14% as a result of wild oat and wild buckwheat competition after herbicide treatment. A 14% yield loss from wild oat and wild buckwheat competition would have resulted in 700,000 tonnes less spring wheat production or an estimated economic loss of $213 million based on 2009 farm receipts (NDASS 2010). Failure to maximize spring wheat production potential not only affects North Dakota receipts but also the United States commodity market and international trade balance as a whole because North Dakota produces 45% of the nation's hard red spring wheat and 62% of the nation's durum wheat (*Triticum durum* Desf.) that are the main ingredients of food staples such as bread and pasta, respectively (NDASS 2011).

Wild oat and wild buckwheat are persistent annual weeds in cereal crop production because of changes in agriculture practices (Swanton et al. 1993; Wilson et al. 2007), selection of resistant biotypes (Holt et al. 1990), and prolific seed production (Mulligan and Findlay1970). A new experimental herbicide, H13, is under investigation for the effectiveness as a cereal crop herbicide. Unlike most cereal crop herbicide active ingredients, H13 affects both grass and broadleaf weeds and has been observed to provide soil residual activity (Dr. Kirk Howatt, personal communication). These two characteristics are ideal for an active ingredient because a wide spectrum of weed control is possible as well as the potential to provide a level of residual control of weeds. H13 has potential to improve the control of wild oat and wild buckwheat in cereal crops, which would result in increased crop yields and profits.

LITERATURE REVIEW

Wild oat, an annual weed in the grass (Poaceae) family, is native to Europe and has spread to all areas in the world where spring cereal crops are grown, including western, upper Midwestern, and northeastern regions of the United States (Lorenzi and Jeffery 1987). Wild oat is a persistent weed in spring cereals because of the ability to germinate at 4 °C and the ability to thrive in cool, moist conditions, characteristics similar to spring cereals (Acevedo et al. 2002; Sharma and Vanden Born 1978). Wild oat favors clay to clay loam soils which are common in North Dakota (Sharma and Vanden Born 1978). Although, wild oat can thrive in several types of environments, such as fallow fields, roadsides, and waste places, the weed is most common in cultivated field areas.

Wild oat produces flowers between June and August and reproduces only by seeds (Whitson et al. 1996). The inflorescence is a large, open panicle with drooping spiklets. One of the key characteristics of wild oat morphology is that the leaves twist counter-clockwise instead of clockwise as with wheat or barley (*Hordeum vulgare* L. ssp.) leaves. Wild oat can be differentiated from tame oat because wild oat awns are long and bent at a sharp angle to help the seeds twist and burrow into the ground as they become moistened whereas the awns of tame oat are usually short and straight. Also, wild oat has a round callus at the base of each grain and slightly roughened leaves, whereas tame oat does not have callus at the base of the grains and leaves are smooth.

Wild buckwheat, also a native of Europe, is an annual weed in the smartweed (Polygonaceae) family (Lorenzi and Jeffery 1987). It is well adapted to several environments and inhabits all continents except for Antarctica but is most commonly found in temperate soils of cultivated fields (Hume et al. 1983). Wild buckwheat leaves have an ocrea, which is a thin membrane around the stem at the nodes. Cotyledons are slender and linear with rounded tips, while true leaves are chordate and arranged in an alternate pattern along the stem. Wild buckwheat is characterized by a vining growth pattern which usually initiates around the four-leaf growth stage. This vining growth habit allows wild buckwheat to effectively maximize sunlight interception by either covering bare ground or climbing up stems of competing plants to overcome sources of shade.

Wild buckwheat also reproduces by seeds. The flowers are found at the leaf axils of the plant and are small, greenish-white, and inconspicuous (Lorenzi and Jeffery 1987). The flowers of wild buckwheat are indeterminate, which enables seed production throughout the growing season. Therefore, flowers, immature seed, and mature seed may be found on an individual plant at the same time (Forsberg and Best 1964). Due to the indeterminate growth pattern, wild buckwheat can still be actively growing and producing seed when a cereal crop is ready to harvest (Fabricius and Nalewaja 1968).

High seed production contributes to the persistence of wild oat and wild buckwheat. Both wild oat (Murray et al. 2002) and wild buckwheat (Mulligan and Findlay 1970) reproduce primarily by self-pollination and are spread by prolific seed production. A single wild buckwheat plant can produce as many as 12,000 small, triangular, black seeds that can remain dormant for as many as seven years and can germinate throughout the growing season, even from a depth of 19 cm (Forsberg and Best 1964; Metzger 1992). In the Pacific Northwest, wild oat plants produced an average of 578 seeds/plant in the first year and 1565 seeds/plant in the second year of an experiment conducted in a controlled environment (Morrow and Gealy 1983). Wild oat seed can remain viable for as many as 14 years (Miller and Nalewaja 1990).

The persistence of wild oat and wild buckwheat allows them to be perpetual, problematic weeds in spring cereal crop production. From 1978 to 2000, the average weed density of wild oat and wild buckwheat tended to increase in cereal crop fields surveyed (Dexter et al. 1981; Zollinger et al. 2003). If seed production of wild oat and wild buckwheat plants is allowed in one year, persistence of potential weed seeds and subsequent weeds can last for several years despite effective POST weed control because of seed germination from the seedbank. Management and control methods to reduce weed seed production can limit the spread of a weed patch. When wild oat seed shed was prevented by clipping and bagging panicles, wild oat patch expansion was restricted to 35% versus 330% for an unclipped wild oat patch (Beckie et al. 2005).

Early control of weeds in cereal crops is important for prevention of seed set and also for full profit potential. In general, larger weeds are tougher to control than smaller weeds and can require a higher, more costly, rate of herbicide. Also, the duration of weed competition in cereal crops influences the severity of yield loss. Barley and spring wheat yield reduction was greatest when wild oat emerged before the crop (O'Donovan et al. 1985). Wild buckwheat should be controlled before the vining stage as the greatest yield reduction of wheat is a result of shading or constriction from wild buckwheat climbing up the stems of wheat (Fabricius and Nalewaja 1968). Bell and Nalewaja (1968) found wild oat allowed to compete with spring wheat all season at densities of 70 plants/m^2 and 160 plants/m^2 reduced wheat yield by 22% and 39%, respectively. In extreme cases, wild oat infestation of 300 plants/m^2 allowed to compete with spring wheat all season resulted in 64% less yield than weed-free wheat (Carlson and Hill 1985).

Several studies have evaluated wild oat competition with cereal crops; however, little research has been conducted to determine direct yield loss of a cereal crop from wild buckwheat competition. Wild buckwheat is most detrimental to potential profit by causing harvest difficulties, spoilage during storage, and price penalties (Scott and Peeper 1994). Wild buckwheat seed is similar in size to grain kernels and is difficult to separate from cereal crop seed. Wild buckwheat causes storage difficulties of grain by increasing the moisture content of a storage area. Grain contaminated with weed seeds can result in a price discount from a grain buyer. The vining characteristic of wild buckwheat can disrupt moving parts of a combine and in some cases can result in repair costs or can prevent a farmer from harvesting a heavily infested section of a field, all of which result in less profit.

Changes in agriculture practices have influenced the populations of wild oat and wild buckwheat. Weed population shifts occur when agricultural practices change. Two influential agricultural practices that have caused weed population shifts are the conversion from conventional tillage to reduced tillage systems (Swanton et al. 1993) and the adaptation of glyphosate-resistant crops (Shaner 2000; Wilson et al. 2007). The success of reduced tillage systems has been dependent on the adaptation of glyphosate-resistant crops (Young 2006). Glyphosate-resistant crops have allowed producers to obtain satisfactory weed control in a reduced tillage system with in-season applications of glyphosate, a non-selective herbicide.

The limiting factor of production in zero-tillage systems also is weed control. Weed density was five times greater in a zero-tillage system than in a conventional tillage system when conventional herbicides were used in an experiment conducted near Mandan, ND (Anderson et al. 1998). Wild buckwheat, along with other summer dicot annual weeds, has been associated with conventional tillage; however, wild buckwheat control was still needed in both conventional and zero-tillage systems (Derksen et al. 1993). Another study found broadleaf weed biomass to be similar among no-tillage, disk-tillage, or plow-tillage systems (Wrucke and Arnold 1985).

Similar to annual broadleaf weeds, there also has been an association between annual grasses and zero-tillage systems (Menalled et al. 2001; Wrucke and Arnold 1985). Wrucke and Arnold (1985) found twice the grass weed biomass production in a zero-tillage system than with a disk-tillage or plow-tillage system. Wild oat has been associated with zero-tillage in a situation when inadequate herbicide treatments for wild oat were applied (Derksen et al. 1993). However, other studies have found wild oat to be less prevalent under zero-tillage than under conventional tillage (Cousens and Moss 1990).

Optimum yield under a zero-tillage system can only be obtained when good weed control is achieved (Hume et al. 1991). Glyphosate is a broad-spectrum herbicide that provides good control of most weeds, many of which are problematic in zero-tillage systems (Anonymous 2009). Glyphosate-resistant crops, such as corn, soybean, sugarbeet, and canola, are common crops grown in sequence with spring cereal crops in North Dakota. Several factors influence the efficacy of glyphosate: rate, timing, and adjuvant (Jordan et al. 1997). If producers apply glyphosate at reduced rates to increase profit potential or are unable to apply glyphosate in a timely manner, weed control can be greatly comprised. In this situation, the possibility of seed production from uncontrolled weeds is increased, thereby increasing the potential number of weeds in the crop for the next growing season.

Control of wild buckwheat with glyphosate can range from 40 to 90% (Zollinger et al. 2011). A wild buckwheat population that started at an undetectable density increased to a very high level when continuous glyphosate-resistant corn was grown and treated with a reduced rate of glyphosate, 0.4 kg ae/ha, versus a full glyphosate rate, 0.8 kg/ha (Westra et al. 2008). Wild buckwheat is difficult to control with glyphosate especially under difficult spraying conditions such as cold weather (Anonymous 1999); therefore, an increase in population after repeated glyphosate applications can result (Blackshaw and Harker 2002; Harker et al. 2005). In a study investigating glyphosate-resistant wheat, glyphosate was most effective at controlling wild buckwheat and wild oat when applied at the three- to five-leaf growth stage of the weeds (Howatt et al. 2006). Despite difficulties to control wild oat and wild buckwheat, glyphosate-resistant biotypes of these weeds have not been confirmed. However, several weeds including common ragweed (*Ambrosia artemisiifolia* L.), kochia (*Kochia scoparia* (L.) Schrad.), and Italian ryegrass (*Lolium perenne* L. ssp. multiflorum (Lam.) Husnot) have been confirmed with glyphosate resistance (HRAC et al. 2011).

Several herbicides can provide effective control of wild oat or wild buckwheat in wheat and barley. Effective control of wild oat can be obtained with Acetyl-CoA carboxylase (ACCase)-inhibiting herbicides in the aryloxyphenoxy propionic acid family of chemistry, for example fenoxaprop, and in the phenylpyrazolin family of chemistry, for example pinoxaden (Zollinger et al. 2011). Tralkoxydim in the cyclohexanedione family of chemistry of ACCase-inhibiting herbicides did have a label registration for wild oat control in North Dakota but the label has been withdrawn. Wild oat can also be controlled with herbicides such as imazamox, mesosulfuron, pyroxulam, and flucarbazone from several of the acetolactate synthase (ALS)-inhibiting families of chemistry. Effective control of wild buckwheat can be obtained with herbicides in the sulfonylurea family of ALS-inhibiting herbicides, for example thifensulfuron;

with growth regulator herbicides dicamba in the benzoic acid family and clopyralid in the pyridine family; and with bromoxynil, a photosystem II inhibitor – site B herbicide. Despite excellent control, 90% or greater, of wild oat and wild buckwheat by currently registered herbicides, persistence of these weeds is still an issue.

Persistence of wild oat and wild buckwheat could be due to herbicide resistance (Beckie et al. 1999; Holt et al. 1990). The repetitive use of a herbicide or herbicides with the same site-of-action results in selection pressure, thus allowing the resistant weed biotype to outnumber the susceptible weeds. Common characteristics of herbicides to which weeds have evolved resistance include inhibition of a single target site and specific site-of-action, high efficacy, long soil residual, and repetitive applications without use of other herbicides or alternative control practices (Holt et al. 1990). ACCase-resistant wild oat has been confirmed at an estimated 101 to 500 locations covering about 468 to 4,049 ha in North Dakota, and ALS-resistant wild oat has been confirmed at 2 to 5 locations in North Dakota covering about 203 to 405 ha (HRAC et al. 2011). In addition, ACCase- and ALS-resistant wild oat has also been confirmed in several locations across Alberta, Saskatchewan, and Manitoba in Canada. Wild buckwheat resistance to ALS inhibiting herbicides has also been confirmed in Canada at one site where it is estimated to infest 41 to 202 ha but has not been confirmed in the United States.

H13 is a proprietary product in the early stages of investigation as a spring cereal crop herbicide. In previous research, H13 has exhibited activity on both broadleaf and grass weeds, which is unique for a selective herbicide in cereal crop production. The use of H13 could provide cereal crop producers an additional herbicide option to help alleviate the selection pressure of resistant weeds and help decrease the density of wild oat and wild buckwheat. The objectives of this research project were to determine: 1) H13 site of entry into plants; 2) if soil type influences H13 efficacy on germinating seedlings; 3) spring wheat, durum and barley tolerance to H13; and 4) H13 efficacy to wild oat and wild buckwheat.

MATERIALS AND METHODS

Formulation Study

Sufficient volume of H13 was not available in a single formulation to complete all studies. All of the greenhouse studies and the weed control study under field conditions were conducted with the suspension concentrate (SC) formulation of H13 while the crop tolerance study under field conditions was conducted with the water-dispersible granule (WG) formulation. The purpose of this study was to determine whether the SC and WG formulations provided equivalent activity of H13.

This study was conducted in the greenhouse at 23 ± 4 °C. Natural light was supplemented with 400 watt high pressure sodium lamps with photoperiod of 16 hr. Flats with water drainage holes measuring 30.5 cm on a side and 7 cm deep were filled with potting media[1]. Twenty seeds of ‘Faller’ hard red spring wheat, ‘Lebsock’ durum, ‘Pinnacle’ two-row barley, ‘Tradition’ six-row barley, and wild mustard (*Sinapis arvensis* L.) were seeded within rows spaced 0.5 cm apart. Wild mustard was chosen because previous observations indicated plants demonstrate injury symptoms but are difficult to control (Dr. Kirk Howatt, personal communication). Plants were watered daily but additional fertilizer was not added. At the two-leaf stage, plants were treated with 0, 50, or 100 g ai/ha of H13 in the WG or SC formulation in a spray chamber equipped with a 650067E nozzle tip[2] that delivered 94 L/ha by pressurized air at 240 kPa. Oil adjuvant[3] was added to each treatment at 1.17 L/ha.

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[1] Sunshine Mix #1, Sun Gro Horticulture Distribution, Inc., 15831 NE 8th St., Suite 100, Bellevue, WA 98008.

[2] Spraying Systems Company, P.O. Box 7900, Wheaton, IL 60189.

[3] Syl-Tac, Wilbur-Ellis, 345 California Street, San Francisco, CA 94104.

Visible injury evaluations were recorded 1, 2, and 3 weeks after treatment (WAT) on a scale from 0 to 100, 0 corresponding with no plant injury and 100 corresponding with plant death. At 3 WAT, 10 plants of each crop and 5 plants of wild mustard were cut at the soil surface and dried at 49 °C for 4 d. Weight of dry biomass was recorded.

The factors of this experiment that were subject to statistical analysis were H13 rate and H13 formulation. Each plant species was analyzed separately. The experiment was established in a factorial, completely-random design and the experiment was repeated twice. Each repetition was not replicated to conserve H13 product. Mean squares were equated to the expected mean squares to determine the correct denominator for each F-test. Repetition was considered a random effect and H13 rate and formulation were considered fixed effects. Data for visible plant response and shoot dry biomass were subjected to analysis of variance in SAS. Means were separated by Fisher's protected LSD with $\alpha=0.05$.

Site of Entry Study

The purpose of this study was to determine H13 site of entry into plants and if soil classification influenced herbicide activity on germinating seedlings. This study was conducted in the greenhouse under conditions previously described. One-thousand grams of either Glyndon silt loam (Coarse silty, mixed, superactive, frigid Aeric Calciaquolls) or Lanona-Swenoda fine sandy loams (Coarse-loamy, mixed, superactive, frigid Calcic Hapludolls) was placed in a 10-cm by 10-cm by 10-cm pot lined with a plastic bag. The Glyndon silt loam had a pH of 8.1, organic matter of 2.6%, and a cation exchange capacity (CEC)[4] of 19 cmol(+)/100 kg. The Lanona-Swenoda soil had a pH of 6.1, organic matter of 2.7%, and a CEC of 14 cmol(+)/100 kg.

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[4] Cation exchange capacity was determined by using the Na-NH4 exchange method.

To enhance germination, both wild oat and wild buckwheat seeds were treated before seeding. Wild oat seeds were dehulled, pricked on the dorsal surface with a sterile needle, and placed on filter paper in a petri dish half filled with distilled water. Petri dishes with wild oat seed were covered to prevent sunlight penetration and were placed in a refrigerator at 6 °C for 36 h. Scarification of wild buckwheat seeds was conducted by rubbing wild buckwheat seeds with sandpaper and then soaking them in 100% sulfuric acid for 5 min. After the acid treatment, wild buckwheat seeds were placed on a screen and rinsed under running tap water for 3 min.

Six wild oat or 20 wild buckwheat seeds were randomly seeded on one half of each pot. Emergence was recorded to estimate establishment rate of weed seeds. Wild oat plants were thinned to three plants while wild buckwheat plants were thinned to two plants. Pots were watered to maintain ± 10% of 55% field capacity and 11 kg/ha of nitrogen, 4 kg/ha of phosphorus, and 8 kg/ha of potassium were applied once five days before herbicide treatment with 24-8-16 fertilizer[5] to stimulate healthy growth.

Preceding the herbicide application, seven additional wild buckwheat or six wild oat seeds were seeded parallel to the two-leaf established plants. The two-leaf established plants will be referred to as established plants and the seeds seeded before herbicide application will be referred to as seedlings. There were two non-treated checks for each weed by herbicide application method by soil type combination; one to determine a biomass baseline at application and a second as the experiment control. Experimental units were treated with H13 at 0, 50, or 100 g/ha in a spray chamber as previously described. Treatments were applied when established weeds reached the two-leaf stage by three application methods to determine site of entry into the

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[5] Miracle-Gro All Purpose Plant Food, The Scotts Company LLC, 14111 Scottslawn Rd., Marysville, OH 43041.

plant. The three application methods included foliar only, soil only, and foliar plus soil application. The foliar only application was applied by covering the soil with 0.5 cm of activated charcoal and removing it once treated leaves had dried. The soil only application was applied by covering the plants with plastic bags, and removing plastic immediately after application. The soil plus foliar application was applied to the entire experimental unit without any covering material.

Visible injury of established plants and seedlings were recorded 1, 2, and 4 WAT on the visual scale previously described. Reduction in germination of seedlings was determined as a percentage of the established plant's germination rate recorded before thinning. At the end of experiment, plants were cut at the soil surface, dried at 49 °C for 4 d, and weighed to record dry biomass.

The factors of this experiment that were subject to statistical analysis included three rates of H13, two soil types, two weed growth stages, and three herbicide application methods. Each weed was analyzed separately. The experiment was established in a factorial, completely-randomized design with four replicates and the experiment was repeated twice. Data were combined for analysis if variances of each run were determined similar by comparing mean square error values (within a factor of 10). Data for visible plant response and shoot dry biomass were subjected to analysis of variance in SAS. Mean squares were equated to the expected mean squares to determine the correct denominator for each F-test. Experimental run was considered a random effect and H13 rate, soil type, weed growth stage, and herbicide application method were considered fixed effects. Means were separated by Fisher's protected LSD with $\alpha=0.05$.

Crop Safety Studies

Greenhouse Cultivar Screening. The purpose of the greenhouse cultivar screening study was to determine if different cultivars within hard red spring wheat (*Triticum aestivum*), durum wheat (*Triticum durum* Desf.), and two-row and six-row barley (*Hordeum vulgare* L. ssp.) exhibit similar response to H13. Four cultivars of each species were screened: Glenn, Faller, Kelby, and RB07 for hard red spring wheat; Divide, Mountrail, Lebsock, and Alkabo for durum wheat; Conlon, Prinnacle, CDC Copeland, and Rawson for two-row barley; and Stellar-ND, Tradition, Drummond, and Robust for six-row barley.

This study was conducted in the greenhouse under conditions previously described. In each 30.5-cm by 30.5-cm by 6.5-cm flat with drainage holes, 20 seeds of each cultivar in a crop species, along with 20 seeds of oat (*Avena sativa* L.) to confirm herbicide activity, were seeded in rows in commercial potting mix[1]. Two non-treated checks were included for each cultivar within a crop species and oat; one to determine a biomass baseline at herbicide application and a second as the experiment control. Plants were watered daily and fertilized as previously described to promote healthy growth. Crops were sprayed at the two-leaf growth stage with H13 at 100 or 400 g/ha plus oil adjuvant[3] at 1.17 L/ha in a spray chamber as previously described.

Visible injury evaluations were recorded 2 and 4 WAT on a 0 to 100 scale as previously described. Plants were harvested by cutting at soil surface 4 WAT. Tissue samples were dried at 49 °C for 4 d and dry biomass was measured.

The factors of this experiment subject to statistical analysis were two rates of H13 and four cultivars of each crop. Only cultivars within the same crop were compared. The experiment was established as a factorial, split-plot with the cultivars as the sub-plot factor and the herbicide treatment as the main plot factor. Four replicates were included and the experiment was repeated. Data were combined for analysis if variances of each run were determined similar by comparing mean square error values (within a factor of 10). Data for visible plant response and shoot dry biomass were subjected to analysis of variance in SAS. Mean squares were equated to expected mean to determine the correct denominator for each F-test. Experimental run was considered a random effect and cultivar and H13 rate were considered fixed effects. Means were separated by Fisher's protected LSD with α=0.05. Variances and degrees of freedom were calculated according to Carmer et al. (1989).

H13 Crop Tolerance under Field Conditions. The purpose of this study was to determine if H13 causes crop injury to hard red spring wheat, durum wheat, two-row barley, or six-row barley under field conditions. The chosen cultivars for this study were Faller hard red spring wheat, Lebsock durum, Pinnacle two-row barley, and Tradition six-row barley. This study was conducted at three locations: 1) North Dakota State University main research station in Fargo, ND; 2) cooperator field near Hillsboro, ND; and 3) cooperator field near St. Thomas, ND. The soil series at Fargo, ND was Fargo-Ryan silty clays (Fine, smectitic, frigid Typic Epiaquerts; Fine, smectitic, frigid Typic Natraquerts) which had a pH of 7.4, organic matter of 5% and CEC of 41 cmol(+)/100 kg. The soil series at Hillsboro, ND was Overly silty clay loam (Fine-silty, mixed, superactive, frigid Pachic Hapludolls) which had a pH of 7.2, organic matter of 7.1%, and CEC of 32 cmol(+)/100 kg. The soil series at St. Thomas, ND was a Glyndon silty loam (Coarse silty, mixed, superactive, frigid Aeric Calciaquolls) which had a pH of 8.0, organic matter of 2.8%, and CEC of 18 cmol(+)/100 g.

This study was established in a factorial split-block design with three replicates. The factors assigned to the whole plots were a factorial combination of herbicide treatment by application timing and the factor assigned to the sub-plots was crop species. A 1.5-m-wide strip each of hard red spring wheat at 101 kg/ha, durum wheat at 101 kg/ha, two-row barley at 80 kg/ha, six-row barley at 80 kg/ha, and oat at 72 kg/ha (to confirm herbicide activity) was seeded with a no-tillage drill[6] in each replicate (Table 1). The order of crop strips in each replicate was randomized within each replicate and location. Locations were fertilized to support spring cereal crop production practices standard for the location.

Table 1. Seeding, spraying, and harvest dates for H13 crop tolerance under field conditions study in 2011.

		Spray date		
Location	Planting date	PRE	POST	Harvest date
Fargo	May 26	May 26	June 20	September 7
Hillsboro	May 19	May 19	June 14	Aug 18 and Sept 7[a]
St. Thomas	May 19	May 19	June 16	September 6

[a]Maturity differences among species resulted in different harvest dates. Two-row and six-row barley were harvested August 18. Hard red spring wheat, durum wheat, and oat were harvested September 7.

Herbicide treatments were applied preemergence and at two-leaf stage of the crop using a CO_2-pressurized backpack sprayer with TT11001 nozzle tips[7] at 241 kPa that delivered 80 L/ha (Tables 1 and 2). Treatments were applied to an area of 3 m by 8 m in each main plot perpendicular to the direction of the crop seeding. The main plots, which included a combination of herbicide treatment by application timing levels, were 3 m wide by 8 m long. The dimensions of the sub-plots were 3 m wide by 1.6 m long.

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[6] Great Plains Mfg., Inc., 1525 E. North Street, Salina, KS 67401.

[7] Turbo Teejet, Spray Systems Co., P.O. Box 7900, Wheaton, IL 60189.

Visible crop injury was recorded 2, 4, and 6 WAT on a 0 to100 scale as previously described. Population estimates of crops were determined 2 weeks after preemergence herbicide treatments, before post emergence treatments, and at the end of the experiment. All plants in a 1 m sample of row were counted to calculate plant population. Crop plant height and grain yield also were recorded at the end of the growing season. Grain yield for each crop was harvested from a 3-m wide by 1.6-m long area with a small plot combine[8] (Table 2).

Table 2. Treatment list for cultivar tolerance under field conditions study.

Treatment[a]	Application timing	Rate
		-----g ai/ha----
H13	PRE	100
H13	PRE	200
Fenoxaprop &[b] bromoxynil & pyrasulfotole	PRE	91 & 197 & 41
Pinoxaden + bromoxynil & MCPA	PRE	60 + 560 & 280
Flucarbazone + clopyralid & fluroxypyr	PRE	22 + 105 & 105
H13	POST	100
H13	POST	200
Fenoxaprop & bromoxynil & pyrasulfotole	POST	91 & 197 & 41
Pinoxaden + bromoxynil & MCPA	POST	60 + 560 & 280
Flucarbazone + clopyralid & fluroxypyr	POST	22 + 105 & 105

[a] Syl-Tac adjuvant (Wilbur-Ellis, 345 California Street, San Francisco, CA 94104) at 1.17 l/ha was used with all H13 treatments and Quad 7 (Loveland Products, Inc., 3005 Rocky Mountain Ave, Loveland, CO 80538) at 1% v/v was used with all flucarbazone + clopyralid & fluroxypyr treatment.

[b] Symbols: “&” denotes premixed active ingredients and “+” denotes tank-mixed active ingredients.

The factors of this experiment subject to statistical analysis included the five herbicide treatments, the five crops, and the two herbicide application timings. Herbicide treatment and application timing factors were treated at the same level of precision. Data were combined for

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[8] Hege plot combine, Wintersteiger Co., Colwich, KS, 67030.

analyses if variances of each run were determined similar by comparing mean square error values (within a factor of 10). Data were subjected to analysis of variance in SAS. Mean squares were equated to the expected mean squares to determine the correct denominator for each F-test. Location was considered a random effect and herbicide treatment, crop, and herbicide application timing were considered fixed effects. Means were separated by Fisher's protected LSD with $\alpha=0.05$. Variances and degrees of freedom were calculated according to Carmer et al. (1989).

Weed Control Studies

H13 Weed Control Rate Response. A recommended rate of H13 has not been established. The purpose of the weed control rate response study was to produce a response curve to determine the minimum rate of H13 that achieved maximum control of wild oat and wild buckwheat at the two-leaf and four-leaf growth stages. This study was conducted in the greenhouse under conditions previously described.

Wild oat and wild buckwheat seeds were treated as previously described to promote even germination. Pots with water drainage holes measuring 15 cm by 10 cm by 5 cm were filled with commercial potting mix[1]. Ten weed seeds of one species were scattered across the surface of each pot and covered with 0.5 cm of media. Pots were watered daily and fertilized as previously described to stimulate healthy growth. Before herbicide treatment, plants were thinned to three weeds per pot for the experimental unit. Herbicide treatments included H13 at 0, 25, 50, 75, 100, 150, and 200 g/ha with an oil adjuvant[3] at 1.17 L/ha. Herbicide treatments were applied to wild oat and wild buckwheat at either the two-leaf or four-leaf stage in a spray chamber as previously described.

Visible weed injury was recorded 1, 2, and 4 WAT on a visual scale of 0 to 100 as previously described. For each weed by leaf stage combination, a non-treated check was harvested before herbicide application to determine a dry biomass baseline and at the end of the experiment to serve as a non-treated check. Plants were harvested 4 WAT by cutting at the soil surface. Tissue samples were dried at 49 °C for 4 d, and dry biomass weight was recorded.

The factors of this experiment that were subject to statistical analysis included seven rates of H13 and two growth stages. The experiment was established as a factorial, completely-randomized design with four replicates and the experiment was repeated twice. Data were combined across repetitions. A regression line for each weed at each growth stage was produced using a three-parameter log-logistic function curve package in R.2.14.2:

$$f(x, (b, d, e)) = \frac{d}{1 + \exp\{b(\log(x) - \log(e))\}}$$

(Ritz and Streibig 2006) and was used to estimate the 80% and 90% effective dose (ED_{80} and ED_{90}) of H13 to two- and four-leaf wild oat and wild buckwheat. Where parameter *d* is the upper asymptote limit and *e* denotes the dose half-way between upper and lower limit. The lower limit of a three-parameter logistic model is set at 0. Parameter *b* is the relative slope around *e.*

H13 Weed Control under Field Conditions. The purpose of this study was to compare weed control of H13 to standard industry herbicides under field conditions. Three wild oat locations and two wild buckwheat locations were identified. Natural infestations were desired so environmental weathering of seed would promote germination and eliminate the need for laboratory treatment of large seed volumes.

Plot locations for wild oat control were at cooperator fields near Crookston, MN; Nielsville, MN; and Hillsboro, ND. The soil series at Crookston, MN were Clearwater loam (Fine, smectitic, frigid Typic Epiaquerts) and Espelie fine sandy loam (Sandy over clayey, mixed over smectitic, frigid Typic Epiaquolls) with a pH of 7.3, organic matter of 5.3%, and a CEC of 28 cmol(+)/100 kg. The soil series at Nielsville, MN was Colvin silty clay loam (Fine-silty, mixed, superactive, frigid Typic Calciaquolls) with a pH of 7.7, organic matter of 5.3%, and CEC of 33 cmol(+)/100 kg. The soil series at Hillsboro, ND was Fargo silty clay (Fine, smectitic, frigid Typic Epiaquerts) with a pH of 6.8, organic matter of 7.0, and CEC of 47 cmol(+)/100 kg.

Plot locations for wild buckwheat control were at North Dakota State University campus at Fargo, ND and at a cooperator field near Hoople, ND. The soil series at Fargo, ND was Fargo silty clay with a pH of 7.1, organic matter of 6.8, and CEC of 44 cmol(+)/100 kg. The soil series at Hoople, ND was Glyndon silt loam with a pH of 7.8, organic matter of 4.9%, and CEC of 32 cmol(+)/100 kg. Locations were selected with large areas of natural infestation sufficient to encompass the entire experiment.

Hard red spring wheat was seeded and fertilized according to local recommendations for spring wheat production (Table 3). Each plot was 3 m wide by 10 m long. Plots were treated at the two- to three-leaf growth stage of the weeds with a backpack sprayer as previously described to the center 2 m the length of plots (Tables 3 and 4). Weed density was estimated before application at a level of 15 to 20 wild oat plants/m^2 at Crookston, five to 10 wild oat plants/m^2 at Nielsville, 10 wild oat plants/m^2 at Hillsboro, five to 10 wild buckwheat plants/m^2 at Fargo, and 10 to 15 wild buckwheat plants/m^2 at Hoople.

Table 3. Seeding, spray, and harvest dates for H13 weed control under field conditions in 2011.

Location	Targeted weed	Seeding date	Spray date	Harvest date
Crookston, MN	Wild oat	May 10	June 3	August 18
Nielsville, MN	Wild oat	May 18	June 3	August 23
Hillsboro, ND	Wild oat	May 18	June 14	-------------[a]
Hoople, ND	Wild buckwheat	May 26	June 16	August 30
Fargo, ND	Wild buckwheat	May 19	June 14	August 19

[a] Hillsboro location was not harvested due to excessive water damage.

Table 4. Treatment list for H13 weed control under field conditions study.

Treatment[a]	Rate
	----g ai/ha----
H13	75
H13	100
H13	150
Fenoxaprop &[b] bromoxynil & pyrasulfotole	91 & 197 & 41
Pinoxaden + bromoxynil & MCPA	60 + 560 & 280
Flucarbazone + clopyralid & fluroxypyr	22 + 105 & 105
Untreated	0

[a] Syl-Tac adjuvant (Wilbur-Ellis, 345 California Street, San Francisco, CA 94104) at 1.17 l/ha was used with all H13 treatments and Quad 7 (Loveland Products, Inc., 3005 Rocky Mountain Ave, Loveland, CO 80538) at 1% v/v was used with flucarbazone + clopyralid & fluroxypyr treatment.

[b] Symbols: “&” denotes premixed active ingredients and “+” denotes tank mixed active ingredients.

Visible weed control and crop injury evaluations were recorded on the 0 to 100 scale as previously described at 2, 4, and 6 WAT. At the end of the experiment, wild oat and wild buckwheat samples were harvested from each plot by cutting plants at the soil surface. Wild oat was harvested from two 0.5-m² quadrats and wild buckwheat was harvested from two 1-m² quadrats in each plot. Tissue samples were dried at 49 °C for 4 d, and 1000 weed seed weights and biomass weights were recorded.

Spring wheat was harvested from the center 1.5 m by the length of each plot with a plot combine[8] to determine crop yield (Table 3). All fields were harvested except the wild oat location near Hillsboro, ND which suffered severe water damage.

The factor of this experiment that was subject to statistical analysis was the seven herbicide treatments. This experiment was established as a randomized, complete-block design with three replicates. Data were combined for analysis if variances of each location were determined similar by comparing mean square error values (within a factor of 10). Location was considered a random effect and herbicide treatment was considered a fixed effect. Data for visible plant response and shoot dry biomass were subjected to analysis of variance in SAS. Means were separated by Fisher's protected LSD with $\alpha=0.05$.

RESULTS AND DISCUSSION

Formulation Comparison Study

The purpose of this greenhouse study was to compare the activity of H13 in the WG formulation with H13 in the SC formulation. The plant species included in this study were hard red spring wheat, durum wheat, two-row barley, six-row barley, oat, and wild mustard. Visible response and dry weight accumulation were similar within species between H13 formulations and among H13 rates. Hard red spring wheat p-values for comparing dry weights among H13 rates and between formulations were 0.59 and 0.79, respectively; durum wheat ANOVA table p-value for dry weights was 0.22; two-row barley p-values for comparing dry weights among H13 rates and between formulations were 0.34 and 0.76, respectively; six-row barley p-values for comparing dry weights among H13 rates and between formulations were 0.18 and 0.16, respectively; wild mustard p-values for comparing dry weights among H13 rates and between formulations were 0.12 and 0.89, respectively; and oat p-values for comparing dry weights among H13 rates and between formulations were 0.14 and 0.06, respectively; (data not shown).

The SC formulation of H13 was used in all of the greenhouse studies and the weed control study under field conditions and the WG formulation of H13 was used for the crop safety study under field conditions. Final conclusions of this project should not be influenced by the characteristics of the H13 formulation used.

H13 Site of Entry

Error mean squares for each repetition were homogeneous for wild oat and wild buckwheat data sets. The plants sprayed at the two-leaf stage will be referred to as the established plants and plants resulting from seeds planted the same day as H13 application will be referred to as seedlings. Non-significant main factors, non-significant interactions, and interactions due to magnitude differences will not be discussed. Main factors will be discussed only if interactions between the main factors were non-significant.

Injury to established wild oat by all three application methods tended to increase over time (Figure 1). Visual injury to wild oat with H13 included stunting and chlorotic leaf margins on the newer leaf tissue. At all three visible injury evaluation dates, established wild oat plants treated with H13 applied foliar only or foliar plus soil developed more injury than plants treated with H13 applied to soil only. It should be noted despite the low injury rating, established wild oat were still affected by H13 applied soil only. Injury ratings of wild oat seedlings among H13 rates averaged across application method and soil type were similar at all evaluation dates (p-value 1 WAT = 0.59, 2 WAT = 0.15, and 4 WAT = 0.14).

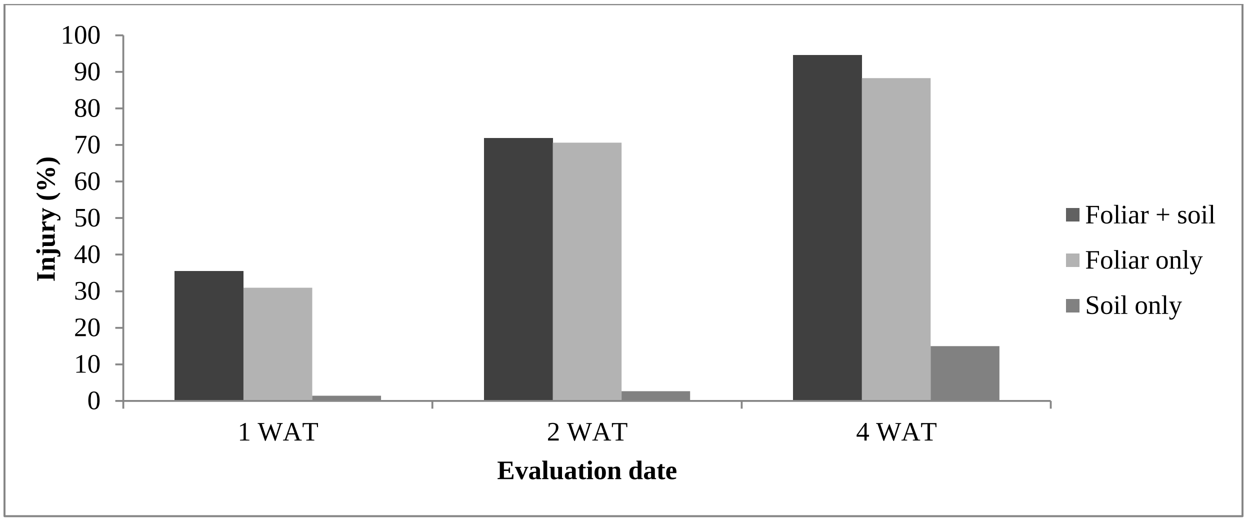

Figure 1. Established wild oat plants visible injury evaluations averaged across H13 rate and soil type 1, 2, and 4 WAT. Means separated by F-protected LSD at α=0.05. 1 WAT LSD=12, 2 WAT LSD=22, and 4 WAT LSD=29.

Visible injury of established wild buckwheat plants tended to reflect visible injury ratings of established wild oat plants. However, visible evaluations for herbicide application method to established wild buckwheat were only different 1 WAT and 4 WAT. Visual injury to wild buckwheat from H13 included stunting and bleached leaf margins on the newer leaf tissue. There was a three-way interaction between soil type, application method, and herbicide rate for the visual evaluation 2 WAT of established wild buckwheat due to magnitude differences that probably confounded differences among the main effects. Established wild buckwheat plants treated with H13 applied either foliar plus soil or foliar only developed more injury than plants treated soil only 1 WAT and 4 WAT regardless of H13 rate (Figure 2).

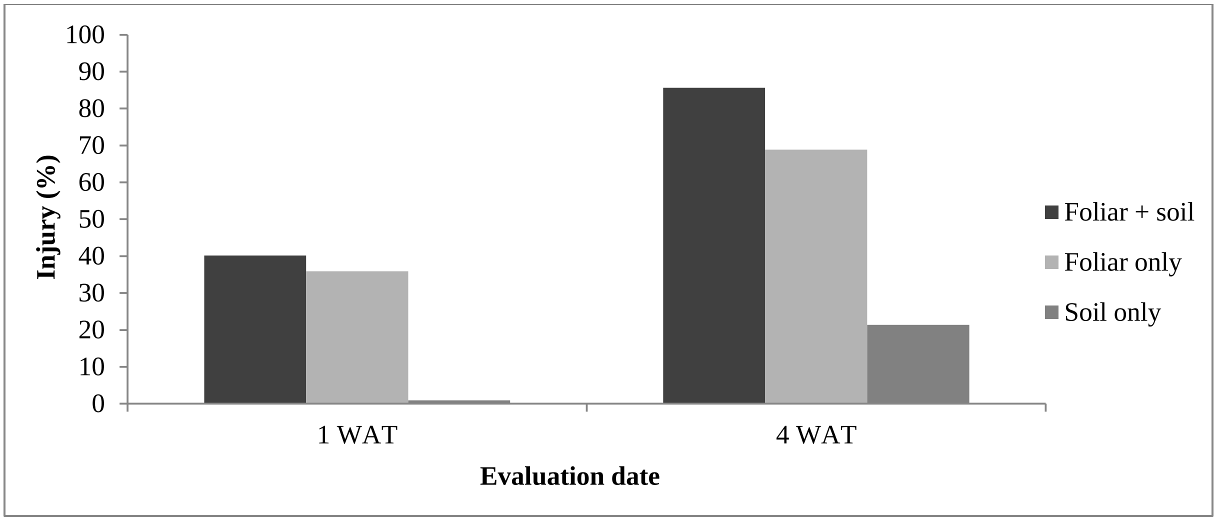

Figure 2. Visual difference of wild buckwheat in herbicide application method 1 and 4 WAT. Means separated by F-protected LSD at α=0.05. 1 WAT LSD=9 and 4 WAT LSD=6.

Dry weights of established wild oat and wild buckwheat plants demonstrated similar results to visual evaluations. There was an interaction between herbicide application method and H13 rate for both established wild oat and wild buckwheat dry weights because plants treated foliar only or foliar plus soil with either H13 at 50 g/ha or 100 g/ha produced less biomass than the untreated plants while plants treated soil only produced similar biomass to the untreated plants regardless of H13 rate (Figure 3 and 4).

Visible injury evaluations and dry weights demonstrated H13 entry into the foliage of established wild oat and wild buckwheat plants is important for H13 activity. Established wild oat and wild buckwheat plants responded similarly to H13 regardless if applied at the 50 g/ha or 100 g/ha rate. The labeled rate of H13 has not been established but the potential field rate of H13 is 100 g/ha. This study shows there is a potential of good H13 activity on wild oat and wild buckwheat even with a rate as low as 50 g/ha, one half the potential field rate. A rate response curve study was conducted to investigate the optimal rate of H13 for weed control and will be discussed later.

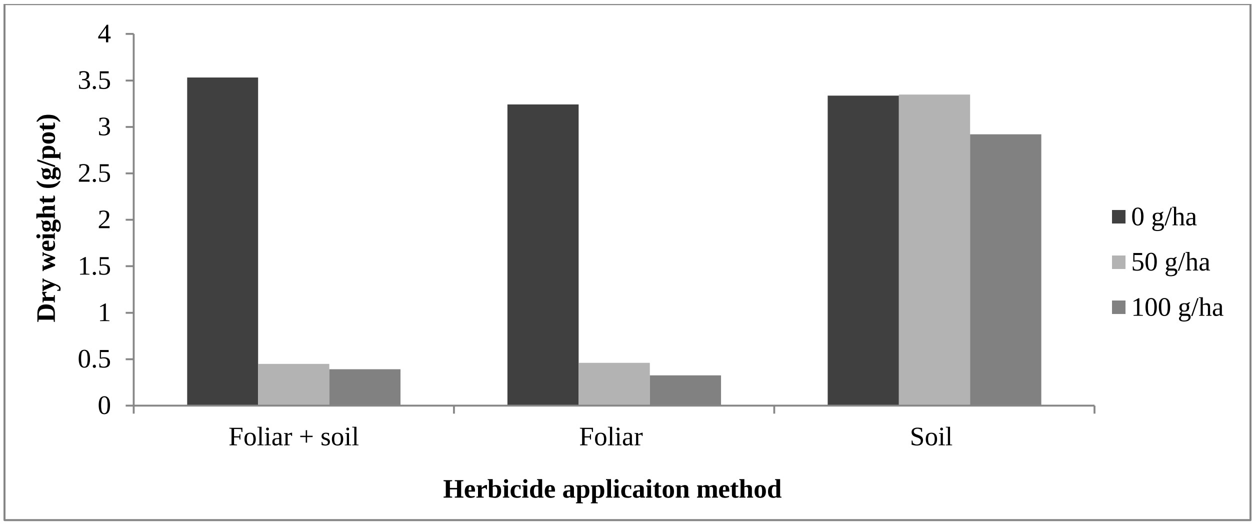

Figure 3. Herbicide application method by herbicide rate interaction for dry weight of established wild oat plants. Means separated by F-protected LSD at α=0.05. To compare different herbicide rates within the same herbicide application method LSD=1.6. To compare different herbicide application method within the same herbicide rate LSD=0.9. To compare any two points LSD=0.5.

H13 also affected wild oat seedlings. There were differences among dry weights of wild oat seedlings but visible injury (p-value for herbicide rate, soil type, and application method were 0.42, 0.32, and 0.15, respectively) and germination rates (p-value of herbicide rate, soil type, and application method were 0.17, 0.32, and 0.07, respectively) were similar among all factors. There was an interaction between herbicide application method and herbicide rate for dry weight of wild oat seedlings (Figure 5). Within a herbicide rate, biomass of the wild oat seedlings was reduced when H13 was applied soil only or foliar plus soil indicating H13 did have activity on wild oat seedlings. Biomass reduction was similar between H13 at 50 and 100 g/ha within the same herbicide application method. Wild oat seedlings treated with foliar only applied H13 produced similar biomass as the untreated plants. This confirms H13 was absorbed by the activated charcoal placed on the soil surface and was not allowed to enter into the soil of the foliar only treated pots.

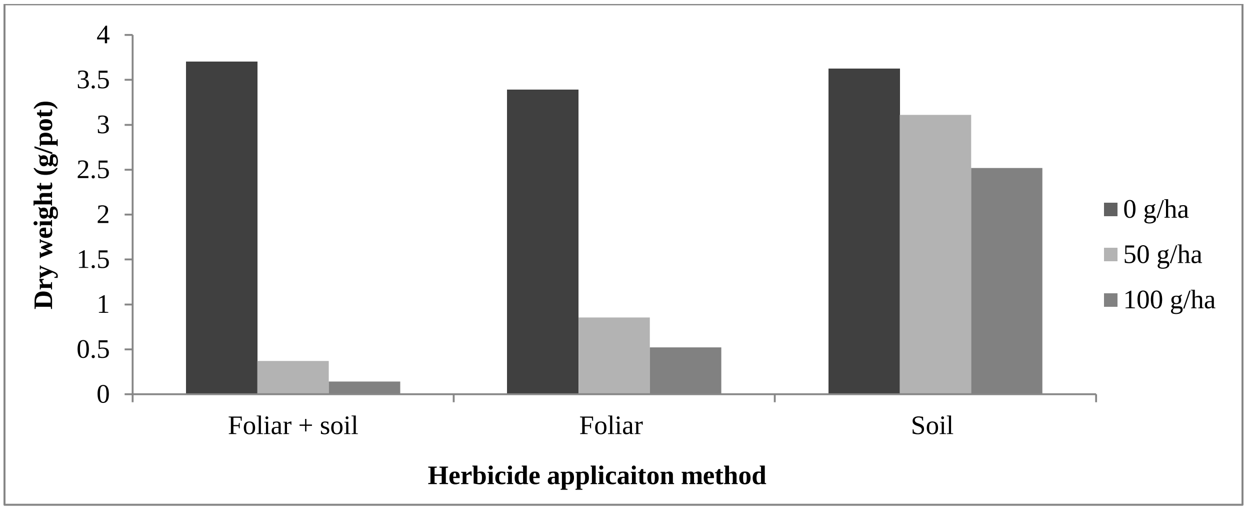

Figure 4. Herbicide application method by herbicide rate interaction for dry weight of established wild buckwheat plants. Means separated by F-protected LSD at α=0.05. To compare different herbicide rates within the same herbicide application method LSD=1.1. To compare different herbicide application method within the same herbicide rate LSD=0.2. To compare any two points LSD=0.3.

Conclusions could not be made about the effect of H13 to wild buckwheat seedlings. Although attempts were made to promote even wild buckwheat germination by scarification, the germination was still highly variable and at the time of wild buckwheat seedling germination, the established wild buckwheat plants were at the vining stage which shaded out the seedlings in pots where the established wild buckwheat plants were not controlled. The shading competition from the established wild buckwheat plants resulted in death of wild buckwheat seedlings prior to development of H13 injury symptoms.

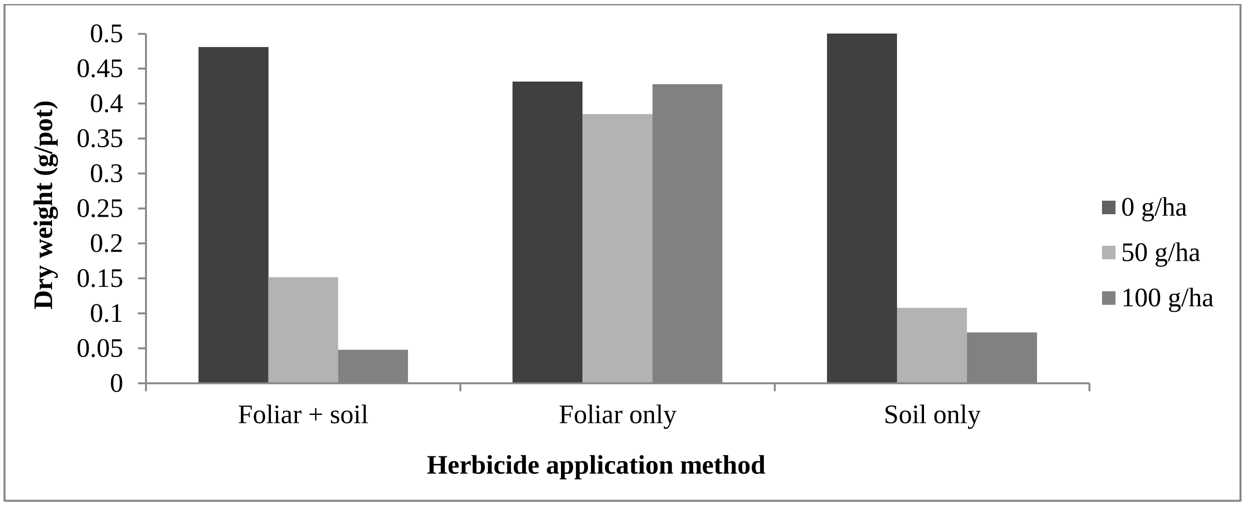

Figure 5. Herbicide application method by herbicide rate interaction for dry weight of wild oat seedlings. Means separated by F-protected LSD at α=0.05. To compare different herbicide rates within the same herbicide application method LSD=0.22. To compare different herbicide application method within the same herbicide rate LSD=0.02. To compare any two points LSD=0.05.

The major site of entry for H13 activity is through the shoots. This would explain why H13 applied to the soil only had activity on germinating seedlings but little effect on established plants. Established wild oat and wild buckwheat plants showed the most injury when H13 was absorbed through the foliage. Wild oat seedlings could absorb H13 into the shoot tissue during emergence. Activity of other soil applied herbicides has been confirmed through emerging shoot tissue rather than root tissue of seedlings (Parker 1965). Also in general, plant root absorption of a herbicide is influenced by soil properties but established wild oat and wild buckwheat plants and wild oat seedling biomass production was similar between the Glyndon silt loam soil and the Lanona-Swenoda fine sandy loams soil (p-values were 0.25, 0.16, 0.68, respectively). The soil texture, pH, and CEC were different between the soil types but organic matter was similar. Either soil type does not influence absorption of H13 through the shoots or organic matter has an overriding influence in H13 absorption. The crop tolerance study under field conditions evaluated crop tolerance of PRE applied H13 at three locations with different soil properties. The influence of soil type on H13 activity will be discussed further in this study.

It is highly unlikely the lack of response from soil applied H13 was due to H13 unavailability to the established plant and seedling roots. It is doubtful H13 was tightly bound to or neutralized by soil particles because activity was observed on wild oat seedlings. If H13 was highly mobile, it would have only been able to move within the soil in the pot because leaching of H13 from each pot was prevented by the plastic bag liner in each pot. At some point, H13 probably came in contact with both the seedling and established roots because root mass explored the entire soil volume before experiment termination. Some possibilities explaining lack of H13 effect through the roots could be lack of an absorption mechanism, barriers to root absorption based on chemical properties, the site of action is not in the roots and translocation to the site-of-action is limited, or metabolism occurs rapidly in roots (Shimabukuro et al 1970). Identification of the actual cause for inactivity of H13 through root exposure would require additional research.

Crop Safety Experiments

Greenhouse Cultivar Screening. Oat was included in this study as a susceptible species to confirm herbicide activity; therefore, oat was not analyzed with the data to prevent skewed comparisons among cultivars. Non-significant main factors, non-significant interactions, and interactions due to magnitude differences will not be discussed. Main factors will only be discussed if interactions between the main factors were non-significant. Visually, cultivars within the same crop sprayed with the same rate of H13 responded similarly (two-row barley, six-row barley, and hard red spring wheat p-value=0.5 and durum wheat p-value=1.0). One cultivar within the same crop did not sustain noticeably more injury than another. Two-row barley, six-row barley and durum wheat sprayed with H13 at 400 g/ha appeared to express more injury than when sprayed with H13 at 0 or 100 g/ha when averaged across cultivar. The visual crop injury symptoms caused from H13 were stunting and chlorosis that started at the leaf tips of newer leaf tissue. Hard red spring wheat did not appear to be influenced by H13 rate (data not shown).

Cultivar dry weights of hard red spring wheat, durum wheat, two-row barley, and six-row barley reflected similar results to visual evaluations. Dry weights of hard red spring wheat plants were similar when averaged across cultivar or H13 rate but dry weight differed among two-row barley, six-row barley, and durum wheat plants.

H13 rate affected durum growth while all cultivars produced similar biomass. Durum wheat sprayed with H13 at 400 g/ha produced less biomass than durum wheat sprayed with 100 g/ha of H13 or the untreated (Figure 6). Durum wheat treated with 100 g/ha produced similar biomass to the untreated control indicating durum wheat could have good crop tolerance to H13. This will be investigated further in the crop tolerance study under field conditions.

Two-row barley biomass was similar within the same H13 rate. However, dry weights of two-row barley cultivars were different averaged across herbicide rate. ‘Rawson’ produced 0.5 to 0.7 g more biomass than the other two-row barley cultivars (data not shown). There was not an interaction between cultivar and H13 rate; therefore, two-row barley cultivars responded similarly when sprayed with the same rate of H13. Biomass production difference of two-row barley cultivars was due to growth characteristic differences among cultivars rather than response differences to H13 (Bailey et al. 2004).

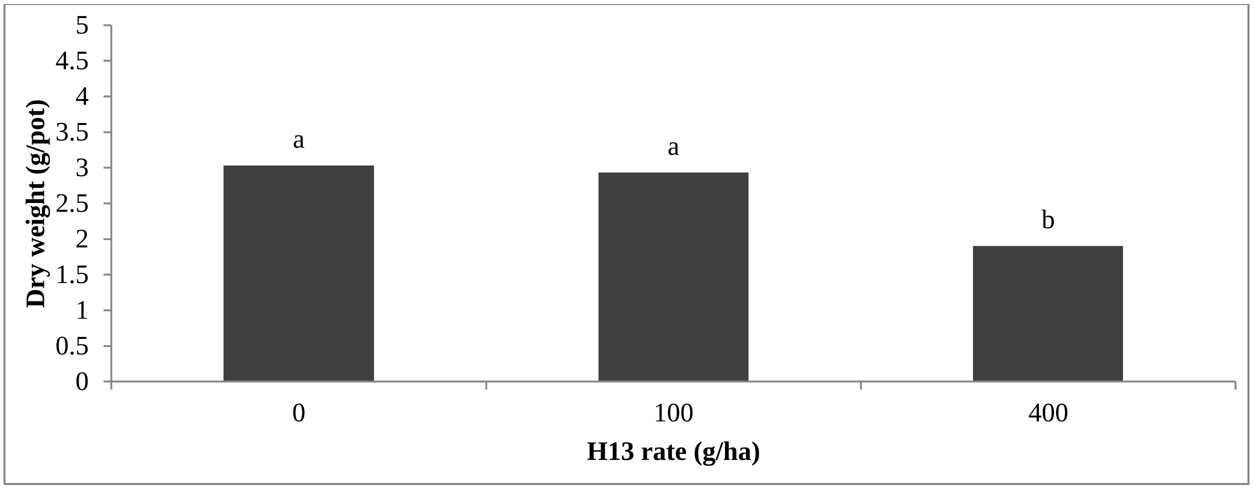

Figure 6. Dry weights of durum wheat averaged across cultivar. Means separated by F-protected LSD. Bars with same letter are similar α=0.05. LSD=0.7.

Dry weights of six-row barley were different when averaged across either cultivar or rate. There was not an interaction between H13 rate and six-row barley cultivars, indicating each cultivar responded similarly when treated with a rate of H13. Six-row barley treated with either 100 g/ha or 400 g/ha of H13 produced less biomass than untreated six-row barley (Figure 7).

Six-row barley could be the most sensitive spring cereal crop to H13. This will be tested further under field conditions.

Herbicide rate rather than cultivar has been more important when considering crop tolerance to a herbicide. Hageman and Behrens (1981) found differences among spring wheat, barley, and oat cultivar tolerances to POST applied chlorsulfuron in a greenhouse experiment when a rate of 50 times more than the labeled rate was used. This difference, however, was not observed under field conditions when a rate of about four and eight times the labeled rate was used. Although differences among cereal crop cultivars were found when treated with chlorsulfuron, it was a rate that that was higher than registered or allowed by the label.

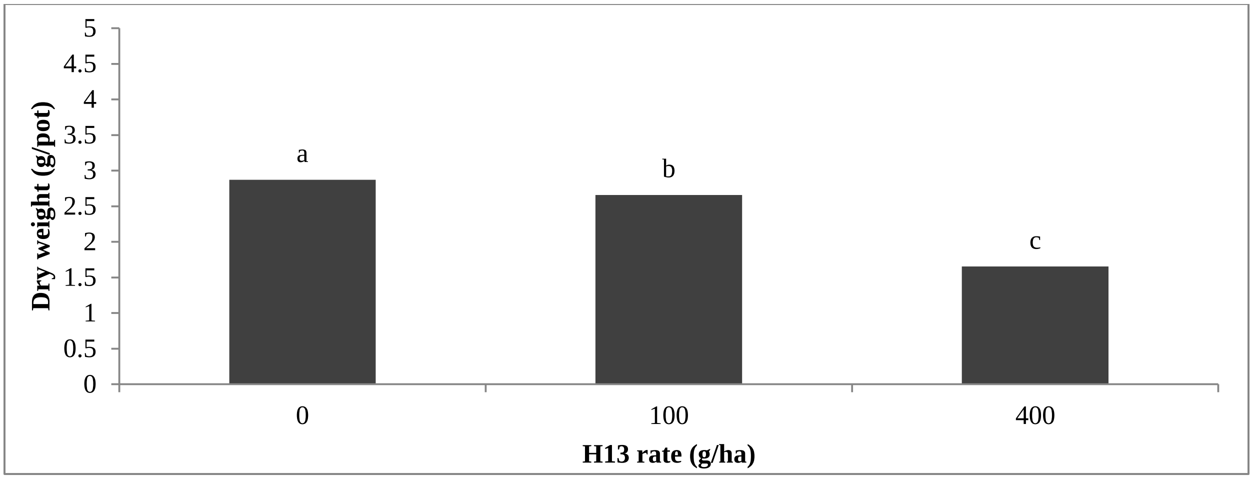

Figure 7. Dry weights of six-row barley averaged across cultivar. Means separated by F-protected LSD. Bars with same letter are similar at α=0.05. LSD = 0.2.

Similar results were found with H13 in this study. The potential field rate of H13 is 100 g/ha; thus, 400 g/ha of H13 is about four times the potential field rate. Differences among hard red spring wheat, durum wheat, two-row barley, and six-row barley cultivars were not found when treated with up to four times the potential field rate of H13. The crop tolerance study under field conditions will focus on the influence of H13 rate rather than crop cultivar to determine crop tolerance of hard red spring wheat, durum wheat, two-row barley, and six-row barley to H13.

Crop Tolerance in Field. The cultivars chosen for the crop safety field study were Faller for hard red spring wheat, Lebsock for durum wheat, Pinnacle for two-row barley, and Tradition for six-row barley. Oat was included in this study to confirm herbicide activity; thus, data was analyzed without oat to obtain more precise comparisons of H13 crop tolerance among hard red spring wheat, durum wheat, two-row barley, and six-row barely. Collectively, herbicide treatments fenoxaprop and bromoxynil and pyrasulfotole, pinoxaden plus bromoxynil and MCPA, and flucarbazone plus clopyralid and fluroxypyr will be referred to as the industry standard herbicide treatments. However, flucarbazone should not be considered a standard herbicide treatment for barley. Flucarbazone is only labeled for use in hard red spring and durum wheat because of unacceptable injury to barley; therefore, similar injury to barley as with flucarbazone should not be considered acceptable. Visible crop injury acceptable by the herbicide market is less than 15 to 20% and varies by company.

When PRE and POST applied herbicides were analyzed together for plant height, plant populations, and yield, an interaction between PRE and POST herbicides confounded the main effects of herbicide treatment and crop. Therefore, PRE and POST applied herbicide applications were analyzed separately to determine more precise comparisons among herbicide treatments and crop within an application timing. Plant height, plant population, and yield data were calculated as a percentage of pinoxaden plus bromoxynil and MCPA values to standardize values across crops and eliminate differences among crops due to natural growth differences of the crops. Standardized data was analyzed without pinoxaden plus bromoxynil and MCPA as it was the defined standard. Not all locations were combinable for all data sets. Non-combinable locations will be discussed separately. Non-significant main factors, non-significant interactions, and interactions due to magnitude differences will not be discussed. Main factors will only be discussed if interactions between the main factors were non-significant.

PRE Applied Herbicides. Crop injury was not observed 2 WAT at St. Thomas and Hillsboro with any herbicide treatment for any crop; however, crop injury was evident at Fargo and there was an interaction between herbicide treatment and crop (Figure 8). At Fargo, H13 at 100 g/ha caused similar minimal crop injury to hard red spring wheat and durum wheat but caused more injury to two-row and six-row barley than the three industry standard herbicide treatments. H13 at 200 g/ha caused more injury to each crop than any of the other PRE herbicide treatments at Fargo 2 WAT.

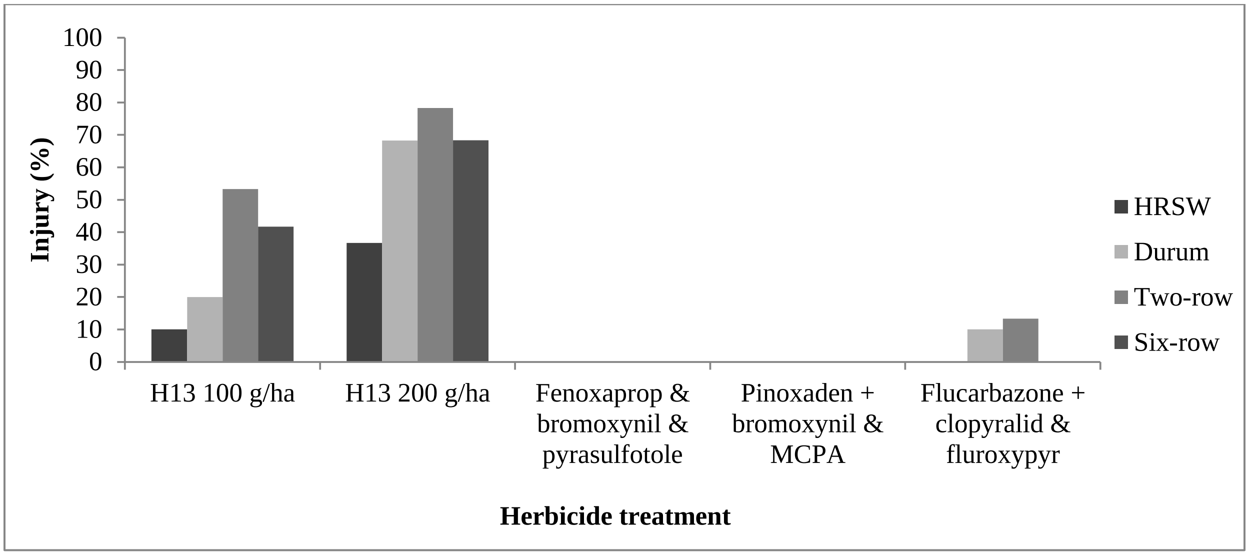

Figure 8. Herbicide by crop interaction 2 weeks after PRE herbicide application at Fargo. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=21. To compare different crops within the same herbicide LSD=18. To compare any two points LSD=25.

Although all crops showed tolerance to H13 PRE at St. Thomas and Hillsboro, the crop injury observed at Fargo shows under certain conditions PRE applications of H13 can cause severe crop injury. The explanation why crop injury was observed at Fargo but not at the other locations 2 WAT of PRE herbicide applications has not been determined. Differences in soil properties among the three locations do not seem sufficient to explain the difference in H13 activity among locations (Table 5). The pH and organic matter at the Fargo locations was intermediate between the values of the St. Thomas and Hillsboro locations. The Fargo location had considerably greater clay content, lesser sand content, and a greater CEC than the other locations. However, soils with such large amount of clay content and a large CEC, herbicides generally tend to bind herbicides more readily to soil particles and are usually less available to plants which should result in less PRE crop response rather than more response (Kerr et al. 2004).

Table 5. Soil properties of locations in the crop tolerance under field conditions study.

Location	pH	CEC[a]	Organic matter	Sand	Silt	Clay
		meq/100 g	----------------------------------	----------(%)----------	----------------------------------	
St. Thomas	8.0	18	2.8	22.5	46.3	31.2
Hillsboro	6.8	32	7.1	40	12.5	47.5
Fargo	7.4	41	5.0	0	25	75

[a] Cation exchange capacity determined by the NDSU Soil Testing Laboratory using the Na-NH4 exchange method.

Rainfall could have influenced the variability in crop response at the different locations but also does not seem to explain the difference in H13 activity among locations. Within five days after PRE herbicide applications, St. Thomas received 3.71 cm of rain, Hillsboro received 2.41 cm of rain, and Fargo received 3.99 cm of rain (NDAWN 2012). Of the rain received, 2.51 cm of rain at Fargo and 3.66 cm of rain at St. Thomas was received within a 24 h period.

Therefore, if a large precipitation event influenced crop injury level, crops at St. Thomas should have expressed substantial injury as well. More research should be conducted to investigate the factors that influence the crop response to H13 applied PRE.

Visual evaluation data for locations 4 and 6 WAT were combinable. Crop injury did not differ by species or herbicide treatment when averaged across locations (p-values were 0.27 and 0.22, respectively). Large differences in treatment ratings within and among location were recorded. Crop injury averaged across crop and herbicide treatment was 15%, 6%, and 34% at St. Thomas, Hillsboro, and Fargo, respectively.

Crop injury of plants treated with H13 tended to decrease from 2 WAT to 6 WAT while crop injury caused by flucarbazone plus clopyralid and fluroxypyr tended to increase at all locations. There was an interaction of PRE applied herbicides between herbicide treatment and crop when averaged across locations 6 WAT (Figure 9). When compared within the same crop, all crops treated with H13 at 100 g/ha responded similar to plants treated with the industry standard treatments of fenoxaprop and bromoxynil and pyrasulfotole, and pinoxaden plus bromoxynil and MCPA. H13 at 200 g/ha caused more crop injury to hard red spring wheat and durum wheat than any other herbicide treatment and caused similar unacceptable damage to two-row and six-row barley as flucarbazone plus clopyralid and fluroxypyr. The viability of H13 as a PRE herbicide is questionable because all crops treated with H13 at 200 g/ha PRE produced greater than 20% injury response. Barley response to H13 applied at the 200 g/ha rate was very similar to flucarbazone, which is known to cause unacceptable injury to barley.

Plant height with PRE applied herbicides showed comparable results to the visual evaluations. Locations were not combinable for plant heights of PRE applied herbicides.

Significant differences were found at St. Thomas and Fargo but plant heights at Hillsboro were similar (p-value=0.53).

The herbicide treatment and crop factors both were significant at St. Thomas. Not surprisingly, plants treated with flucarbazone plus clopyralid and fluroxypyr were shorter than plants treated with the other herbicide treatments when averaged across crops (Figure 10), and when averaged across herbicide treatment, six-row barley was one crop that was shorter than the control (Figure 11). However, hard red spring wheat also was shorter than the control even though hard red spring wheat visibly responded the least to the herbicide treatments (Figure 9). Plant height results may be slightly different from visual evaluations because visible injury estimates included plant discoloration and plant vigor differences as well as plant height differences.

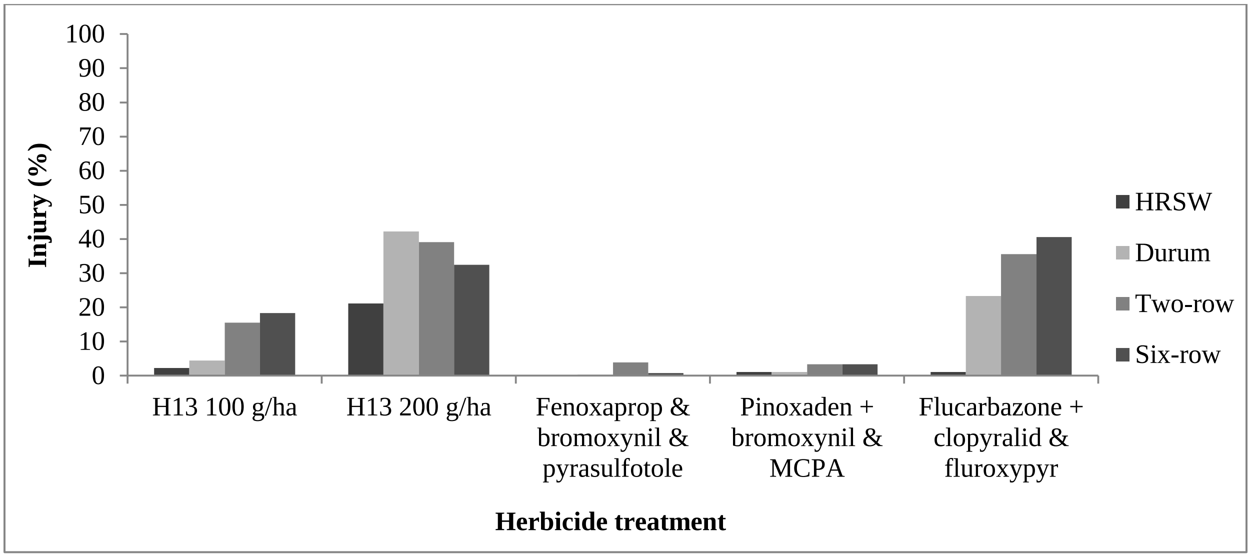

Figure 9. Herbicide by crop interaction 6 weeks after PRE herbicide application averaged across locations. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=32. To compare different crops within the same herbicide LSD=15. To compare any two points LSD=33.

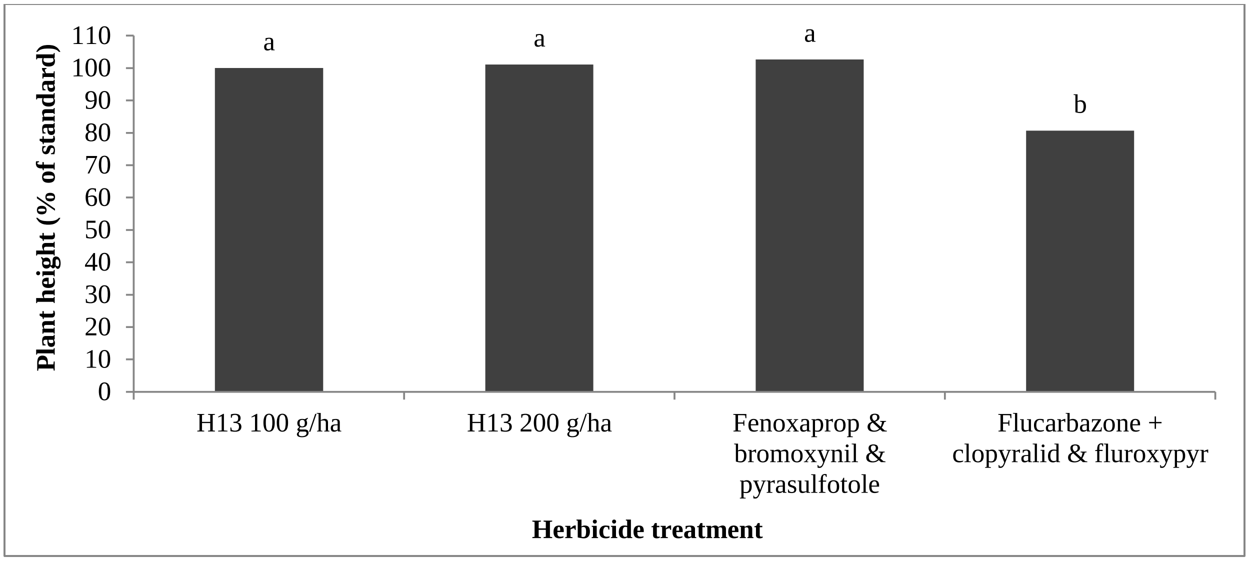

Figure 10. Plant heights of PRE herbicide treatments averaged across crop at St. Thomas. Means separated with F-protected LSD. Bars with same letter are similar at α=0.05. LSD=9.

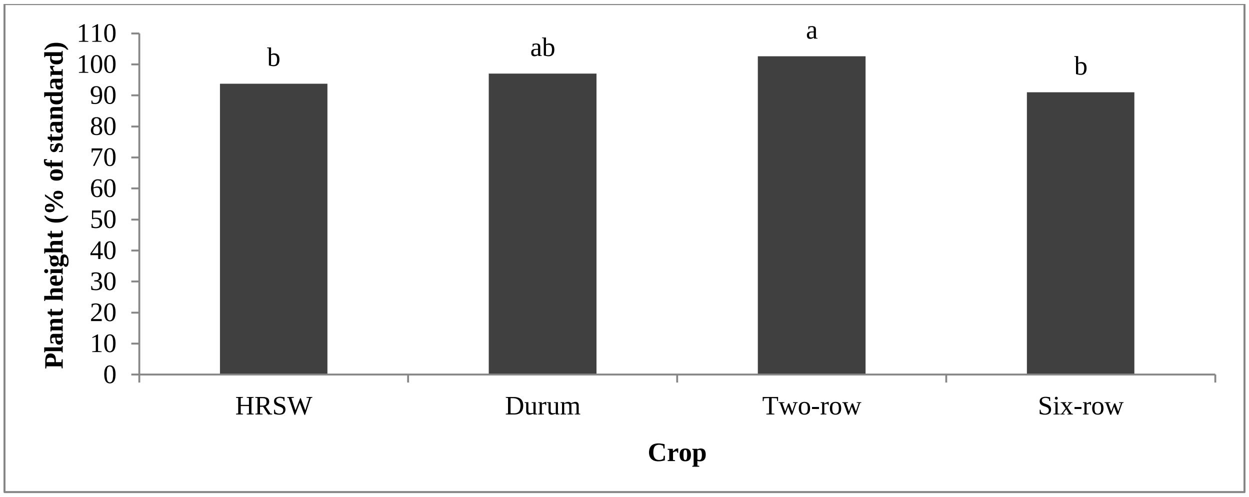

Figure 11. Plant height of PRE treatments averaged across herbicide treatment at St. Thomas. Means separated with F-protected LSD. Bars with same letter are similar at α=0.05. LSD=8.

Herbicide treatment and crop were also significant main effects at Fargo for plant heights. However, at Fargo, heights of plants treated with H13 at 200 g/ha were the shortest based on height of the standard when averaged across crop (Figure 12) and durum wheat and six-row barley height were less than the control when averaged across herbicide treatment (Figure 13). Six-row barley plant height was consistently one of the most affect by these herbicides.

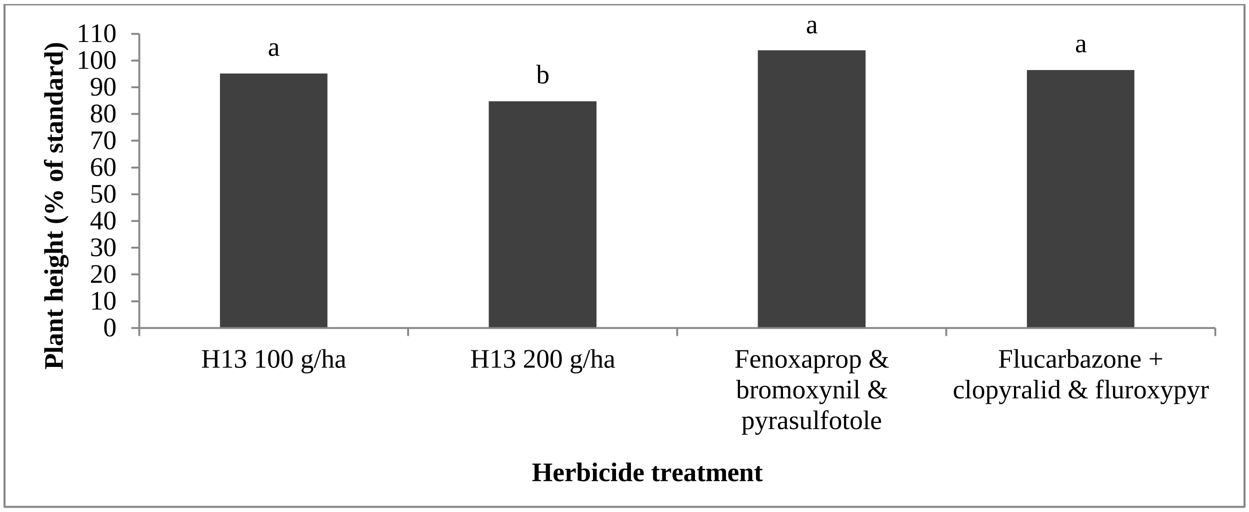

Figure 12. Plant height of PRE herbicide treatments averaged across crop at Fargo. Means separated with F-protected LSD. Bars with same letter are similar at α=0.05. LSD=10.

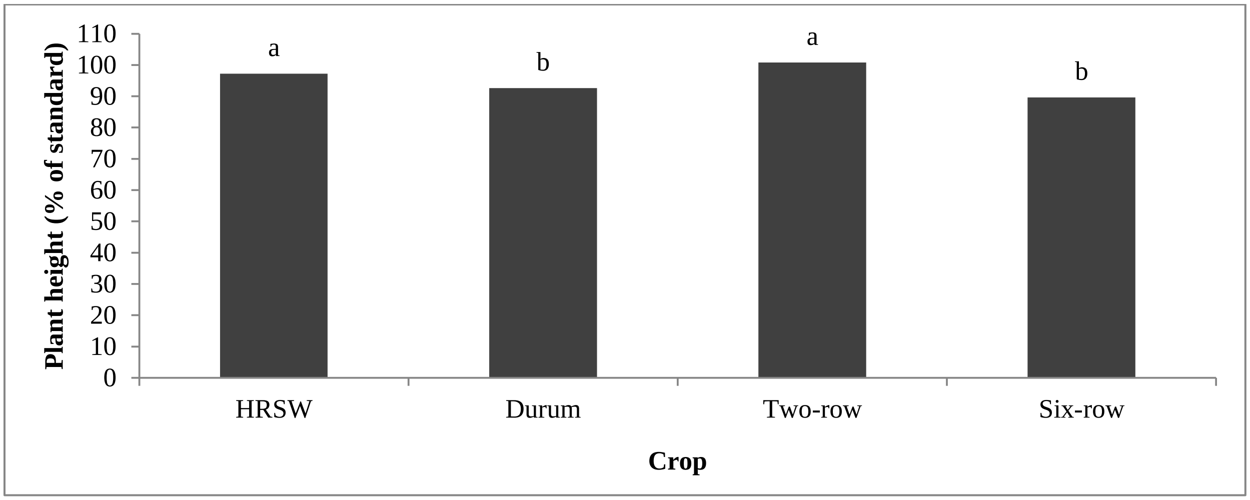

Figure 13. Plant height of PRE treatments averaged across herbicide treatment at Fargo. Means separated with F-protected LSD. Bars with same letter are similar at α=0.05. LSD=4.

Despite significant differences among visible injury rates and plant height measurements, plant populations of crops treated with PRE applied herbicides were similar 2 WAT (p-value for crop=0.84 and p-value for herbicide treatment=0.86) and at the end of the experiment (p-value for crop=0.98 and p-value for herbicide treatment=0.94). Yield was similar among herbicide treatments and crop treated with PRE applied herbicides despite noted injury and height reduction (p-value for crop=0.39 and p-value for herbicide treatment=0.7).

Although visible crop injury was statistically similar to the industry standard herbicides 6 WAT, H13 at 100 g/ha caused 16% and 18% crop injury to two-row and six-row barley, respectively, which may be more injury than may be accepted by the industry (Figure 9). Chemical companies consider marketing a product if 15% to 20% or less crop injury is observed when the product is applied at twice the labeled application rate. Although there may not be yield loss with 15 to 20% visible crop injury, the injury may deter producers from using the product. The crop injury caused by H13 at 200 g/ha PRE was not acceptable for any of the crops evaluated using the 20% injury threshold. This also is a concern because unintentional application of herbicides at a 2X rate, which is potentially H13 at 200 g/ha, happens either by overlapping spray passes or misapplication. Based on this research, H13 caused excessive crop injury to be marketed as a PRE herbicide. However, the soil activity of H13 may be a good quality for controlling weeds that emerge after H13 is applied POST. If H13 is effective at controlling weeds under field conditions, producers could achieve good control of the emerged weeds at application time and could prevent the establishment of new weeds. This would provide a producer season-long weed control with one herbicide application.

POST Applied Herbicides. Locations were not combinable for POST applied herbicide visible injury ratings 2 and 4 WAT but were combinable 6 WAT. There was an interaction between herbicide treatment and crop factors at each evaluation date.

Only flucarbazone plus clopyralid and fluroxypyr caused crop injury greater than the control at St. Thomas 2 WAT (Figure 14). Crop injury with flucarbazone to two-row and six-row barley was expected as flucarbazone is not labeled for barley. H13 at either 100 or 200 g/ha did not injure any crop species at St. Thomas.

Crop injury from POST herbicides 2 WAT tended to be greatest at Hillsboro compared to St. Thomas and Fargo. Crop injury with H13 at 100 g/ha at Hillsboro was similar to all three industry standard herbicides on hard red spring wheat and durum wheat and was similar to fenoxaprop and bromoxynil and pyrasulfotole, or pinoxaden plus bromoxynil and MCPA for two-row and six-row barley (Figure 15). H13 at 200 g/ha caused more injury to durum wheat than all three industry standards and caused more injury to two-row and six-row barley than fenoxaprop and bromoxynil and pyrasulfotole, or pinoxaden plus bromoxynil and MCPA.

Flucarbazone plus clopyralid and fluroxypyr was the only herbicide treatment to cause injury at Fargo (Figure 16). Flucarbazone caused injury to two-row and six-row barley which was expected. All crop species showed good tolerance to H13 at Fargo at both the 100 and 200 g/ha rates.

Visible crop injury with POST herbicides 4 WAT tended to follow the same pattern as visual evaluations 2 WAT of POST herbicides by location. Little to no crop injury was observed at St. Thomas and Fargo with H13 at 100 g/ha, H13 at 200 g/ha, fenoxaprop and bromoxynil and pyrasulfotole, or pinoxaden and bromoxynil plus MCPA (Figures 17 and 18). Flucarbazone caused substantial injury to two-row and six-row barley 4 WAT at St. Thomas and Fargo, which was expected.

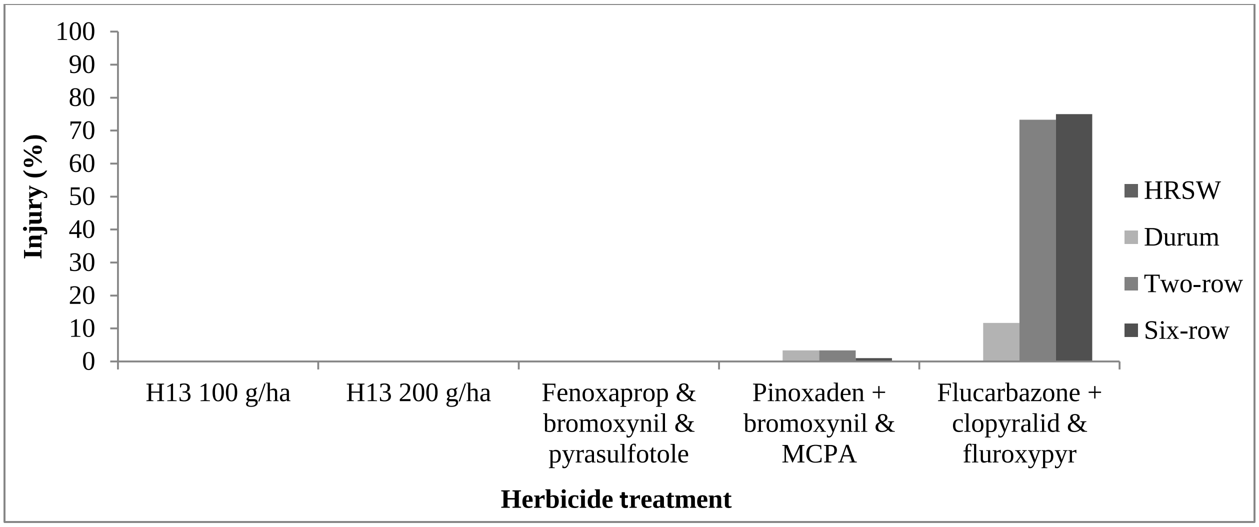

Figure 14. Herbicide by crop interaction 2 weeks after POST herbicide application for visible crop injury at St. Thomas. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=4. To compare different crops within the same herbicide LSD=3. To compare any two points LSD=6.

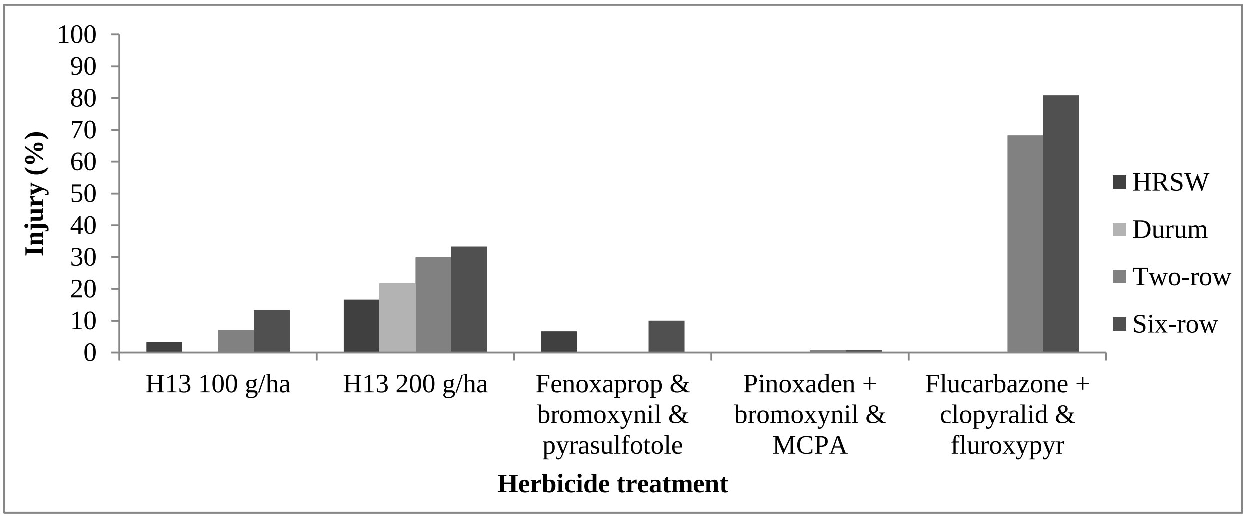

Figure 15. Herbicide by crop interaction 2 weeks after POST herbicide application at Hillsboro. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=32. To compare different crops within the same herbicide LSD=15. To compare any two points LSD=33.

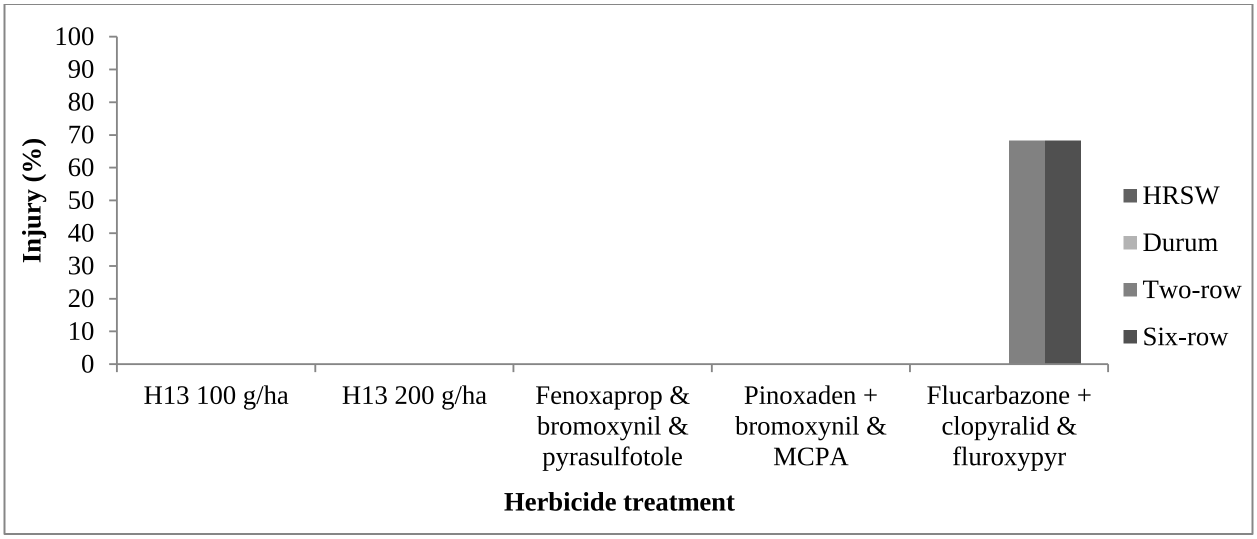

Figure 16. Herbicide by crop interaction 2 weeks after POST herbicide application at Fargo. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=2. To compare different crops within the same herbicide LSD=1. To compare any two points LSD=2.

Hard red spring wheat or durum wheat produced very minor herbicide injury response, regardless of herbicide at Hillsboro 4 WAT of POST herbicides (Figure 19). H13 at 100 g/ha caused a small amount of crop injury to two-row barley that was similar to injury with fenoxaprop and bromoxynil and pyrasulfotole or pinoxaden and bromoxynil plus MCPA. However, H13 at 200 g/ha caused more injury to two-row barley than fenoxaprop and bromoxynil and pyrasulfotole or pinoxaden and bromoxynil plus MCPA but less injury to two-row barley than flucarbazone. This injury could potentially be unacceptable to the commercial herbicide market.

Locations were combinable 6 WAT for POST herbicide applications. Crop injury with flucarbazone plus clopyralid and fluroxypyr to two-row and six-row barley was 38% and 46%, respectively. This was different from all other herbicide by crop combinations, which gave less than 10% injury (Figure 20). By 6 WAT, all crops appeared relatively unaffected by H13 at either 100 g/ha or 200 g/ha, with 9% or less injury.

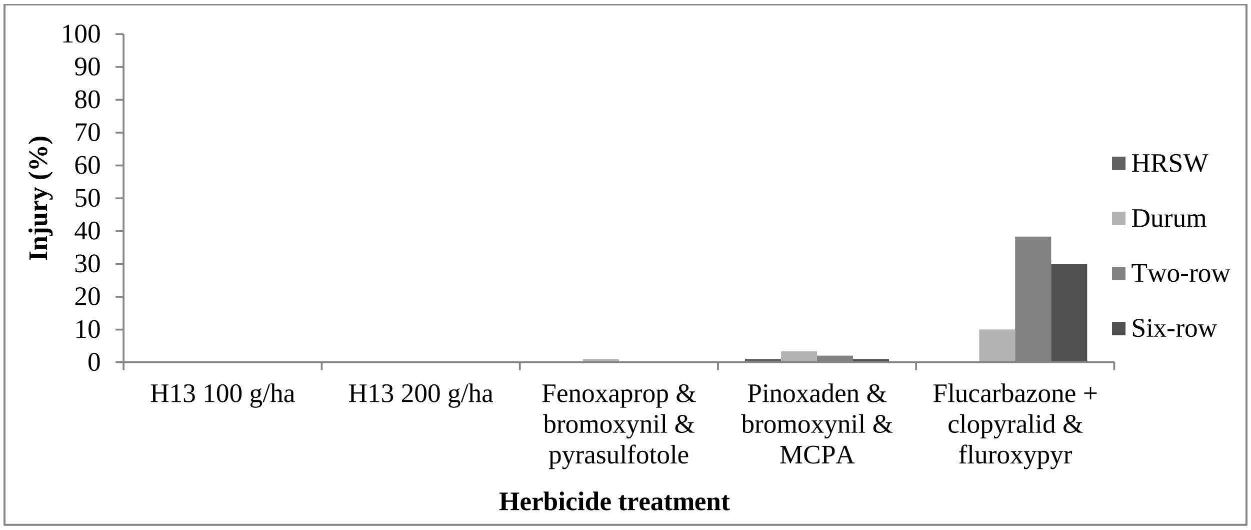

Figure 17. Herbicide by crop interaction 4 weeks after POST herbicide application at St. Thomas. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=6. To compare different crops within the same herbicide LSD=5. To compare any two points LSD=6.

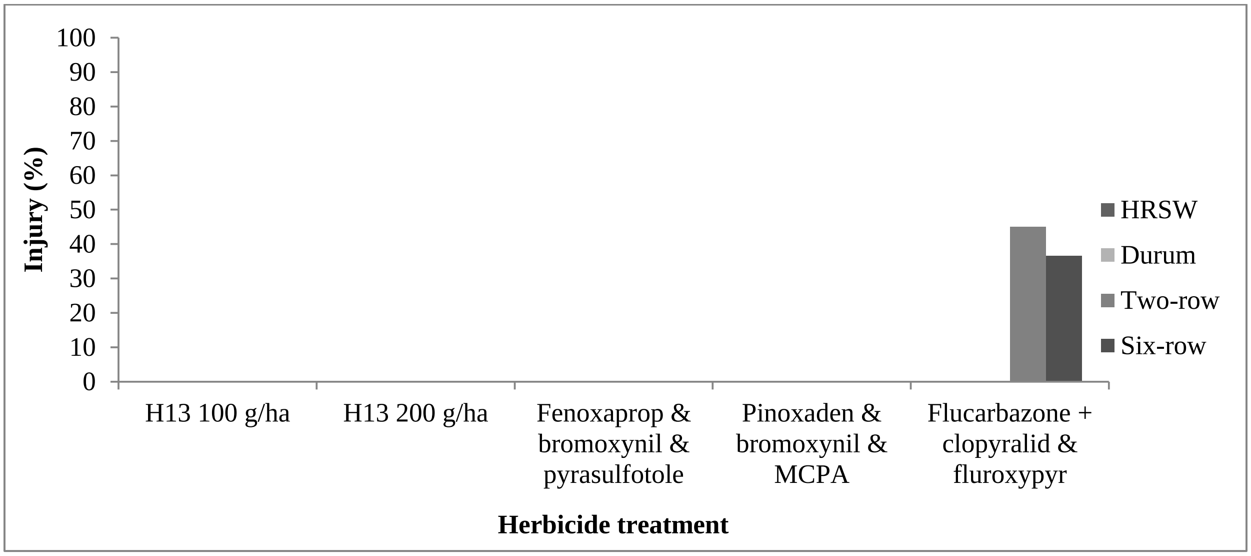

Figure 18. Herbicide by crop interaction 4 weeks after POST herbicide application at Fargo. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=3. To compare different crops within the same herbicide LSD=3. To compare any two points LSD=3.

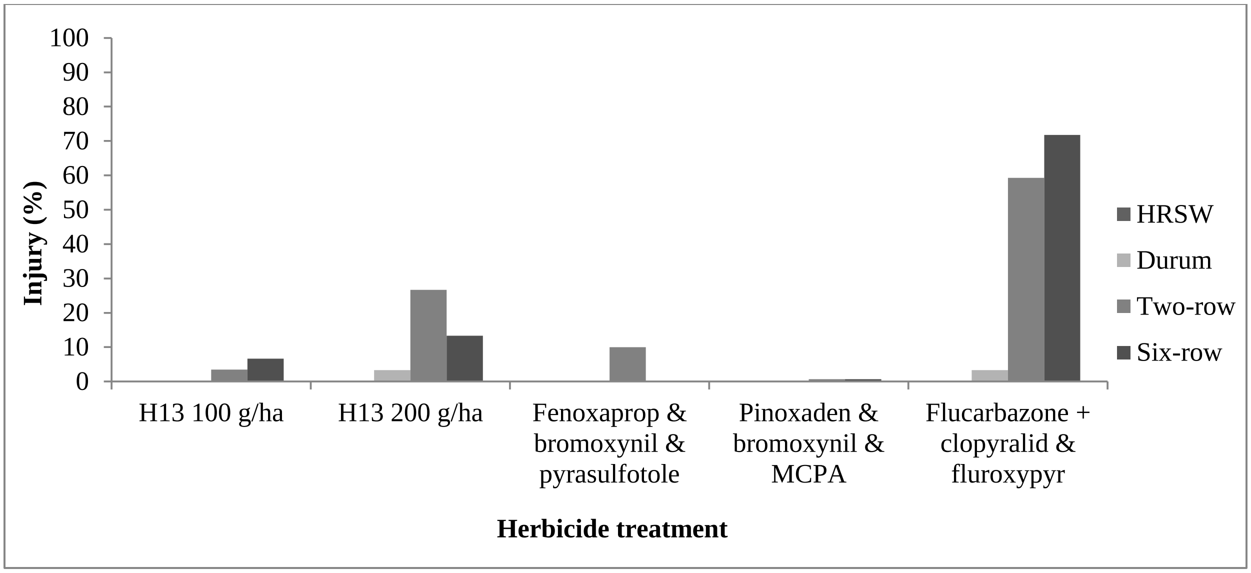

Figure 19. Herbicide by crop interaction 4 weeks after POST herbicide application at Hillsboro. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=15. To compare different crops within the same herbicide LSD=15. To compare any two points LSD=16.

Height of plants treated with POST herbicides reflect the visual evaluations that were recorded. Plants treated with flucarbazone plus clopyralid and fluroxypyr were the shortest in relation to the standard (Figure 21). This was to be expected because of the large amount of crop injury to barley with flucarbazone. Plants treated with H13 at 200 g/ha were similar in height deviation from the standard to those treated with flucarbazone. This confirms that visible injury is possible when plants are treated with H13 at 200 g/ha.

The plant population of crops treated with POST applied herbicides was similar for plant populations recorded before POST herbicide application (p-value for crop=0.7 and p-value for herbicide treatment=0.94) and at the end of the experiment (ANOVA p-value=0.15). Although, plant populations were similar among herbicide treatments, there was a difference in crop yield.

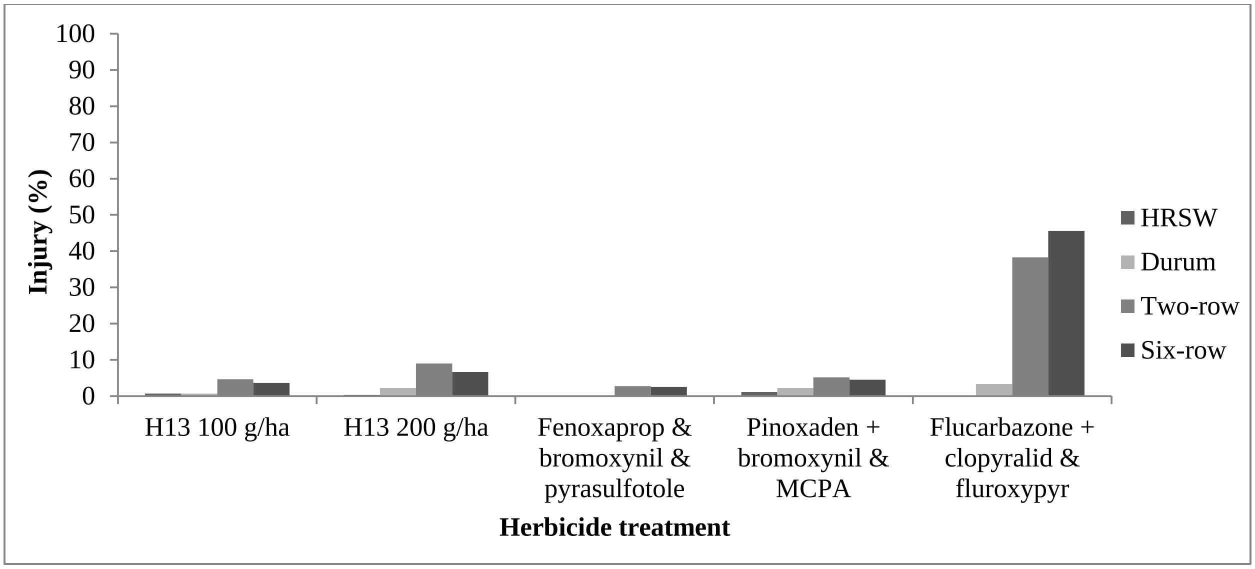

Figure 20. Herbicide by crop interaction 6 weeks after POST herbicide application averaged across location. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=8. To compare different crops within the same herbicide LSD=9. To compare any two points LSD=9.

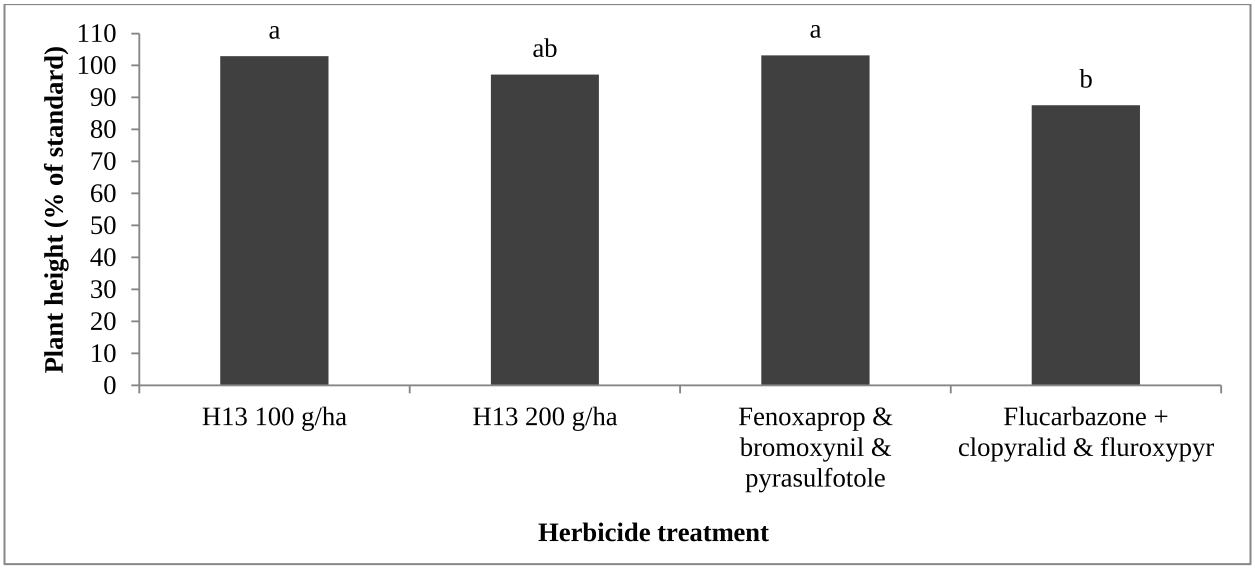

Figure 21. Heights of crop plants after POST herbicide applications averaged across crop and location. Means separated by F-protected LSD. Bars with same letter are similar at α=0.05. LSD=13.

An interaction between the herbicide treatment and crop factors was determined for grain yield with POST applied herbicides. Hard red spring wheat yield was similar regardless of which herbicide was applied POST (Figure 22). Although statistically similar, there was large numerical difference between yield of durum wheat when treated with H13 at 100 g/ha, 99% of the standard, and when treated with H13 at 200 g/ha, with a yield of 82% of the standard. The greatest yield of two-row and six-row barley was achieved when H13 at 100 g/ha or 200 g/ha was applied and the least yield was achieved when flucarbazone was applied, which was expected. However, six-row barley treated with fenoxaprop and bromoxynil and pyrasulfotole yielded similar to six-row barley treated with flucarbazone, which was unexpected. Fenoxaprop mixed with bromoxynil has caused crop injury to spring cereal crops under cool weather conditions but temperatures after POST herbicide treatments did not get below 10° C at any of the locations (NDAWN 2012).

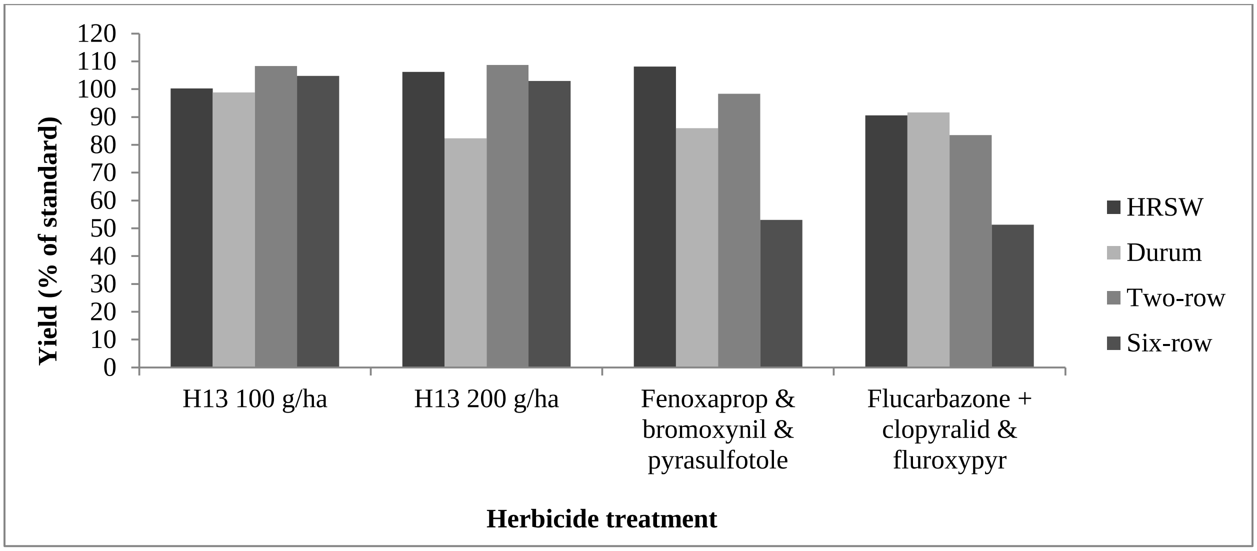

Figure 22. Herbicide by crop interaction for grain yield after POST applied herbicides averaged across location. Means separated by F-protected LSD at α=0.05. To compare different herbicide treatments within the same crop LSD=18. To compare different crops within the same herbicide LSD=25. To compare any two points LSD=30.

H13 has the potential to be a useful POST applied herbicide. Visual injury of crops when H13 was applied at 100 g/ha was similar to the industry standards on all crops; however, H13 applied at 200 g/ha has the potential to cause substantial injury to barley. More research should be conducted to determine the consistency of crop injury with H13 at 200 g/ha and whether or not visible injury to crop vegetation has a measureable influence on grain yield. There may have been an environmental factor at Hillsboro that triggered more visible injury of H13 at 200 g/ha than at other locations. Although injury ratings were similar to the industry standards, durum wheat treated with H13 at 200 g/ha produced less yield than durum wheat treated with the other herbicide treatments. From this research, hard red spring wheat appears to be the only crop with sufficient tolerance to meet the industry standards of a POST applied spring cereal herbicide.

Weed Control Studies

H13 Weed Control Rate Response. Log-logistic analysis was conducted for dry weights of two-leaf wild oat (p-value=0.6) and two- and four-leaf wild buckwheat (p-value=0.9). A lack-of-fit F-Test was conducted to determine the data did not fit a linear model. Therefore, a non-significant F-value was evidence that data was well described by a non-linear model (Knezevic et al. 2007).

A log-logistic analysis for dry weights of four-leaf wild oat could not be performed because four-leaf wild oat did not respond sufficiently to the rates of H13 included in this study to conduct this analysis. H13 at 200 g/ha did not provide a sufficient estimation of the lower limit of dry weight for four-leaf wild oat. This indicates wild oat may be difficult to control with H13 at the four-leaf growth stage. To achieve good control of wild oat with H13, plants should be sprayed before the four-leaf stage.

The estimated ED_{80} and ED_{90} of two-leaf wild oat was the application of H13 at 74 and 127 g/ha, respectively (Figure 23). Rates included in this study were not sufficiently large to estimate the ED_{80} and ED_{90} of four-leaf wild oat. Although not concluded from this data, it could be assumed a higher rate of H13 would be needed for an ED_{80} or ED_{90} for four-leaf wild oat because larger weeds are typically more difficult to control than smaller weeds (Barker et al. 1984 and Hager et al. 2003).

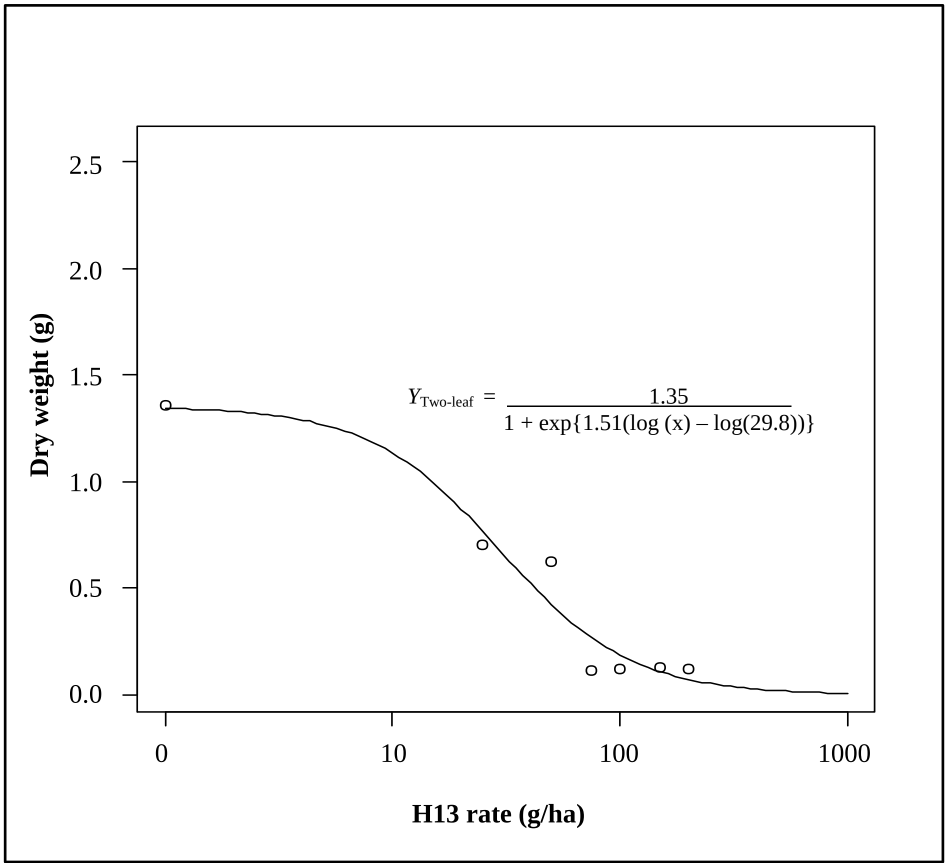

Figure 23. Rate response curve of two-leaf wild oat to H13. Symbols denote mean of eight dry weight data points.

Estimated ED_{80} and ED_{90} of two- and four-leaf wild buckwheat were numerically less than the ED_{80} and ED_{90} of two-leaf wild oat. The estimated ED_{80} and ED_{90} for two-leaf wild buckwheat were 55 and 90 g/ha of H13, respectively (Figure 24). The ED$_{80}$ and ED$_{90}$ of four-leaf wild buckwheat was 52 and 106 g/ha of H13, respectively. The difference between ED$_{80}$ and ED$_{90}$ values of two-leaf wild oat, 74 and 127 g/ha, respectively, and two-leaf wild buckwheat, 55 and 106 g/ha, respectively, suggests wild buckwheat was more susceptible to H13 than wild oat.

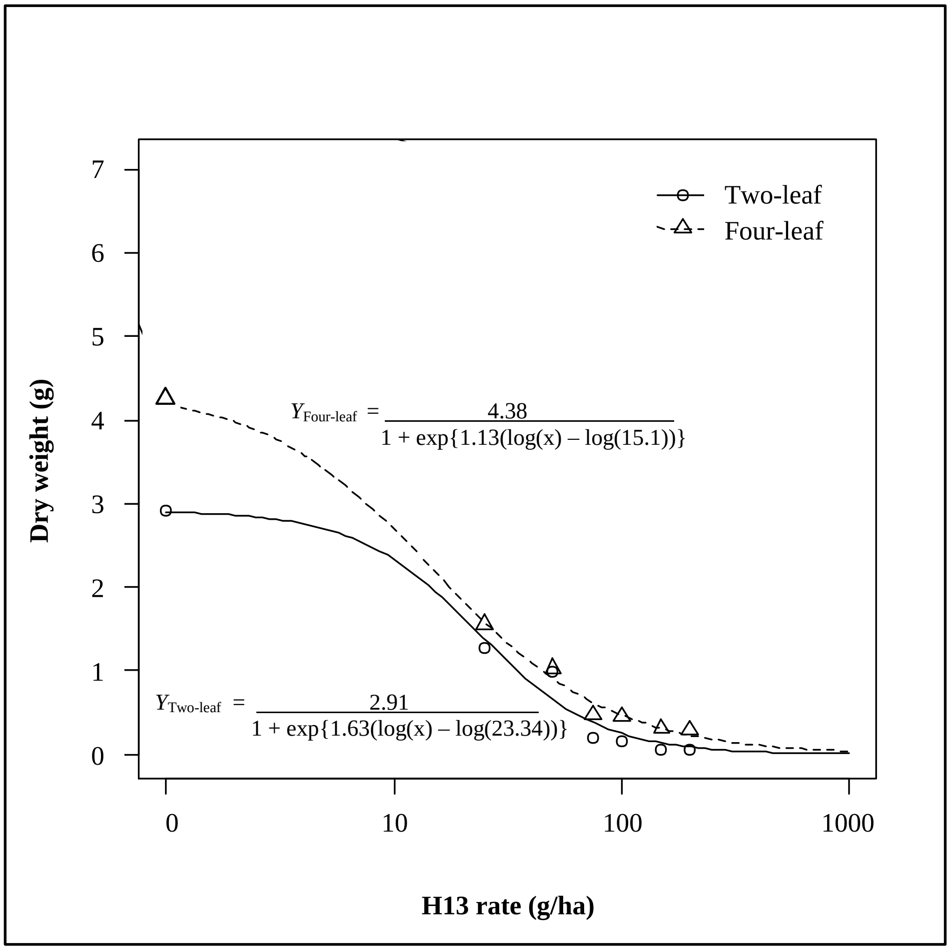

Figure 24. Rate response curve of wild buckwheat at two-leaf and four-leaf growth stage. Symbols denote mean of eight dry weight data points.

A 100 g/ha rate of H13 should provide good (80-89%) to excellent (90-99%) control of both two-leaf wild oat and two- and four-leaf wild buckwheat on the scale used for the North Dakota Weed Guide (Zollinger et al. 2011). More than 100 g/ha of H13 should be needed to control 90% of four-leaf wild oat, assuming a higher rate of H13 is needed to control four-leaf wild oats than two-leaf wild oat. Control of wild oat with H13 before the four-leaf stage is imperative to achieve good wild oat control unless much greater rates of H13 can be used without detrimental crop injury. However, at a rate above 100 g/ha, crop tolerance of durum wheat, two-row barley, and six-row barley could become an issue as determined by the crop tolerance study under field conditions.

Weed Control under Field Conditions. Error mean squares of wild oat dry weights were different among locations; therefore, locations will be discussed separately. Locations for all other wild oat and wild buckwheat data were combinable.

Wild Oat. Herbicide treatments provided similar control of wild oat with the level of control ranging between 50% and 65% 2 WAT (p-value=0.69) and ranging between 40% and 70% control 4 WAT (p-value=0.06). Differences among herbicide treatments were not distinguishable until 6 WAT. At 6 WAT, H13 gave wild oat control of 37%, 47%, and 59% at 75, 100, and 150 g/ha, respectively, based on estimates of visible injury (Figure 25). Although H13 at 75 and 100 g/ha controlled wild oat similar to fenoxaprop and bromoxynil and pyrasulfotole, which controlled 64% of wild oat, a wild oat control rating of 64% is unusually low for fenoxaprop and bromoxynil and pyrasulfotole which typically provides between 90 to 99% control of wild oat (Zollinger et al 2011). Wild oat at Nielsville was particularly difficult to control regardless of herbicide treatment. The magnitude difference in control ratings among locations was especially evident for fenoxaprop and bromoxynil and pyrasulfotole, which was observed as a larger gap across control values (27% to 93% control) among locations than for other treatments.

Dry weights of wild oat samples showed little separation among herbicide treatments (Figure 26). All herbicide treatments at Crookston and Hillsboro decreased wild oat biomass compared with the untreated plots. The amount of wild oat biomass was similar across all herbicide treated plots. At Nielsville, all herbicide treatments except for H13 at 75 g/ha reduced wild oat biomass compared with the untreated. All 1000 kernel weed seed weights were similar among herbicide treatments including the control (p-value=0.09, data not shown).

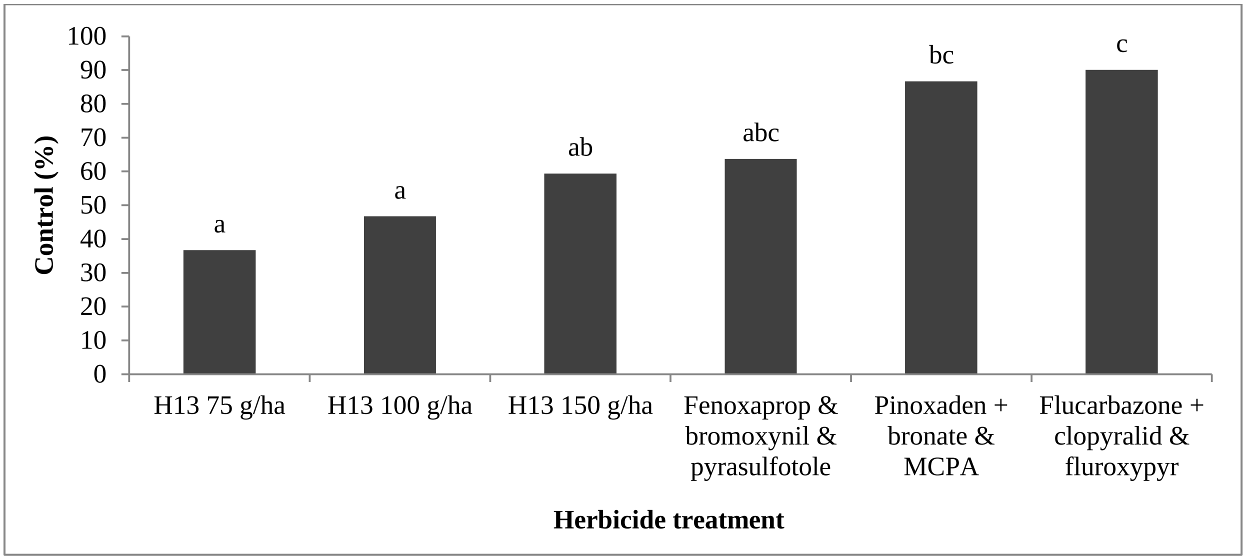

Figure 25. Wild oat control 6 WAT averaged across three locations. Means separated by F-protected LSD. Bars with the same letter are similar at α=0.05. LSD=27.

H13 did not meet the standards of a wild oat herbicide under field conditions. At six weeks after treatment, H13 applied at the 150 g/ha rate provided only 60% visible control, versus pinoxaden and flucarbazone which provided 87% and 90% control, respectively. A 60% visible control rating by industry standards is described as poor control (Zollinger et al. 2011). Good herbicide control is considered to be 80 to 90% visual control rating and excellent control is considered to be 90 to 99% visible control.

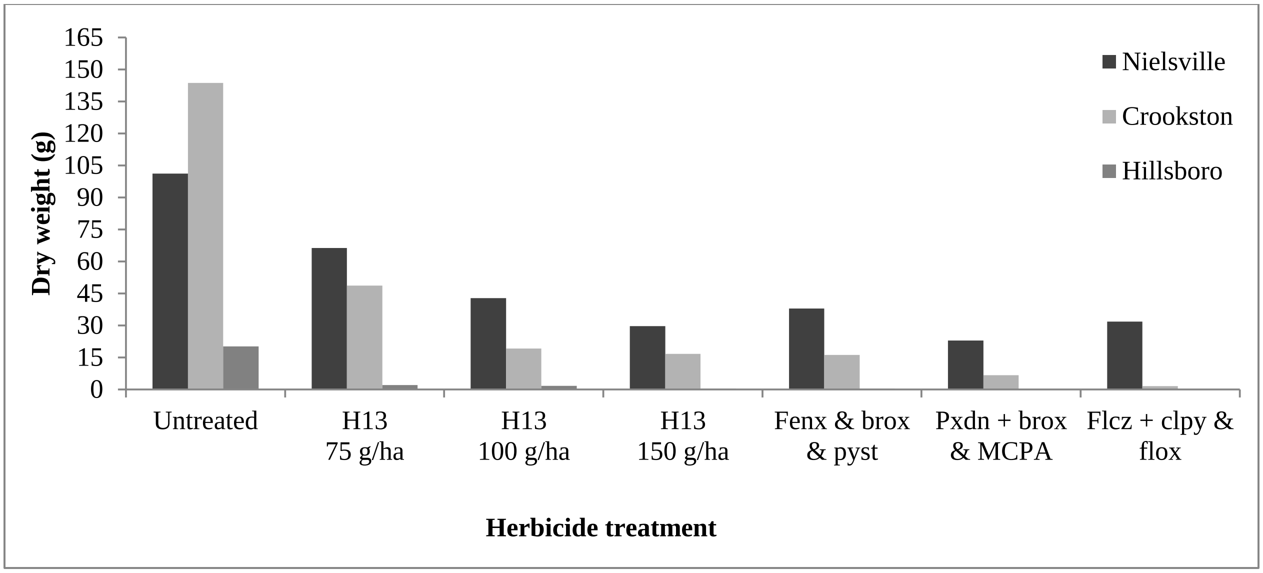

Figure 26. Dry weight of wild oat samples from Nielsville, Crookston, and Hillsboro. Means were separated by F-protected LSD at α=0.05. To compare means at Nielsville LSD=38, at Crookston LSD=65, and at Hillsboro LSD=9. Herbicide treatment abbreviations: Fenx & brox & pyst = fenoxaprop and bromoxynil and pyrasulfotole, Pxdn + brox & MCPA = pinoxaden plus bromoxynil and MCPA, and Flcz + clpy & flox = flucarbazone plus clopyralid and fluroxypyr.

Wild Buckwheat. Visual evaluation 2 WAT was only recorded at the campus location because the Hoople location was inaccessible due to water saturated soil. At the 2, 4, and 6 WAT visual evaluations, all rates of H13 gave wild buckwheat control of less than 30% while the industry standard treatments provided a minimum of 80% control (Figure 27). Wild buckwheat dry weight (p-value=0.22) and 1000 weed seed kernel weight (p-value=0.59) were similar among herbicide treatments. Dry weight of wild buckwheat was likely similar among treatments because the natural infestations of wild buckwheat at the locations were low, with only about 5 to 10 plants/m^2, and good crop competition was provided by a vigorous wheat canopy.

H13 did not meet the standard of a wild buckwheat herbicide either. Poor control of wild buckwheat under field conditions with H13 may have been due to poor H13 contact with the wild buckwheat leaves. As learned earlier in the site of entry study, H13 absorption through leaves is important for control of established plants. At application, wheat was at the four-leaf stage and the wild buckwheat was at the two- to three-leaf stage. The combination of the wheat canopy preventing droplets from reaching the wild buckwheat plants and small leaf area of the young wild buckwheat plants could have reduced the amount of H13 product that came in contact with the wild buckwheat leaves. However, more than just poor herbicide leaf contact must have attributed to a lack of H13 activity under field conditions because the industry standard herbicides still provided good to excellent control of wild buckwheat. There could be a formulation issue or the need to include a different adjuvant to ensure good leaf penetration.

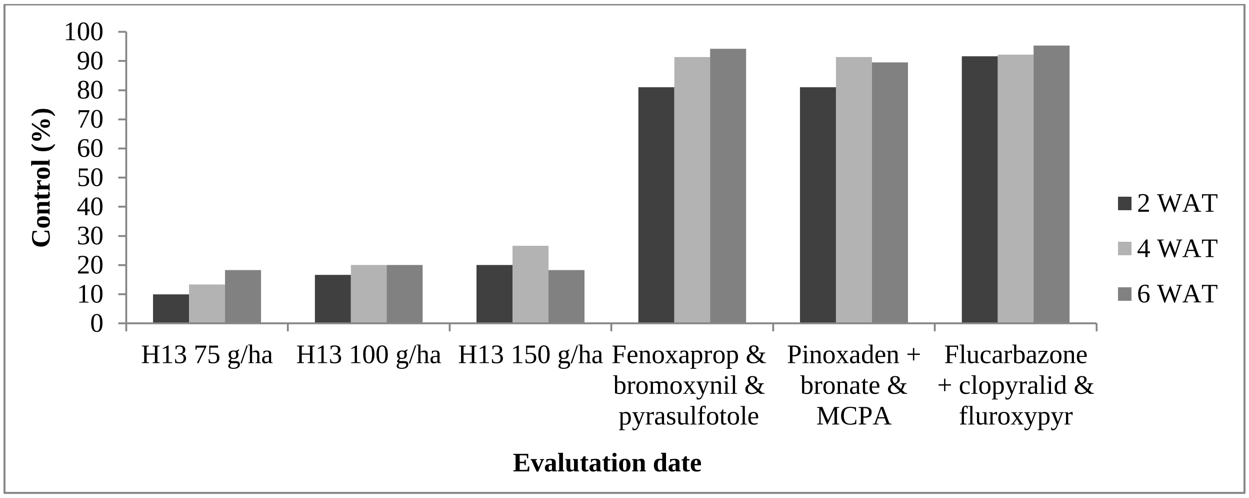

Figure 27. Visual evaluations of wild buckwheat control 2, 4, and 6 WAT. 2 WAT evaluation only included data from Fargo because the Hoople location was inaccessible due to saturated soil. The 4 and 6 WAT evaluations were averaged across the two locations. Means were separated using F-protected LSD at α=0.05. LSD to compare evaluations 2 WAT=21, 4 WAT=12, and 6 WAT=9.

SUMMARY

Greenhouse and field studies were conducted to determine: 1) H13 site of entry into plants; 2) if soil type influences H13 efficacy on germinating seedlings; 3) spring wheat, durum and barley tolerance to H13; and 4) H13 efficacy to wild oat and wild buckwheat.

Insufficient amount of H13 product in a single formulation was available to complete all the greenhouse and field experiments. All of the greenhouse studies and the weed control study under field conditions were conducted with the SC formulation of H13 while the crop tolerance study under field conditions was conducted with the WG formulation. It was determined in a greenhouse study that the activity of H13 in the SC and WG formulations was similar.

A greenhouse study was conducted to determine H13 site of entry into wild oat and wild buckwheat plants. Activity on established wild oat and wild buckwheat plants was greatest when H13 was applied foliar only or foliar plus soil. Established plants treated with H13 applied to soil only were similar to the untreated plants in injury ratings and dry biomass. Wild oat seedlings exposed to H13 through soil only or foliar plus soil produced less biomass than the untreated or foliar only treated. This indicated absorption through shoot tissue, whether a germinating seedling or established plant, was important for good weed control. Injury ratings and dry biomass were similar regardless of soil type or H13 rate, indicating these factors did not influence H13 activity.

Both a greenhouse and field study were conducted to determine crop tolerance of hard red spring wheat, durum wheat, two-row barley, and six-row barley to H13. It was concluded from the crop cultivar screening study that H13 application rate rather than crop cultivar would be the limiting factor in determining crop tolerance of hard red spring wheat, durum wheat, two-

row barley, and six-row barley. Cultivars within the same crop were similar for visual evaluations and plant dry weight comparisons. Hard red spring wheat and six-row barley produced similar biomass regardless of H13 rate while durum wheat and two-row barley produced less biomass when treated with H13 at the 400 g/ha rate than with H13 at 100 g/ha or the untreated control.

Under field conditions, H13 applied at both 100 g/ha and 200 g/ha rate has the potential to cause crop injury to all crops evaluated when applied PRE. It is still not understood why crop injury to H13 applied PRE was observed at Fargo but not at Hillsboro or St. Thomas. More research should be conducted to determine the environmental factors that influence crop injury to H13 PRE. All crops had good crop tolerance to H13 at 100 g/ha applied POST; however, only hard red spring wheat was tolerant to H13 at 200 g/ha POST. When treated with H13 at 200 g/ha POST, durum wheat produced less yield than durum wheat treated with any other herbicide treatment and unacceptable visible injury to two-row and six-row barley was observed. H13 should not be used on durum wheat or barley POST because of the susceptibility at the 200 g/ha rate. H13 can safely be used on hard red spring wheat POST at a field rate of 100 g/ha. For a herbicide to be marketable, intended crop tolerance should be observed at the 2X rate and hard red spring wheat did show tolerance to H13 at 200 g/ha, which is 2X the proposed 100 g/ha rate.

The estimated ED_{90} to control two-leaf wild oat, and two- and four-leaf wild buckwheat was 127 g/ha, 90 g/ha, and 106 g/ha, respectively. A recommended field use rate of H13 at 100 g/ha should provide between good, 80 to 90%, and excellent, 90 to 99%, control of two-leaf wild oat and wild buckwheat up to the four-leaf stage.

H13 applied POST at the 75, 100, or 150 g/ha rate did not control wild oat or wild buckwheat as well as the three included industry standard herbicide treatments under field conditions in 2011. If good to excellent control of wild oat and wild buckwheat cannot be obtained with H13 at 150 g/ha, H13 probably will not be a marketable product for the purpose of controlling wild oat or wild buckwheat herbicide because at a rate above 150 g/ha there is an unacceptable risk of crop injury. However, it should be noted that field data was collected from a limited number of locations and only in one year. H13 should be evaluated in more locations under different growing conditions to fully determine the value of this herbicide to control wild oat and wild buckwheat.

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