Weed Control and Cultivar Tolerance to Saflufenacil in Soybean (*Glycine max*)

by

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ABSTRACT

Weed Control and Cultivar Tolerance to Saflufenacil in Soybean (*Glycine max*)

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Studies were conducted in 2009 and 2010 under field and growth room conditions to determine a) cultivar tolerance of soybean to preemergence (PRE) applications of saflufenacil and b) the biologically effective rate of saflufenacil/dimethenamid-p for control of annual weeds applied PRE alone and prior to an in-crop application of glyphosate. Environmental conditions following application influenced the amount of soybean injury caused by saflufenacil, as well as the rate of saflufenacil/dimethenamid-p required for the control of annual weeds. Increased soybean injury from saflufenacil was observed when soybean emergence was delayed due to cool, wet conditions following planting. Injury decreased with time; however, sensitive soybean cultivars were unable to fully recover from early season injury under adverse environmental conditions. OAC Hanover was the most sensitive cultivar in both field and hydroponic testing. With adequate moisture and above average temperatures in 2010, between 224 and 374 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p was required for 80% control of common ragweed, common lambsquarters, and green foxtail 4 weeks after treatment (WAT). In contrast, with below average temperatures and excessive moisture in 2009, between 528 and 613 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p was necessary for the same level of weed control. Pigweed species were least affected by environmental conditions after application with
only 245 g a.i. ha$^{-1}$ required for 80% control 4 WAT in both years. Excellent full season control of all weed species was achieved with saflufenacil/dimethenamid-p applied PRE followed by glyphosate postemergence (POST). However, there was no difference in yield when saflufenacil/dimethenamid-p was followed by glyphosate POST compared to a single glyphosate POST application.
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1.0 Review of Literature

1.1 Introduction

Glyphosate resistant technology has been widely accepted by soybean producers in North America since its introduction in 1996. With multiple glyphosate resistant crops on the market and a reduction in tillage practices, there is a tendency to rely solely on glyphosate for weed control in these crops year after year. Consequently, there is greater selection pressure on weed communities due to a limited number of herbicides with different modes of action being used (Owen and Zelaya 2005). Although glyphosate is a broad-spectrum herbicide, weed shifts to naturally tolerant species and glyphosate resistant weeds are an increasing concern. Currently there are 12 weed species that are resistant to glyphosate in the United States and three in Canada (Heap 2011).

One way to reduce the selection pressure for glyphosate resistant weeds is to use soil-applied herbicides in glyphosate resistant cropping systems. However, herbicide screening for cultivar tolerance to other herbicides has not been routinely conducted in recent years (Poston et al. 2008). Saflufenacil is a herbicide used in corn, soybean, and cereals for burndown and residual broadleaf weed control (Grossmann et al. 2010; Liebl et al. 2008). It effectively controls many key broadleaf species, including acetolactate synthase (ALS), triazine, and glyphosate resistant biotypes (Anonymous 2008; Liebl et al. 2008). Sensitive broadleaf weed species are controlled through the inhibition of protoporphyrinogen IX oxidase (PPO), an important enzyme in the synthesis of chlorophyll (Grossmann et al. 2010).
In corn, a premix formulation of saflufenacil and dimethenamid-p in a 1:8.8 ratio provides control of annual grass and broadleaf weeds at the registered use rate of 735 g a.i. ha\(^{-1}\) (75:660 g a.i. ha\(^{-1}\), respectively) (Anonymous 2008). Saflufenacil/dimethenamid-p is pending registration in Canada for use in soybean at a maximum use rate of 245 g a.i. ha\(^{-1}\) (25:220 g a.i. ha\(^{-1}\) of saflufenacil:dimethenamid-p) applied prior to planting as a setup application for a postemergence (POST) herbicide. Although reduced rates of soil-applied herbicides may not provide season-long control, the reduction in weed growth can extend the POST herbicide application window depending on the weed species composition and weed density (Ellis and Griffin 2002).

1.2 Saflufenacil

1.2.1 Molecular

Within the protoporphyrinogen IX oxidase (PPO) inhibiting herbicide group, there are eight chemistries which include: diphenylether, \(N\)-phenylphthalimide, oxadiazole, oxazolidinediones, phenylpyrazole, pyrimidinedione, thiadiazole, and triazinone (Senseman 2007). Saflufenacil (\(N'\)-(2-chloro-4-fluoro-5-(3-methyl-2,6-dioxo-4(trifluoromethyl)-3,6-dihydro-1(2H)-pyrimidinyl)-benzoyl]-\(N\)-isopropyl-\(N\)-methylsulfamide) is a uracil-based herbicide which belongs to the pyrimidinedione class of chemistry (Ashigh and Hall 2010; Grossmann et al. 2011). It is a weak acid with a pKa of 4.41 and an octanol/water partition coefficient (Log Po/x) of 2.6 which allows it to be absorbed through the hydrophobic lipid structures of plant tissues (Grossmann et al. 2011; Hixson 2008). The weak acid property of saflufenacil, which is unique among commercial PPO inhibitors, is enabled by the side chain of the molecule, which carries an
acidic proton at the nitrogen atom in the amide position (Figure 1.1) (Ashigh and Hall 2010; Grossmann et al. 2011). In the plant vascular system, pH values typically range from 6 in the xylem to 8 in the phloem; therefore, saflufenacil exists in the anionic form in the xylem and phloem making it more mobile within the plant compared to other PPO inhibitors (Grossmann et al. 2011).

Even though PPO inhibiting herbicides have been used on a variety of crops for a number of years, weed resistance has been slow to evolve (Lee et al. 2008). Waterhemp (Amaranthus tuberculatus Moq.) and common ragweed (Ambrosia artemisiifolia L.) are the only two species in North America which have demonstrated resistance to PPO herbicides (Heap 2011; Lee et al. 2008; Patzoldt et al. 2005). Since PPO enzymes are present in both the chloroplast and mitochondria, herbicides that inhibit PPO have two sites of action and weed resistance to the PPO inhibiting herbicides may require the simultaneous selection of a mutant allele of two genes (Lee et al. 2008).

1.2.2 Mode of Action

Protoporphyrinogen IX, an important enzyme in the synthesis of both chlorophyll and heme, is present in yeast, bacterial and plant cells (Jacobs and Jacobs 1987). The chlorophylls, heme, and cytochrome present in plants, along with other proteins, are involved in light harvesting, energy transduction, signal transduction and detoxification (Grossmann et al. 2010). Within the chloroplasts, PPO catalyzes the conversion of protoporphyrinogen IX to protoporphyrin IX by occupying the binding site for protoporphyrinogen IX (Beale and Weinstein 1990; Duke et al. 1991; Grossmann et al. 2010). This process involves the removal of 6 protons and 6 electrons, making it the last
common step in heme and chlorophyll biosynthesis (Jacobs and Jacobs 1987; Matringe et al. 1989, 1992). At this stage, the pathways for heme and chlorophyll synthesis diverge with the insertion of either iron or magnesium into protoporphyrinogen IX to form precursors to heme or chlorophyll (Fig. 1.2) (Beale and Weingstein 1990; Devine et al. 1993; Matringe et al. 1992).

When PPO is inhibited, protoporphyrinogen IX is not converted to protoporphyrin IX and an accumulation of protoporphyrinogen IX occurs in the chloroplast which then diffuses from the organelles into the cytoplasm, where it is converted to protoporphyrin IX via enzymes through extraplastidic oxidation (Duke et al. 1991; Grossmann et al. 2011). Upon exposure to light, protoporphyrin IX molecules interact with oxygen to form singlet oxygen and oxygen radicals (Witkowski and Halling 1989; Wright et al. 1995). Ion leakage and water loss from the cell occur, followed by lipid peroxidation which causes a rapid loss of membrane integrity and function (Grossmann and Schiffer 1999). Further effects include bleaching of chloroplast pigments, tissue necrosis, growth inhibition, and eventually plant death within a few days of treatment (Grossmann et al. 2011; Grossmann and Schiffer 1999).

The roots and shoots of plants are the primary tissues that absorb soil-applied herbicides such as saflufenacil (Bromilow and Chamberlain 1995). Once absorbed, it is predominantly translocated in xylem tissue, with relatively low movement via the phloem (Ashigh and Hall 2010; Bowe et al. 2008; Hixson 2008). Corn (Zea mays L.) exhibits more tolerance than black nightshade (Solanum nigrum L.) to soil-applied applications of saflufenacil through rapid metabolism, combined with low root translocation (Grossmann et al. 2011). Similarly, Frihauf et al. (2010a) found that minimal translocation of
saflufenacil occurred between treated and untreated winter wheat (*Triticum aestivum* L.) tillers, indicating that wheat is tolerant to soil-applied applications of saflufenacil (Knezevic et al. 2010b; Sikkema et al. 2008). When saflufenacil was foliar applied, phytotoxic symptoms occurred within 2 to 3 hours of treatment, with foliar applications approximately 100-fold more sensitive than root applications (Grossmann et al. 2011). Grossmann et al. (2011) determined that when saflufenacil was applied to the third leaf of corn and black nightshade, 4 and 100% of the herbicide remained unchanged after 16 hours, respectively. However, the systemic mobility of saflufenacil depends on the integrity of the vascular tissue. The general expectation is that the high initial activity of a PPO inhibitor causes rapid necrotic damage of the vascular tissues, which could negatively affect systemic translocation (Grossmann et al. 2011).

Inhibition from saflufenacil is thought to lead to slightly delayed injury of vascular tissues after foliar uptake which could enable the transport of the herbicide within the plant tissue before death (Grossmann et al. 2011). Increased absorption of saflufenacil occurs with the addition of the surfactant Merge (50% surfactant blend + 50% solvent petroleum hydrocarbons, BASF Canada Inc.) and glyphosate in plants with a thick cuticle such as cabbage (Ashigh and Hall 2010). However, this increase may negatively influence translocation of saflufenacil in highly susceptible species and reduce glyphosate activity since the rapid contact activity of saflufenacil causing cell death can limit glyphosate translocation (Ashigh and Hall 2010). Although the rapid foliar activity of saflufenacil may negatively affect glyphosate translocation, the addition of glyphosate to saflufenacil had no effect on the translocation of saflufenacil in glyphosate resistant
species (Ashigh and Hall 2010). Therefore, this makes saflufenacil an effective herbicide for the control of glyphosate resistant weeds and glyphosate resistant crop volunteers.

1.2.3 Environmental Fate

Herbicide availability in soil for uptake by plants is dependent on a number of soil factors including organic matter (OM), soil texture, pH and cation exchange capacity (CEC). CEC is the sum of positive charges of sorbed cations that a soil can adsorb, and is directly related to OM and clay mineral content (Hixson 2008). Crop injury increases as the soil CEC decreases (Kerr et al. 2004). In addition, as the soil pH increases, more acidic herbicide anions remain in soil solution and are available for plant uptake (Hixson 2008). Since the pKₐ value of saflufenacil is less than five, it will primarily be in the anion form in most agricultural soils. Therefore, it is repelled by negatively charged soil particles which results in higher concentrations of saflufenacil in the soil solution (Hixson 2008). However, among the soil properties, herbicidal activity is highly correlated to the OM (Blumhorst et al. 1990). Hixson (2008) determined that soils with higher OM have a higher affinity for saflufenacil, which results in less herbicide available for plant uptake. In the same study, it was determined that the highest saflufenacil bioactivity occurred in coarse textured, low OM (<1.5%) soils, and the lowest bioavailability occurred in higher OM (>4%), regardless of the soil texture. Therefore, the application rate of saflufenacil should be adjusted based on OM content and soil texture (Hixson 2008).
1.2.4 Toxicology

For humans, exposure to saflufenacil may occur through the consumption of food and water, or when handling and applying the product (Health Canada, 2010). In Canada, two key factors must be considered when assessing the health risks of a herbicide. These include: 1) the level where no health effects occur and 2) the level to which people may be exposed (Health Canada 2010). When exposure levels are well below those that cause no effects in animal testing, a herbicide is then considered acceptable for registration. Dose levels are then established to help protect the most sensitive sets of the human population, namely nursing mothers and children (Health Canada 2010).

Saflufenacil has a low mammalian toxicity with an LD$_{50}$ $>2000$ mg/kg body weight (Anonymous 2008). Ecotoxicological testing of saflufenacil has demonstrated that there are no concerns for acute or chronic effects on birds, fish, aquatic invertebrates, sediment-dwelling organisms, or earthworms (Anonymous 2008). When tested on laboratory animals, technical saflufenacil was not genotoxic, oncogenic, neurotoxic, or toxic to the reproductive system (Health Canada 2010). Therefore, such a reputable profile makes saflufenacil a very favorable herbicide to control broadleaf weeds in a number of crops in Canada.

1.3 Efficacy

1.3.1 Saflufenacil

In Canada, saflufenacil is currently registered on a number of crops and can be applied pre-plant (PP), pre-plant incorporated (PPI), and pre-emergence (PRE) in corn at a use rate of 50 to 100 g a.i. ha$^{-1}$. In cereals and pulse crops, it can be applied PP and PRE
at 18 to 50 g a.i. ha\(^{-1}\). Severe crop injury can occur in corn and cereals if saflufenacil is applied after crop emergence (Knezevic et al. 2010b; Moran 2010; Sikkema et al. 2008). For effective control of emerged broadleaf weeds prior to planting soybean, saflufenacil can be applied at 25 g a.i. ha\(^{-1}\). Although the lower use rate in soybean is not expected to provide full season residual control of annual broadleaf weeds (Knezevic et al. 2009b), this rate can be effectively used to reduce the selection for herbicide resistant weeds.

In reduced or no-till management systems, saflufenacil provides rapid burndown of emerged broadleaf weeds with susceptible weeds often demonstrating initial injury symptoms within a few hours (Liebl et al. 2008). POST applications of saflufenacil prior to crop emergence can control emerged weeds such as common cocklebur (*Xanthium strumarium* L.), velvetleaf (*Abutilon theophrasti* Medik.), redroot pigweed (*Amaranthus retroflexus* L.), common ragweed, giant ragweed (*Ambrosia trifida* L.), common waterhemp (*Amaranthus redus* Sauer), ladysthumb (*Polygonum persicaria* L.), and common lambsquarters (*Chenopodium album* L.), including ALS, triazine, and glyphosate resistant biotypes (Anonymous 2008; Liebl et al. 2008). Differences in weed sensitivity to applications of saflufenacil applied POST have been documented. Blue mustard (*Chorispora tenella* (Pall). D.C.) was found to be more sensitive than flixweed (*Descurainia sophia* L.) which in turn was more sensitive than henbit (*Lamium amplexicaule* L.) when saflufenacil alone was applied POST (Frihauf et al. 2010b; Geier et al. 2009), however, 60 % control of flixweed was achieved at 3 days after treatment (DAT) (Frihauf et al. 2010b). In greenhouse studies, relatively low rates of 6 to 30 g a.i. ha\(^{-1}\) of saflufenacil applied POST reduced weed biomass by at least 90% for blue
mustard, flixweed, palmer amaranth (*Amaranthus palmeri* S.), redroot pigweed, and tumble pigweed (*Amaranthus albus* L.) (Geier et al. 2009).

Knezevic et al. (2009a, 2010a) discovered that control of field bindweed (*Convolvulus arvensis* L.), prickly lettuce (*Lactuca serriola* L.), henbit, shepherd’s-purse (*Capsella bursa-pastoris* (L) Medicus), dandelion (*Taraxacum officinale* Weber), Canada fleabane (*Erigeron canadensis* L.) and field pennycress (*Thlaspi arvense* L.) was improved with the addition of an adjuvant. Methylated seed oil (MSO) [1% v/v] was most effective, followed by crop oil concentrate (COC) [1% v/v] and nonionic surfactant (NIS) [0.25% v/v] was the least effective of all the adjuvants tested (Knezevic et al. 2009a, 2010a). As well as adjuvants, the addition of glyphosate results in a reduction in the rate of saflufenacil required for adequate weed control. Knezevic et al. (2009b) determined that the rate of saflufenacil to achieve 90% control of field pennycress was 104, 39 and 20 g a.i. ha⁻¹ for saflufenacil alone, saflufenacil + MSO and saflufenacil + glyphosate, respectively. Similarly, 183 and 163 g a.i. ha⁻¹ of saflufenacil provided 90% control of field bindweed and dandelion, respectively, but only 30 and 20 g a.i. ha⁻¹ of saflufenacil was required to achieve the same level of control when glyphosate was added (Knezevic et al. 2009b). Comparable results have been obtained on resistant weed species. Owen et al. (2011) found that the control of glyphosate resistant Canada fleabane in cotton increased from 0% with glyphosate alone to 99% at 37 DAT with the addition of 25 g a.i. ha⁻¹ of saflufenacil. Furthermore, there was no difference between 25 and 50 g a.i. ha⁻¹ of saflufenacil when tankmixed with glyphosate for the control of glyphosate resistant Canada fleabane (Owen et al. 2011). These results indicate that Canada fleabane
is sensitive to applications of saflufenacil, and that saflufenacil tankmixed with
glyphosate can be an effective tool to manage glyphosate resistant Canada fleabane.

Weed size at the time of the POST application also affects the speed of activity of
saflufenacil. As the weed size increases, higher rates are required for adequate control.
Knezevic et al. (2010a) found that 22, 29, 33, 40, 45, 59, and 85 g a.i. ha\(^{-1}\) saflufenacil +
MSO (1% v/v) provided 90% control of field bindweed, prickly lettuce, henbit,
shepherd’s purse, field pennycress, and dandelion, respectively. When application was
delayed two weeks, the rate of saflufenacil required to achieve the same level of control
increased to 33, 44, 62, 59, 62, 79, and 141 g a.i. ha\(^{-1}\) for the same species, respectively.

PRE applications of saflufenacil can provide residual control of troublesome
weeds such as velvetleaf, redroot pigweed, common ragweed, and common
lambsquarters (Anonymous 2008; Liebl et al. 2008). Geier et al. (2009) determined in
greenhouse studies that blue mustard, flixweed, palmer amaranth, redroot pigweed, and
tumble pigweed responded similarly to saflufenacil when applied PRE, with 6 to 30 g a.i.
ha\(^{-1}\) reducing weed density by 77 to 98% (Geier et al. 2009). There was also no difference
in weed biomass when the rate of saflufenacil was greater than 12 g a.i. ha\(^{-1}\) (Geier et al.
2009). Studies by Soltani et al. (2010a) determined that 75 g a.i. ha\(^{-1}\) of saflufenacil
applied PRE provided 85% control of common cocklebur (\textit{Xanthium strumarium} L.) at 8
weeks after corn emergence (WAE). In addition, saflufenacil applied PRE at the same
rate decreased cocklebur density and shoot dry weight 78 and 75% respectively. The use
of saflufenacil as a soil-applied herbicide prior to crop emergence provides residual
control of broadleaf weeds that emerge after planting and possibly eliminates the need for
a second herbicide application in-crop, saving the grower both time and additional application cost.

### 1.3.2 Dimethenamid-p

Chloroacetamides have been used for several decades but their specific target site has only been found in recent years (Götz and Böger 2004). Dimethenamid-p [(S)-2-chloro-\(N\)-(2,4-dimethyl-3-thienyl)-\(N\)-(2-methoxy-11-methylethyl)acetamide] is a chloroacetamide that inhibits the biosynthesis of very long chain fatty acids, lipids, proteins, isoprenoids, and flavonoids (Senseman 2007). Dimethenamid-p is absorbed though the coleoptile in grasses and through the shoots and roots of emerging broadleaf weeds (Senseman 2007), and is xylem-transported by acropetal movement (Böger et al. 2000). Sensitive weeds usually germinate but growth is inhibited and they do not emerge (Böger et al. 2000). Dimthenamid-p is commonly used in corn, soybean, dry common bean and horticulture crops in Canada. Depending on the soil type and organic matter, use rates range from 544 to 693 g a.i. ha\(^{-1}\), with higher rates required on fine textured soils with higher organic matter (Anonymous 2010b). In soybean, dimethenamid-p can be applied prior to soybean emergence to control many annual grasses such as foxtail species (\textit{Setaria spp.}), barnyardgrass (\textit{Echinochloa crusgalli} L.), fall panicum (\textit{Panicum dichotomiflorum} M.), and crabgrass species (\textit{Digitaria spp.}), as well as certain annual broadleaf weeds such as redroot pigweed and eastern black nightshade (\textit{Solanum ptycanthum} D.) (OMAFRA 2010; Senseman 2007).

Dimethenamid-p can effectively be used to control resistant weed species in Canada since there are currently no weed biotypes that are resistant to this group of
herbicides (Heap 2011). Ashigh and Tardif (2006) found that dimethenamid applied at the recommended rate provided at least 90% control of ALS resistant eastern black nightshade in Ontario. Also, Vyn et al. (2007) found that dimethenamid provided 97% control of waterhemp that was resistant to ALS inhibiting herbicides, as well as 84% on biotypes that were resistant to both ALS and photosystem II-inhibiting herbicides. However, other studies have documented that only 67 and 41% control of waterhemp was achieved at 28 and 70 days after treatment with the same rate of dimethenamid (Soltani et al. 2009).

1.3.3 Saflufenacil/dimethenamid-p

A premix formulation of saflufenacil and dimethenamid-p in a 1:8.8 ratio is registered in Canada to provide residual control of annual grass and broadleaf weeds in corn at the registered use rate of 735 g a.i. ha\(^{-1}\) (75:660 g a.i. ha\(^{-1}\), respectively) (Anonymous 2008). Differences in weed response have been reported with PRE applications of saflufenacil/dimethenamid-p. Moran et al. (2011) found that common ragweed was the most difficult weed to control with saflufenacil/dimethenamid-p and as a result, could be the first weed to escape since greater than 735 g a.i. ha\(^{-1}\) was required to achieve a 95% reduction in weed dry weight. Similarly, Soltani et al. (2011) found that at 8 WAE, saflufenacil/dimethenamid-p achieved 43-57% control of giant ragweed and reduced weed density and dry weight by 77 and 78%, respectively. Common lambsquarters, pigweed species (*Amaranthus* spp.), and wild mustard (*Sinapis arvensis* L.) were more sensitive to PRE applications of saflufenacil/dimethenamid-p, with 325, 186, and 115 g a.i. ha\(^{-1}\) respectively, required to reduce weed dry weight by 95% (Moran et al. 2011).
Saflufenacil/dimethenamid-p applied PRE provided 85% control at 8 WAE and reduced cocklebur density and dry weight by 74 and 84% respectively (Soltani et al. 2010a). Using a soil-applied herbicide such as saflufenacil/dimethenamid-p prior to an in-crop application of glyphosate may provide better full season control and maximize yield in corn.

Moran (2010) concluded that there was flexibility in the effective rate of saflufenacil/dimethenamid-p when followed by an in-crop application of glyphosate in corn. Optimal corn yields were achieved with saflufenacil/dimethenamid-p applied alone at rates ranging from 368 to 1470 g a.i. ha⁻¹ (Moran 2010). When these preemergence treatments were followed by an in-crop glyphosate application at the 6 to 8 leaf stage of corn, the required rate of saflufenacil/dimethenamid-p for optimal corn yield decreased to between 46 and 1470 g a.i. ha⁻¹. A minimum of 184 g a.i. ha⁻¹ was required to increase corn yield compared to a single POST application of glyphosate at the 6 to 8 leaf stage (Moran 2010).

The use of a soil-applied herbicide in glyphosate resistant soybean can reduce the selection pressure for glyphosate resistant weeds. Mulugeta and Boerboom (2000) demonstrated that under no-till conditions, glyphosate resistant soybean must be kept free from weeds until the fourth trifoliate stage in order to maximize yield. Saflufenacil/dimethenamid-p is pending registration for use in soybean at a maximum use rate of 245 g a.i. ha⁻¹ (25:220 g a.i. ha⁻¹ of saflufenacil:dimethenamid-p) applied PP as a set-up application for a POST herbicide. The addition of a soil-applied herbicide such as saflufenacil/dimethenamid-p applied PRE in glyphosate resistant soybean can reduce the selection pressure for glyphosate resistant weeds and extend the POST application.
window for glyphosate. This will reduce weed interference and could increase soybean yield when the POST glyphosate application is delayed due to untimely rainfall, equipment breakdowns or large acreages which cannot be sprayed at the optimal time.

1.4 Soybean Tolerance

1.4.1 General

Soybean cultivars have displayed differential tolerances to several herbicides, including chlorimuron (Newsom and Shaw 1992), imidazolinone (Wixon and Shaw 1991), metribuzin (De Weese et al. 1989; Ivany et al. 1992; Mangot et al. 1979) metolachlor, dimethenamid (Osborne et al. 1995), sulfentrazone (Dayan et al. 1997; Hulting et al. 2001; Li et al. 1999, 2000a, 2000b; Swantek et al. 1998), and flumioxazin (Taylor-Lovell et al. 2001). The risk of injury from soil-applied herbicides increases with cool and wet environmental conditions shortly after planting (Hulting et al. 2001; Li et al. 2000b; Niekamp et al. 1999; Poston et al. 2008; Swantek et al. 1998), since the herbicide is more readily available for plant uptake, and cool temperatures decrease the soybean’s ability to metabolize the herbicide (Poston et al. 2008).

Extensive research has been conducted on the triazine herbicide metribuzin. The physiological basis for soybean cultivar sensitivity to metribuzin can be attributed to rapid metabolism (Mangeot et al. 1979), as well as cultivars carrying the Rps 1-k allele for Phytophthora rot (*Pythopthora megasperma*) are more tolerant (Buzzell and Hamill 1988). Even though there are soybean cultivar tolerance differences to metribuzin, it is still a herbicide that is commonly used in Ontario agriculture and through effective
management, growers have been able to minimize the risk of soybean injury while controlling weeds.

1.4.2 PPO Tolerance in Soybean

Sulfentrazone is a soil-applied phenyl triazolinone herbicide that controls many weed species in soybean and tobacco at use rates between 140 and 420 g ha\(^{-1}\) (Figure 1.3) (Hulting et al. 2001; Reiling et al. 2006; Senseman 2007). Sulfentrazone is primarily absorbed by the roots and causes necrosis and death of susceptible emerging plants after exposure to light (Wehtje et al. 1997). Injury consists of callusing of the hypocotyl arch or soybean stem at the soil surface, shortened internodal length, and speckling or necrosis of leaf tissue (Hulting et al. 2001). Depending on the environmental conditions and the time of application relative to planting, soybean can be injured from soil applications of sulfentrazone. Soybean injury from sulfentrazone can increase with cool, wet conditions shortly after planting which leads to poor soybean growth and development (Hulting et al. 2001; Niekamp et al. 1999). Additionally, PRE applications of sulfentrazone are noted as being more injurious than PP applications (Swantek et al. 1998). The closer the PRE application is to emergence, the higher the risk of soybean injury due to the fact that there is an increased level of sulfentrazone available in the soybean germination zone, which makes the herbicide more available for uptake through the hypocotyl (Hulting et al. 2001; Li et al. 2000b; Niekamp et al. 1999; Reiling et al. 2006; Swantek et al. 1998). Soil characteristics can also affect the level of soybean injury. Sulfentrazone has a pKa of 6.56 (Senseman 2007) and the potential for injury increases when the soil pH is above the pKa value because more sulfentrazone is available for plant uptake (Grey et al. 1997). Injury
symptoms from sulfentrazone can be overcome throughout the course of the growing season with no yield penalty if environmental conditions are favourable for soybean plants to compensate for reduced stand counts or early stunting (Hulting et al. 2001; Taylor-Lovell et al. 2001).

Several studies have indicated that there is differential tolerance among soybean cultivars to soil applications of sulfentrazone (Dayan et al. 1997; Hulting et al. 2001; Li et al. 1999, 2000a, 2000b; Swantek et al. 1998). Soybean cultivars can be classified as either having high, medium or low tolerance to sulfentrazone (Hulting et al. 2001; Li et al. 1999). Dayan et al. (1997) noted a 0 to 58% height reduction among five cultivars when sulfentrazone was applied at 0.5 kg ai ha\(^{-1}\). Hulting et al. (2001) also found differences in plant height ranging from 0 to 71% with 40 commonly used soybean cultivars.

Research has indicated that soybean tolerance to sulfentrazone is due to different rates of metabolism (Dayan et al. 1997; Niekamp et al. 1999; Swantek et al. 1998). Dayan et al. (1997) noted this after no recordable differences were observed in either root uptake or translocation. It was determined that cultivar differences can be attributed in part to the soybean cultivar’s ability to cope with the peroxidative stress from the herbicide at the target site (Dayan et al. 1997). Furthermore, Swantek et al. (1998) determined that tolerance to sulfentrazone among soybean cultivars appears to be controlled by a single dominant gene, with tolerance being dominant over susceptibility. However, the cultivars currently used in production have too many common ancestors and it is therefore difficult to determine how much influence one ancestral line has had over another in terms of specific herbicide tolerance (Hulting et al. 2001).
More recent studies have indicated that root absorption during the earliest stages of soybean development is the basis for the differential response among soybean cultivars (Li et al. 2000a). Sulfentrazone does not affect soybean germination in either tolerant or sensitive cultivars (Dayan et al. 1997). Therefore, cultivar differences must occur soon after the start of germination and are probably complete prior to emergence, with differential metabolism and translocation being independent of cultivar (Li et al. 2000b). Li et al. (1999) determined differences in sensitivity among 28 soybean cultivars by using a combination of field testing and in-vitro hypocotyl and root length reduction measurements. They determined that the amount of sulfentrazone absorbed by the roots was greater in sulfentrazone sensitive cultivars compared to tolerant ones and determined that the amount of sulfentrazone translocated from the roots into the cotyledon or hypocotyl tissues did not differ between sensitive and tolerant cultivars (Li et al. 2000b). Therefore, using soybean hypocotyl and root elongation in the lab, combined with field testing, can be used as a guideline for classifying soybean cultivar sensitivity to sulfentrazone.

Flumioxazin is another soil-applied PPO inhibiting herbicide and belongs to the N-phenylphthalimide family (Figure 1-4) (Senseman 2007). Although flumioxazin and sulfentrazone have the same mode of action, differences in cultivar sensitivity with flumioxazin may be unrelated to those with sulfentrazone (Taylor-Lovell et al. 2001). Taylor-Lovell et al. (2001) determined in greenhouse testing that sulfentrazone was more injurious than flumioxazin for 40 common soybean cultivars. This could have been due to the differential degradation of the two herbicides (Taylor-Lovell et al. 2001), with a soil half-life of 11.9 to 17.5 days for flumioxazin, and 121 to 302 days for sulfentrazone.
(Senseman 2007). The cultivars most sensitive to flumioxazin were different from those that were sensitive to sulfentrazone, indicating that the soybean tolerance mechanisms may be different for the two herbicides (Taylor-Lovell et al. 2001). More research will need to be conducted to determine soybean cultivar sensitivity with different soil-applied PPO inhibiting herbicides.

1.4.3 Saflufenacil Tolerance in Soybean

Saflufenacil is a relatively new herbicide for soybean producers, and very few studies have been conducted on soybean cultivar tolerance to saflufenacil. Studies have reported differences in cultivar sensitivity to saflufenacil with soybean (Hixson 2008), proso millet (Panicum miliaceum L.) (Lyon and Kniss 2010), and grain sorghum (Sorghum bicolor L.) (Brown 2010). Soybean tolerance to saflufenacil applied PP at 18 to 25 g a.i. ha\(^{-1}\) is considered to be good to excellent (Hixson et al. 2008). Soltani et al (2010b) found that the soybean cultivar DK 28-52R was tolerant up to 100 g a.i. ha\(^{-1}\) of saflufenacil, but Hixson (2008) reported that the soybean cultivar Hutcheson was sensitive. Weather conditions shortly after applications of saflufenacil reportedly affect the level of crop injury. Stunting and necrosis could be attributed to cool, wet conditions following planting, with newly emerged tissue from the seed being the most susceptible to saflufenacil (Hixson 2008). If significant rainfall occurred prior to crop emergence and if saflufenacil moved into the root zone, injury was more likely to occur since soybean plants were able to absorb saflufenacil through both emerging shoot and root tissue, with the most severe injury occurring when shoot, roots and seed are all exposed (Hixson 2008).
1.5 Study Objectives

The purpose of this research is to determine weed control and cultivar tolerance to saflufenacil in soybean. Over the past decade, soybean producers in Canada have become dependent on glyphosate to control emerged weeds. With the increase in the number of glyphosate resistant weed species, herbicides with different modes of action will be required to control resistant biotypes. However, herbicide screening for soybean cultivar tolerance to new soil applied herbicides has not been routinely conducted in recent years (Poston et al. 2008). Since saflufenacil is a relatively new herbicide for use in soybean, the objectives of this research were:

1. To determine the biologically effective rate of saflufenacil/dimethenamid-p applied PRE as a set-up treatment for glyphosate applied POST in glyphosate resistant soybean.

2. To determine the tolerance of 12 glyphosate tolerant soybean cultivars grown in Ontario to saflufenacil.

1.5 Hypotheses

1. There is no difference in control among weed species to applications of saflufenacil/dimethenamid-p applied PRE in soybean.

2. There is no difference among soybean cultivars in their tolerance to saflufenacil applied PRE.
Figure 1.1: The structure of saflufenacil (Grossmann et al. 2011).
Figure 1.2: The biosynthetic pathway of chlorophyll and heme production in plants. (Devine et al. 1993).

\[ \delta \text{-Aminolevulinic acid (\(\delta\text{-ALA}\))} \]
\[ \rightarrow \text{Porphobilinogen} \]
\[ \rightarrow \text{Uroporphyrinogen III} \]
\[ \rightarrow \text{Protoporphyrinogen IX} \]
\[ \text{Protoporphyrinogen IX oxidase} \]
\[ \text{H}_2\text{O}_2 \]
\[ \text{Protoporphyrin IX} \]
\[ \text{Fe – chelatase} \]
\[ \text{Mg-chelatase} \]
\[ \text{Heme} \]
\[ \text{Mg-Portoporphyrin IX} \]
\[ \text{Chlorophyll} \]
Figure 1.3. The chemical structure of sulfentrazone (Dayan et al. 1998).
Figure 1.4. The chemical structure of flumioxazin (Grossmann et al. 2011).
2.0 Biologically Effective Rate of saflufenacil/dimethenamid-p in Soybean (*Glycine max*)

2.1 Abstract

A total of five field studies were conducted over a two-year period (2009, 2010) at three Ontario locations to determine the biologically effective rate of saflufenacil/dimethenamid-p applied preemergence (PRE) for the control of annual weeds in soybean. The rate of saflufenacil/dimethenamid-p required for the control of annual weeds was influenced by environmental conditions. With adequate moisture and above average temperatures in 2010, between 224 and 374 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p was required for 80% control of common ragweed, common lambsquarters, and green foxtail 4 weeks after treatment (WAT). In contrast, below average temperatures and excessive moisture in 2009 resulted in higher rates of saflufenacil/dimethenamid-p being necessary for the same level of weed control. Pigweed species were least affected by environmental conditions after application at 4 WAT with only 245 g a.i. ha\(^{-1}\) required for 80% control in both years. By 11 WAT, 320 g a.i. ha\(^{-1}\) or less of saflufenacil/dimethenamid-p was required to achieve 80% control of all species in 2010, while 845 g a.i. ha\(^{-1}\) or more was needed in 2009 for equivalent control. The potential of saflufenacil/dimethenamid-p as a set-up treatment prior to a postemergence (POST) glyphosate application was also examined. Excellent full season control of all weed species was achieved with saflufenacil/dimethenamid-p applied PRE followed by glyphosate POST. However, there was no difference in yield when
saflufenacil/dimethenamid-p was followed by glyphosate POST compared to a single glyphosate POST application.

2.2 Introduction

Glyphosate resistant technology has been widely accepted by soybean producers in North America since its introduction in 1996. With multiple glyphosate resistant crops on the market and a reduction in tillage practices, there is a tendency to rely solely on glyphosate for weed control in these crops year after year. Consequently, there is greater selection pressure on weed communities due to a limited number of herbicides with different modes of action being used (Owen and Zelaya 2005). Although glyphosate is a broad-spectrum herbicide, weed shifts to naturally tolerant species and glyphosate resistant weeds are an increasing concern. Currently there are 12 weed species that are resistant to glyphosate in the United States and three in Canada (Heap 2011).

One way to reduce the selection pressure for glyphosate resistant weeds is to use soil-applied herbicides in glyphosate resistant cropping systems. In order to maximize yield in no-till glyphosate resistant soybean, the crop must be kept free from weeds until the fourth trifoliate stage (Mulugeta and Boerboom 2000). Soil-applied herbicides can change the spectrum of weeds that emerge in the crop (Corrigan and Harvey 2000), and decrease the need for subsequent POST tank mixtures with glyphosate (Taylor-Lovell et al. 2002). Gonzini et al. (1999) reported more consistent weed control when glyphosate followed a PRE residual herbicide compared to a single POST glyphosate application. Ellis and Griffin (2002) determined that in situations where a soil-applied herbicide was used in soybean production, only a single POST application of glyphosate was needed to
control weeds. Although reduced rates of soil-applied herbicides may not provide season-long control, the reduction in weed growth can extend the POST herbicide application window depending on the weed species and density (Ellis and Griffin 2002).

Saflufenacil is a new herbicide for burndown and residual broadleaf weed control in multiple crops (Liebl et al. 2008). It effectively controls many key broadleaf species, including acetolactate synthase (ALS), triazine and glyphosate resistant biotypes (Anonymous 2008; Liebl et al. 2008). Sensitive broadleaf weed species are controlled through the inhibition of protoporphyrinogen IX oxidase (PPO), an important enzyme in the synthesis of chlorophyll (Grossmann et al. 2010). Saflufenacil is readily absorbed by root and shoot tissue of plants. Once absorbed, it is predominantly translocated via xylem tissue, with relatively low movement via the phloem (Bowe et al. 2008). PRE applications can control troublesome weeds such as velvetleaf (Abutilon theophrasti Medik.), redroot pigweed (Amaranthus retroflexus L.), common ragweed (Ambrosia artemisiifolia L.), and common lambsquarters (Chenopodium album L.) (Anonymous 2008; Liebl et al. 2008). In corn, a premix formulation of saflufenacil and dimethenamid-p in a 1:8.8 ratio provides control of annual grass and broadleaf weeds at the registered use rate of 735 g a.i. ha$^{-1}$ (75:660 g a.i. ha$^{-1}$, respectively) (Anonymous 2008). Saflufenacil/dimethenamid-p is pending registration for use in soybean at a maximum use rate of 245 g a.i. ha$^{-1}$ (25:220 g a.i. ha$^{-1}$ of saflufenacil:dimethenamid-p) applied prior to planting as a set-up application for a POST herbicide.

Dimethenamid-p is a chloroacetamide herbicide that inhibits very long chain fatty acid biosynthesis (Senseman 2007). It can be applied prior to soybean emergence to control many annual grasses such as foxtail species (Setaria spp.), barnyardgrass
(Echinochloa crusgalli L.), fall panicum (Panicum dichotomiflorum Michx.), and crabgrass species (Digitaria spp.), as well as certain annual broadleaf weeds such as redroot pigweed and eastern black nightshade (Solanum ptycanthum Dunal) (OMAFRA 2010; Senseman 2007). Dimethenamid-p is absorbed though the shoots and roots of emerging broadleaf weeds and through the coleoptile in grasses (Senseman 2007).

In corn, the application of a PRE residual herbicide prior to an in-crop application of glyphosate can improve weed control, increase yield, and eliminate the need for multiple applications of glyphosate (Nurse et al. 2006). Moran (2010) concluded that there is flexibility in the biologically effective rate of a soil-applied herbicide when followed by an in-crop application of glyphosate. Optimal corn yields were achieved with saflufenacil/dimethenamid-p applied alone at rates ranging from 368 to 1470 g a.i. ha⁻¹ (Moran 2010). When these PRE treatments were followed by an in-crop glyphosate application at the 6 to 8 leaf stage of corn, the required rate of saflufenacil/dimethenamid-p for optimal corn yield dropped to between 46 and 1470 g a.i. ha⁻¹, with a minimum of 184 g a.i. ha⁻¹ required to increase yield compared to a single POST application of glyphosate (Moran 2010). Similarly, Norsworthy (2004) showed that in a wide-row soybean production system, a soil-applied herbicide followed by glyphosate can improve yields by reducing early season weed competition. Legleiter et al. (2009) determined that in the presence of glyphosate resistant biotypes, a single POST glyphosate application resulted in lower yields compared to a soil-applied herbicide followed by glyphosate POST.

The level of residual broadleaf weed control that saflufenacil/dimethenamid-p applied PRE at 245 g a.i. ha⁻¹ will provide in soybean is unknown. It is hypothesized that there is
no difference in control among weed species to applications of saflufenacil/dimethenamid-p applied PRE in soybean. The objective of this study was to determine the biologically effective rate of saflufenacil/dimethenamid-p applied PRE in soybean alone and prior to an in-crop glyphosate application.

2.3 Materials and Methods

A total of five field research trials were conducted near Bryanston, Maryhill, and Ridgetown, Ontario over a two-year period (2009-2010). The soil characteristics for each site are presented in Table 2-1. Seedbed preparation at the Bryanston and Maryhill (2009) sites consisted of spring offset disk, followed by two passes with a cultivator with rolling basket harrows. In 2010, seedbed preparation consisted of an offset disk the previous fall, followed by two passes with a cultivator with rolling basket harrows in the spring. At Ridgetown, seedbed preparation consisted of fall moldboard plowing, followed by two passes with a cultivator with rolling basket harrows in the spring.

The experiments were established as a randomized complete block design with 4 replications. All sites were fertilized based on soil test results. Glyphosate resistant cultivars were selected for each location based on maturity (Table 2-3). Soybean was seeded at 470 000 seeds ha\(^{-1}\) at Bryanston and Maryhill, and 480 000 seeds ha\(^{-1}\) at Ridgetown. Each plot consisted of four rows of soybean spaced 75 cm apart that were 8.0 m in length. PRE applications were made within two days of planting, and the POST treatments were applied at the fourth trifoliate (Table 2-2). A CO\(_2\) pressurized backpack sprayer was used to deliver 200 L ha\(^{-1}\) of water at 275 kPa with Teejet 110-02 flat-fan nozzle tips (Spraying Systems Co., North Avenue and Schmale Road, Wheaton, IL
60188) at the Bryanston and Maryhill sites, and 241 kPa with Hypro Ultra low drift 120-02 nozzle tips (Hypro, New Brighton, MN) at Ridgetown. Weed-free control plots were maintained using a combination of glyphosate and hand-weeding when needed.

Saflufenacil/dimethenamid-p was applied PRE at 30.6, 61.3, 122.5, 245, 490 and 980 g a.i. ha\(^{-1}\) either alone or followed by an in-crop application of glyphosate (900 g a.i. ha\(^{-1}\)) at the fourth trifoliate (Table 2-4). Visible crop injury was rated on a scale of 0 to 100 (0=no visible crop injury and 100=plant death) at 1, 2, and 4 weeks after soybean emergence (WAE). Weed assessments were rated as a percentage of the untreated control with 0=no control and 100=no visible plants at 2, 4, 7, 11, and 15 weeks after the PRE treatment (WAT). In addition to visual control assessments, weed density and dry weight data were collected at 8 WAT from treatments 1 and 3 to 8 (Table 2-4). All other treatments previously received an in-crop glyphosate application, therefore there were no weeds present. Weeds in two random 0.5 m\(^2\) quadrants per plot were counted, the weeds were then cut at ground level, separated by species and placed into paper bags. The weeds were then kiln-dried at approximately 80°C to a constant weight before weighing. The centre two rows of each soybean plot were machine harvested at maturity, and moisture was adjusted to 13.0%.

2.3.1 Statistical analysis

All data were subjected to analysis of variance using the MIXED procedure in SAS (Ver. 9.2, SAS Institute Inc., Cary, NC). The Shapiro-Wilk test for normality and residual plots were used to confirm that the assumptions of the variance analysis (errors were random, independent, and normally distributed with a mean of zero) were met. The rate
of saflufenacil/dimethenamid-p was a fixed effect, with random effects consisting of environment (composed of year and location), replicate within environment, and the environment by rate interaction. Significance of random effects and their interaction with fixed effects were tested using the Z-test of the variance estimate, while the significance of fixed effects were tested using the F-test. Environments were combined where a non significant (P>0.05) environment by treatment interaction was present. In 2010, Maryhill (environment 5) had extreme and inconsistent weed pressure, and was therefore excluded from the analysis.

2.3.2 Statistical Analysis – Regression

Prior to the POST application of glyphosate, data were pooled for treatments that received an identical rate of saflufenacil/dimethenamid-p for crop injury and for weed control at 2 and 4 WAT. Only the treatments which did not receive glyphosate POST were used for regression analysis at 7, 11, and 15 WAT. Non-linear regression (PROC NLIN in SAS) was used to evaluate the response of crop injury, weed control, density, and dry weight. Weed density and dry weight were converted to a percentage of the untreated control for analysis. An exponential regression equation was used to describe the percent crop injury as a function of saflufenacil/dimethenamid-p rate:

\[ Y = a \times \exp(b \times \ln \text{rate}) \]  

[1]

where \( Y \) is the percent crop injury, \( a \) is the magnitude constant, and \( b \) is the rate constant. If the data did not exhibit an exponential form, a segmented linear regression was used instead (Bowely 2008):
\[ Y_L = a_0 + b_1 \times \text{rate} \]  \[ 2a \]
\[ Y_R = a_0 + b_1 \times j + b_{r1} \times (\text{rate} - j) \]  \[ 2b \]

where \( Y_L \) and \( Y_R \) represent the left and right segments, respectively, \( a_0 \) is the intercept of the left segment, \( b_1 \) is the slope of the left segment, \( b_{r1} \) is the slope of the right segment, and \( j \) is the junction point of the two segments. The regression equations were used to calculate ER5, 10, and 20 values, which correspond to the effective rates of saflufenacil/dimethenamid-p that caused 5, 10, and 20 percent visual crop injury, respectively.

A four-parameter log-logistic function was used to regress weed control, density and dry weight assessments over saflufenacil/dimethenamid-p rate (Seefeldt et al. 1995):

\[ Y = C + (D - C) / \{1 + \exp \left[ B \times (\ln \left( \text{rate} \right) - \ln \left( I_{50} \right) ) \right]\} \]  \[ 3 \]

where \( Y \) is percent weed control or density or dry weight, \( C \) is the lower limit, \( D \) is the upper limit, \( B \) is the slope of the line (negative for weed control), and \( I_{50} \) is the rate required to give 50 percent of the total response between the upper and lower limit. For weed control, the lower limit corresponded to the mean response of the untreated control. For density and dry weight, the upper limit corresponded to the mean response of the untreated control. Weed species were selected based on uniformity across all replicates of the untreated control. After examination of the residuals, if one replicate within an environment had a low density or dry weight, that replicate was removed from the analysis. Where Eq. 3 was not appropriate for the weed control data, a segmented linear regression was used (Eq. 2a and 2b). If Eq. 3 did not adequately describe the relationship for weed density or dry weight, an inverse exponential function was used (Chism et al., 1992):
\[ Y = e + f \cdot \exp(-g \cdot \text{rate}) \]  \[4\]

where \( e \) is the lower asymptote, \( f \) is the reduction in \( Y \) from intercept to \( e \), and \( g \) is the slope. In the one case where Eq. 3 and 4 were insufficient for dry weight, linear regression was used:

\[ Y = h \cdot \text{rate} + k \]  \[5\]

where \( h \) is the slope and \( k \) is the \( Y \) intercept.

The regression equations were used to calculate ER50, 80, and 95 values, which correspond to the biologically effective rates of saflufenacil/dimethenamid-p that were required to achieve 50, 80, and 95 percent weed control, or a 50, 80, and 95 percent reduction in density and dry weight, respectively.

2.3.3 Statistical Analysis - Contrasts

Percent weed control evaluations after the POST glyphosate application at 7, 11 and 15 WAT were compared using contrasts in PROC MIXED of SAS. To satisfy the assumptions of normality, data for weed control and yield (as a percent of the weed free control), were arcsine square root transformed, with the exception of common lambsquarters (CHEAL) (7 WAT, environments 2 and 3) and pigweed species (AMASS) (15 WAT, environments 4 and 6) which were square root transformed, and CHEAL (11 WAT, environments 2 and 3 and common ragweed (AMBEL) 11 WAT, environment 1) which needed no transformation. Two sets of contrasts were evaluated: a) glyphosate applied POST vs saflufenacil/dimethenamid-p applied PRE followed by glyphosate POST, and b) saflufenacil/dimethenamid-p PRE vs saflufenacil/dimethenamid-p PRE
followed by glyphosate. Means were transformed back to the original scale for presentation.

2.4 Results and Discussion

Environments were combined when the environment by treatment interaction was not significant. Temperatures in 2009 were average to below average in May, and below average in June and July at all locations (Table 2-5). At Ridgetown in 2009, precipitation was also much lower than average (Table 2-6), with less than 20 mm of rain within 21 days of the PRE application (DAT) (Table 2-7). Precipitation at Bryanston in 2009 was above average, while Maryhill was average (Table 2-6); however, there was 112.6 and 51 mm of precipitation within the first 7 days after application at these two locations, respectively (Table 2-7). Due to below average temperatures and excessive moisture at these locations after planting, soybean emergence took 13 and 17 days at Bryanston and Maryhill, respectively, in 2009 (Table 2-2). With this delay in soybean emergence combined with cooler temperatures in June and July, there was the potential for a reduction in the soybean canopy which may have resulted in more competition from weeds (Yelverton and Colbe 1991).

In 2010, temperatures at Bryanston and Ridgetown were average to above average (Table 2-5), with adequate precipitation (Table 2-6). Higher temperatures, combined with adequate moisture prior to planting and within the first 21 DAT (Table 2-7), resulted in soybean emergence within 4 days at Ridgetown and 7 days at Bryanston in 2010 (Table 2-2).
2.4.1 Crop Injury

At Maryhill (2009) and Bryanston (2010), less than 5% soybean injury was observed with 980 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p at 1 and 2 WAE (Table 2-8). Soybean injury consisted of stunting, chlorosis, and necrosis. At the other locations, 663 and 779 g a.i. ha\(^{-1}\) resulted in 10% soybean injury at 1 and 2 WAE, respectively. There was no crop injury observed at Ridgetown (2009) at 4 WAE (data not shown). All other locations were combined at 4 WAE with 645 and 857 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p resulting in 5 and 10% injury, respectively. Across all environments, the rate of saflufenacil/dimethenamid-p that resulted in 5% injury was greater than the proposed registered use rate of 245 g a.i. ha\(^{-1}\). These results are similar to those by Soltani et al. (2010b), who found 6% injury when saflufenacil was applied PRE in soybean at 100 g a.i. ha\(^{-1}\). Hixson (2008) determined that soils with an organic matter content greater than 4% have a higher affinity for saflufenacil, and therefore less herbicide is available for plant uptake. This may explain why minimal soybean injury was observed with saflufenacil/dimethenamid-p at 2 and 4 times the registered use rate, since the soil at all locations had organic matter content greater than 4% (Table 2-1).

2.4.2 Weed Control

The environment by treatment interaction were not significant for visible control of barnyard grass, green foxtail and pigweed species at 2 WAT, therefore environments were combined. At 2 WAT, the rate of saflufenacil/dimethenamid-p required to provide 80% control of green foxtail, barnyard grass and pigweed species was 168, 175 and 140 g a.i. ha\(^{-1}\), respectively (Table 2-9). Pigweed species included redroot pigweed
(Amaranthus retroflexus L.) and green pigweed (Amaranthus powelli S. Watson). The rates of saflufenacil/dimethenamid-p required to control velvetleaf, lambsquarters, and common ragweed were more dependent on environmental conditions shortly after application. When temperature and rainfall were not limiting factors (Bryanston and Ridgetown 2010), the rates of saflufenacil/dimethenamid-p required to achieve 80% control of velvetleaf, lambsquarters, and ragweed were 131, 142 and 203 g a.i. ha⁻¹, respectively (Table 2-9). However, the rates required for the same level of control under cool and wet (Bryanston 2009) or cool and dry (Ridgetown 2009) conditions were double for ragweed and more than five times for lambsquarters and velvetleaf (Table 2-9).

Saflufenacil/dimethenamid-p applied PRE at 245 g a.i. ha⁻¹ provided 80% control of pigweed species regardless of environment at 4 WAT (Table 2-10), while temperature and the amount of moisture following application continued to have an impact on the control of the other weed species in this study. At Ridgetown in 2009, which was cool and dry (Tables 2-5 and 2-6), 790 g a.i. ha⁻¹ of saflufenacil/dimethenamid-p was required to achieve 80% control of velvetleaf, while only 224 g a.i. ha⁻¹ was needed for the same level of velvetleaf control under the warm temperatures and normal precipitation at Ridgetown in 2010 (Table 2-10). Lambsquarters, ragweed, green foxtail, and barnyard grass followed the same trend as velvetleaf. When conditions were optimal in 2010 at Bryanston and Ridgetown, the rate of saflufenacil/dimethenamid-p needed for 80% control of these weeds ranged from 227 to 374 g a.i. ha⁻¹ (Table 2-10). However, under less than optimal conditions such as those experienced in 2009 resulted in close to double these rates of saflufenacil/dimethenamid-p being necessary for the same level of control of these weeds (Table 2-10).
As the season progressed, the effect of environmental conditions on the saflufenacil/dimethenamid-p rates needed to achieve 80% control of the various weed species continued to be apparent. At 7 WAT, under near optimal conditions in 2010 at Bryanston and Ridgetown, less than 400 g a.i. ha⁻¹ of saflufenacil/dimethenamid-p provided 80% control of pigweed, ragweed, velvetleaf, barnyard grass and green foxtail (Table 2-11). The same weeds required 674 to 936 g a.i. ha⁻¹ of saflufenacil/dimethenamid-p for 80% control at Bryanston and Ridgetown in 2009, which both had less than optimal temperatures and precipitation. Lambsquarters was the only exception, needing 609 g a.i. ha⁻¹ of saflufenacil/dimethenamid-p for 80% control at all locations (Table 2-11).

By 11 WAT, 320 g a.i. ha⁻¹ or less of saflufenacil/dimethenamid-p was required for 80% control of pigweed, lambsquarters, ragweed, velvetleaf, and green foxtail in 2010 at Bryanston and Ridgetown (Table 2-12). These same weeds needed 845 g a.i. ha⁻¹ or more of saflufenacil/dimethenamid-p for 80% control at all locations in 2009. Weed control data at 15 WAT was similar to 11 WAT (data not shown).

The results of this study are consistent with the findings of Knezevic et al. (2009b) and Moran (2010), who concluded that the rates of saflufenacil and saflufenacil/dimethenamid-p required to achieve 50, 80, and 95% control was weed species dependent. Environmental conditions at and after application of saflufenacil/dimethenamid-p influenced the rate required for weed control in this study. Pigweed species were more sensitive to PRE applications of saflufenacil/dimethenamid-p and were less affected by environment than other weed species. In addition to saflufenacil having activity on pigweed species (Anonymous 2008; Geier et al. 2009 Liebl et al.
the dimethenamid-p component also has activity on selected small seeded
broadleaf weeds (OMAFRA 2010; Senseman 2007;), which may have contributed to the
control of pigweed at a lower rate. These results are consistent with those of Geier et al.
(2009), who showed that after 22 DAT in a greenhouse, an 82 to 98% reduction in weed
biomass of three amaranthus species (palmer amaranth, redroot pigweed, and tumble
pigweed) was achieved when saflufenacil was applied PRE at 6 to 30 g a.i. ha⁻¹. Soybean
plants were delayed in emergence in 2009 at Bryanston and Maryhill compared to 2010 (Table 2-2). With this delay in soybean emergence, a delay in canopy closure occurred (data not shown) which may have resulted in more competition from weed species for light and nutrients (Yelverton and Colbe 1991). This may also have impacted the growth and development of weeds such as ragweed which has a rapid growth rate in July and August (Bassett and Cromption 1975), as well as common lambsquarters which emerges from April until mid-July (Hilgenfeld et al. 2004; Leblanc et al. 2004). Stewart et al. (2010) concluded that there was a reduction in lambsquarters and ragweed control in environments with low precipitation between 7 days before and after a PRE herbicide application. Also, there was lower lambsquarters and green foxtail control when the cumulative precipitation during the 12 days after application exceeded the monthly average by at least 60% (Stewart et al. 2010).

2.4.3 Weed density and dry weight

The effect of saflufenacil/dimethenamid-p on density and dry weight of pigweed
species was less influenced by environmental conditions than for other weed species in
this experiment. At 8 WAT, 234 and 247 g a.i. ha⁻¹ of saflufenacil/dimethenamid-p were
required to reduce weed density and dry weight, respectively, by 80% across all environments (Tables 2-13 and 2-14). Similar to weed control, environmental conditions following the application of saflufenacil/dimethenamid-p influenced the rates necessary for reducing weed density and dry weight. Locations with sufficient moisture for activation and above average temperatures required lower rates to reduce weed density by 50, 80, and 95 percent of the untreated control. For example, at Ridgetown in 2009, 238 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p was required to reduce velvetleaf density by 80%, compared to only 92 g a.i. ha\(^{-1}\) in 2010. However, lower rates of saflufenacil/dimethenamid-p were required to reduce velvetleaf dry weight in a dry environment (Ridgetown 2009) compared to one with adequate moisture (Ridgetown 2010). This indicates that there were more small velvetleaf seedlings that emerged in a dry environment once sufficient moisture occurred, and fewer but larger velvetleaf plants were present in environments with warm, moist conditions following application. Under the cool wet conditions at Bryanston in 2009, in order to reduce ragweed density by 80%, 491 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p was required compared to 200 g a.i. ha\(^{-1}\) in 2010. Similarly, more than 980 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p was required to reduce ragweed dry weight in 2009 compared to 124 g a.i. ha\(^{-1}\) in 2010. Therefore, under warm, moist conditions, lower rates of saflufenacil/dimethenamid-p reduced the density of velvetleaf and ragweed, but higher rates were required to reduce weed dry weight. Westhoven et al. (2008) determined that when a preplant residual herbicide was used in a glyphosate resistant soybean system, the population density of common lambsquarters was reduced at the time of a POST application of glyphosate, compared to not using a residual herbicide. Only 171 g a.i. ha\(^{-1}\) of saflufenacil/dimethenamid-p was required to
reduce lambsquarters density by 80%. However, the rate necessary for an 80% reduction in lambsquarters dry weight increased to 416 g a.i. ha$^{-1}$. Nurse et al. (2007) found that with the suppression of annual grasses and other weeds in treated plots, an increase in the biomass of lambsquarters occurred due to a decrease in interspecific competition for resources.

Orthogonal contrasts were used to compare a single application of glyphosate POST to saflufenacil/dimethenamid-p applied PRE followed by glyphosate POST at the fourth trifoliate. When the environment by treatment interaction was not significant, environments were combined. Even though there was limited moisture for activation early in the year at Ridgetown (2009), it was minimally beneficial to add 245 g a.i. ha$^{-1}$ or more of saflufenacil/dimethenamid-p PRE followed by glyphosate compared to glyphosate alone POST to control barnyard grass at 11 WAT (Table 2-15). Since grass species are more sensitive to glyphosate than broadleaf weeds (Jordan et al. 1997; Krausz et al. 1996), glyphosate applied POST provided excellent control of all grass species shortly after application. At Ridgetown in 2010, the addition of 61 g a.i. ha$^{-1}$ or more of saflufenacil/dimethenamid-p PRE followed by glyphosate provided better control of lambsquarters compared to glyphosate alone at 11 WAT, however, the difference was only 1% (Table 2-15). There was no benefit to adding saflufenacil/dimethenamid-p PRE for the control of lambsquarters in the other environments. These results agree to those of Nurse et al. (2007) and Stewart et al. (2010) who showed that a PRE soil-applied application followed by glyphosate did not improve common lambsquarters control compared to a single application of glyphosate POST.
Taylor-Lovell et al. (2002) determined that velvetleaf control was better when using a PRE soil-applied herbicide followed by a POST herbicide, compared to using only a POST herbicide. Under warm, moist conditions at Ridgetown in 2010, 122 g a.i. ha$^{-1}$ of saflufenacil/dimethenamid-p applied PRE followed by glyphosate POST increased the control of velvetleaf compared to glyphosate alone at 11 WAT (Table 2-15). However, under dry conditions following application at Ridgetown in 2009, 980 g a.i. ha$^{-1}$ of saflufenacil/dimethenamid-p was required to provide a benefit compared to a single application of glyphosate. Hixson (2008) concluded that a small amount of movement of saflufenacil could lead to increased efficacy on larger seeded broadleaf weeds such as velvetleaf, which may explain why less saflufenacil/dimethenamid-p was required at Ridgetown in 2010.

2.4.4 Soybean Yield

Although there was an increase in weed control using a soil-applied herbicide before a glyphosate application in soybean, no differences in yield were detected when saflufenacil/dimethenamid-p was applied PRE followed by glyphosate POST compared to glyphosate applied alone at the fourth trifoliate (Table 2-15). These results are similar to those of other studies that found no yield benefit to using a soil-applied herbicide followed by glyphosate POST compared to glyphosate alone POST in soybean (Corrigan and Harvey 2000; Ellis and Griffin 2002; Krausz and Young 2003; Nurse et al. 2007).
2.5 Conclusion

Most soil-applied herbicides require moisture to dissolve the herbicide into a soil-water solution so that it can be taken up by developing weed seedlings (Buhler and Werling 1989; Salzman and Renner 1992). Under cool, wet growing conditions, water soluble herbicides such as saflufenacil (Hixson 2008), and dimethenamid-p (Senseman 2007) can readily move through the soil profile which can result in reduced weed control. Saflufenacil/dimethenamid-p biologically effective rates varied depending on weed species. Therefore, the hypothesis that there is no difference in control among weed species to applications of saflufenacil/dimethenamid-p applied PRE in soybean is rejected. Weed control with saflufenacil/ dimethenamid-p is influenced by weed species and environmental conditions after planting. With below average temperatures and excessive moisture at Bryanston and Maryhill in 2009, weed control was reduced compared to 2010, which had adequate moisture and above average temperatures. Conversely, Ridgetown (2009) did not receive sufficient moisture for activation and higher rates of saflufenacil/dimethenamid-p were required for adequate weed control in the first four weeks after application. Therefore, in environments with adequate moisture and average to above average temperatures, it is more beneficial to add saflufenacil/dimethenamid-p PRE followed by glyphosate POST compared to a single application of glyphosate POST in order to control velvetleaf. When below average temperatures are coupled with either excessive moisture or dry conditions at planting, it is not as advantageous to apply saflufenacil/dimethenamid-p PRE in a glyphosate resistant soybean production system.
The addition of a soil-applied herbicide such as saflufenacil/dimethenamid-p applied PRE in glyphosate resistant soybean will reduce the selection pressure for glyphosate resistant weeds and will extend the POST application window for glyphosate. This will reduce weed interference and increase soybean yield when the POST glyphosate application is delayed due to untimely rainfall, equipment breakdowns or large acreages which cannot be sprayed at the optimal time. More research will need to be conducted in order to determine which soybean cultivars are sensitive to saflufenacil (Hixson 2008) and if there is the potential to increase the rate of saflufenacil/dimethenamid-p above the current registered rate so that there is an increase in the length of residual weed control.
Table 2-1. Soil characteristics for each location, including soil type, percent composition of sand, silt, clay, organic matter and pH.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Soil type</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>OM</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston</td>
<td>2009</td>
<td>Silty Loam</td>
<td>32</td>
<td>51</td>
<td>17</td>
<td>5.1</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Silty Loam</td>
<td>32</td>
<td>51</td>
<td>17</td>
<td>5.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>Sandy Loam</td>
<td>58</td>
<td>37</td>
<td>5</td>
<td>4.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>Clay Loam</td>
<td>33</td>
<td>33</td>
<td>34</td>
<td>5.7</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Sandy Clay Loam</td>
<td>55</td>
<td>24</td>
<td>21</td>
<td>4.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>
Table 2-2. Planting, soybean emergence, herbicide application and harvest dates in each year at each location for the biologically effective rate of saflufenacil/dimethenamid-p alone and as a set-up in glyphosate resistant soybean.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Planting</th>
<th>PRE application</th>
<th>Emergence</th>
<th>POST application</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston</td>
<td>2009</td>
<td>21-May</td>
<td>22-May</td>
<td>3-Jun</td>
<td>6-Jul</td>
<td>19-Oct</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>17-May</td>
<td>19-May</td>
<td>25-May</td>
<td>25-Jun</td>
<td>24-Sept</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>22-May</td>
<td>23-May</td>
<td>8-Jun</td>
<td>9-Jul</td>
<td>20-Oct</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>21-May</td>
<td>23-May</td>
<td>27-May</td>
<td>1-Jul</td>
<td>20-Oct</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>27-May</td>
<td>28-May</td>
<td>1-Jun</td>
<td>1-Jul</td>
<td>7-Oct</td>
</tr>
</tbody>
</table>

* Abbreviations: POST, postemergence; PRE, preemergence.
Table 2-3. Glyphosate resistant tolerant soybean cultivars used in each year at each location.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Cultivar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston</td>
<td>2009</td>
<td>Dekalb 26-55R</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Dekalb 27-60RY</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>Dekalb 00-99R</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>Dekalb 31-10RY</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Dekalb 36-60RY</td>
</tr>
</tbody>
</table>
Table 2-4. Herbicide treatments and application timing to determine the biologically effective rate of saflufenacil/dimethenamid-p alone PRE and as a set-up for a POST application of glyphosate in soybean.\(^a\)

<table>
<thead>
<tr>
<th>Trt</th>
<th>Herbicide</th>
<th>Application Timing</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>untreated check</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>weed-free check</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>30.6</td>
</tr>
<tr>
<td>4</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>61.3</td>
</tr>
<tr>
<td>5</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>122.5</td>
</tr>
<tr>
<td>6</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>245</td>
</tr>
<tr>
<td>7</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>490</td>
</tr>
<tr>
<td>8</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>980</td>
</tr>
<tr>
<td>9</td>
<td>glyphosate</td>
<td>POST</td>
<td>900</td>
</tr>
<tr>
<td>10</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>30.6</td>
</tr>
<tr>
<td></td>
<td>glyphosate</td>
<td>POST</td>
<td>900</td>
</tr>
<tr>
<td>11</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>61.3</td>
</tr>
<tr>
<td></td>
<td>glyphosate</td>
<td>POST</td>
<td>900</td>
</tr>
<tr>
<td>12</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>122.5</td>
</tr>
<tr>
<td></td>
<td>glyphosate</td>
<td>POST</td>
<td>900</td>
</tr>
<tr>
<td>13</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>245</td>
</tr>
<tr>
<td></td>
<td>glyphosate</td>
<td>POST</td>
<td>900</td>
</tr>
<tr>
<td>14</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>490</td>
</tr>
<tr>
<td></td>
<td>glyphosate</td>
<td>POST</td>
<td>900</td>
</tr>
<tr>
<td>15</td>
<td>saflufenacil/dimethenamid-p</td>
<td>PRE</td>
<td>980</td>
</tr>
<tr>
<td></td>
<td>glyphosate</td>
<td>POST</td>
<td>900</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: POST, postemergence; PRE, preemergence; Trt, treatment.
Table 2-5. Mean and 30 year average temperatures for Bryanston, Maryhill, and Ridgetown from May to August in 2009 and 2010.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>May Mean</th>
<th>30 year avg</th>
<th>June Mean</th>
<th>30 year avg</th>
<th>July Mean</th>
<th>30 year avg</th>
<th>August Mean</th>
<th>30 year avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston\textsuperscript{b}</td>
<td>2009</td>
<td>13.0</td>
<td>13.0</td>
<td>17.5</td>
<td>18.0</td>
<td>18.3</td>
<td>20.5</td>
<td>19.7</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>15.2</td>
<td>13.0</td>
<td>19.1</td>
<td>18.0</td>
<td>22.0</td>
<td>20.5</td>
<td>21.7</td>
<td>19.5</td>
</tr>
<tr>
<td>Maryhill\textsuperscript{c}</td>
<td>2009</td>
<td>11.9</td>
<td>12.9</td>
<td>16.4</td>
<td>18.0</td>
<td>17.3</td>
<td>20.2</td>
<td>18.7</td>
<td>19.3</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>13.0</td>
<td>13.8</td>
<td>17.3</td>
<td>19.3</td>
<td>18.5</td>
<td>21.6</td>
<td>19.6</td>
<td>20.6</td>
</tr>
<tr>
<td>Ridgetown\textsuperscript{d}</td>
<td>2009</td>
<td>13.0</td>
<td>13.8</td>
<td>19.4</td>
<td>19.3</td>
<td>22.4</td>
<td>21.6</td>
<td>21.7</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>15.1</td>
<td>13.8</td>
<td>19.3</td>
<td>22.4</td>
<td>21.6</td>
<td>21.7</td>
<td>20.6</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} Distance of weather station from location: Bryanston 10 km; Maryhill 6 km; Ridgetown, 1 km.
\textsuperscript{b} Mean temperature data from Environment Canada, London Ontario Airport.
\textsuperscript{c} Mean temperature data from Environment Canada, Kitchener Waterloo Airport.
\textsuperscript{d} Mean temperature data from University of Guelph, Ridgetown Campus.
Table 2-6. Mean and 30 year average precipitation data for Bryanston, Maryhill, and Ridgetown from May to August in 2009 and 2010. 

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>May Mean</th>
<th>30 year avg</th>
<th>June Mean</th>
<th>30 year avg</th>
<th>July Mean</th>
<th>30 year avg</th>
<th>August Mean</th>
<th>30 year avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston</td>
<td>2009</td>
<td>156.6</td>
<td>83.0</td>
<td>110.1</td>
<td>87.0</td>
<td>95.7</td>
<td>82.0</td>
<td>94.7</td>
<td>85.0</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>57.2</td>
<td>83.0</td>
<td>140.7</td>
<td>87.0</td>
<td>128.0</td>
<td>82.0</td>
<td>13.0</td>
<td>85.0</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>79.0</td>
<td>85.0</td>
<td>84.0</td>
<td>81.0</td>
<td>114.5</td>
<td>85.0</td>
<td>108.0</td>
<td>89.0</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>30.6</td>
<td>80.1</td>
<td>61.4</td>
<td>73.4</td>
<td>31.6</td>
<td>76.8</td>
<td>91.0</td>
<td>88.8</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>122.2</td>
<td>80.1</td>
<td>84.5</td>
<td>73.4</td>
<td>136.0</td>
<td>76.8</td>
<td>26.0</td>
<td>88.8</td>
</tr>
</tbody>
</table>

* a Distance of weather station less than 1 km from location; 30 year average precipitation data from Farmzone 2010.
Table 2-7. Amount of precipitation for 0-7 DBP, 0-7 DAT, and 0-21 DAT for Bryanston, Maryhill and Ridgetown in 2009 and 2010.\(^a\)

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>0-7 DBP</th>
<th>0-7 DAT</th>
<th>0-21 DAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston</td>
<td>2009</td>
<td>4.8</td>
<td>112.6</td>
<td>132.4</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>13.0</td>
<td>8.0</td>
<td>113.7</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>6.5</td>
<td>51.0</td>
<td>73.0</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>1.8</td>
<td>7.8</td>
<td>19.4</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>3.1</td>
<td>20.2</td>
<td>73.9</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: DAT, days after PRE treatment; DBP, days before planting; PRE, preemergence.
<table>
<thead>
<tr>
<th>WAE</th>
<th>Env&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Regression parameters&lt;sup&gt;b&lt;/sup&gt; (±SE)</th>
<th>saflufenacil/dimethenamid-p rate&lt;sup&gt;c&lt;/sup&gt;</th>
<th>ER5</th>
<th>ER10</th>
<th>ER20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Segmented Linear</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;b&gt;a&lt;/b&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>br1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>j</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2, 4</td>
<td>-2.6 × 10&lt;sup&gt;-16&lt;/sup&gt; (1.3 × 10&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>4.4 × 10&lt;sup&gt;-18&lt;/sup&gt; (9.8 × 10&lt;sup&gt;-4&lt;/sup&gt;)</td>
<td>4.0 × 10&lt;sup&gt;-3&lt;/sup&gt; (5.2 × 10&lt;sup&gt;-4&lt;/sup&gt;)</td>
<td>448.5 (88.6)</td>
<td>&gt;980</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Exponential</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1, 3, 6</td>
<td>4.2 × 10&lt;sup&gt;-4&lt;/sup&gt; (8.8 × 10&lt;sup&gt;-4&lt;/sup&gt;)</td>
<td>1.55 (0.31)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2, 4</td>
<td>3.7 × 10&lt;sup&gt;-8&lt;/sup&gt; (2.2 × 10&lt;sup&gt;-7&lt;/sup&gt;)</td>
<td>2.56 (0.88)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1, 3, 6</td>
<td>9.9 × 10&lt;sup&gt;-5&lt;/sup&gt; (1.8 × 10&lt;sup&gt;-4&lt;/sup&gt;)</td>
<td>1.73 (0.27)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1, 2, 4, 6</td>
<td>6.8 × 10&lt;sup&gt;-7&lt;/sup&gt; (1.8 × 10&lt;sup&gt;-6&lt;/sup&gt;)</td>
<td>2.44 (0.38)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>424</td>
<td>663</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td>&gt;980</td>
</tr>
<tr>
<td></td>
<td></td>
<td>424</td>
<td>663</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td>&gt;980</td>
</tr>
<tr>
<td></td>
<td></td>
<td>522</td>
<td>779</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td>&gt;980</td>
</tr>
<tr>
<td></td>
<td></td>
<td>645</td>
<td>857</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td>&gt;980</td>
</tr>
</tbody>
</table>

<sup>a</sup> Abbreviations: Env, environment; PRE, preemergence; WAE, weeks after crop emergence.
<sup>b</sup> Exponential corresponds to equation 1 and segmented linear corresponds to equation 2a and 2b.
Exponential parameters: a, magnitude constant; b, rate constant.
Segmented linear parameters: a<sub>0</sub>, intercept of left segment; b<sub>1</sub>, slope of left segment; b<sub>r1</sub>, slope of right segment; j, junction between left and right segment.
<sup>c</sup> ER5, ER10, and ER20 are the rates required to give 5, 10, and 20% crop injury, respectively.
Table 2-9. Dose response parameters (±SE) for visual weed control evaluations at 2 WAT with saflufenacil/dimethenamid-p applied PRE for Bryanston (2009-2010), Maryhill (2009), and Ridgetown (2009-2010), Ontario.\textsuperscript{a}  

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env\textsuperscript{d}</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>I50</th>
<th>ER50</th>
<th>ER80</th>
<th>ER95</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABUTH</td>
<td>3</td>
<td>100.0 (0.0)</td>
<td>1.4 (1.5)</td>
<td>2.5 (0.2)</td>
<td>525 (19.5)</td>
<td>519</td>
<td>914</td>
<td>&gt;980</td>
</tr>
<tr>
<td>ABUTH</td>
<td>6</td>
<td>98.8 (2.3)</td>
<td>0.0 (0.0)</td>
<td>2.5 (0.3)</td>
<td>74 (3.8)</td>
<td>74</td>
<td>131</td>
<td>266</td>
</tr>
<tr>
<td>AMASS</td>
<td>1, 4, 6</td>
<td>100.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>1.9 (0.2)</td>
<td>68 (3.6)</td>
<td>68</td>
<td>140</td>
<td>315</td>
</tr>
<tr>
<td>AMBEL</td>
<td>1</td>
<td>100.0 (0.0)</td>
<td>2.8 (3.2)</td>
<td>3.4 (0.7)</td>
<td>272 (17.3)</td>
<td>267</td>
<td>405</td>
<td>643</td>
</tr>
<tr>
<td>AMBEL</td>
<td>4, 6</td>
<td>100.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>2.0 (0.2)</td>
<td>103 (5.0)</td>
<td>103</td>
<td>203</td>
<td>436</td>
</tr>
<tr>
<td>CHEAL</td>
<td>1, 2, 4, 6</td>
<td>98.0 (2.3)</td>
<td>0.0 (0.0)</td>
<td>2.0 (0.2)</td>
<td>68 (3.7)</td>
<td>69</td>
<td>142</td>
<td>373</td>
</tr>
<tr>
<td>CHEAL</td>
<td>3</td>
<td>100.0 (0.0)</td>
<td>0.0 (1.2)</td>
<td>2.3 (0.1)</td>
<td>416 (11.8)</td>
<td>416</td>
<td>752</td>
<td>&gt;980</td>
</tr>
<tr>
<td>ECHCG</td>
<td>1, 4</td>
<td>99.9 (3.7)</td>
<td>0.0 (0.0)</td>
<td>1.5 (0.2)</td>
<td>69 (6.3)</td>
<td>70</td>
<td>175</td>
<td>498</td>
</tr>
<tr>
<td>SETVI</td>
<td>1, 4</td>
<td>99.5 (3.9)</td>
<td>0.0 (0.0)</td>
<td>1.5 (0.2)</td>
<td>65 (6.4)</td>
<td>65</td>
<td>168</td>
<td>510</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lamb’s quarters; ECHCG, barnyard grass; Env, environment; PRE, preemergence; SETVI, green foxtail; WAT, weeks after PRE treatment.

\textsuperscript{b} Dose-response corresponds to equation 3.

\textsuperscript{c} ER50, ER80, and ER95 are the rates required to give 50, 80, and 95% control, respectively, of a given weed species.

Table 2-10. Dose response parameters (±SE) for visual weed control evaluations at 4 WAT with saflufenacil/dimethenamid-p applied PRE for Bryanston (2009-2010), Maryhill (2009), and Ridgetown (2009-2010), Ontario.\(^a\)

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env(^d)</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>I50</th>
<th>ER50</th>
<th>ER80</th>
<th>ER95</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABUTH</td>
<td>3</td>
<td>100.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>1.8 (0.1)</td>
<td>358 (12.8)</td>
<td>358</td>
<td>790</td>
<td>&gt;980</td>
</tr>
<tr>
<td>ABUTH</td>
<td>6</td>
<td>100.0 (0.0)</td>
<td>1.2 (2.6)</td>
<td>2.0 (0.1)</td>
<td>114 (5.4)</td>
<td>113</td>
<td>224</td>
<td>483</td>
</tr>
<tr>
<td>AMASS</td>
<td>1, 4, 6</td>
<td>100.0 (0.0)</td>
<td>0.3 (3.4)</td>
<td>1.8 (0.2)</td>
<td>112 (7.8)</td>
<td>111</td>
<td>245</td>
<td>595</td>
</tr>
<tr>
<td>AMBEL</td>
<td>1</td>
<td>100.0 (0.0)</td>
<td>0.8 (1.6)</td>
<td>4.2 (0.5)</td>
<td>382 (13.5)</td>
<td>381</td>
<td>529</td>
<td>765</td>
</tr>
<tr>
<td>AMBEL</td>
<td>4, 6</td>
<td>100.0 (0.0)</td>
<td>2.1 (5.1)</td>
<td>1.6 (0.2)</td>
<td>125 (14.0)</td>
<td>121</td>
<td>290</td>
<td>767</td>
</tr>
<tr>
<td>CHEAL</td>
<td>1, 4, 6</td>
<td>95.1 (2.8)</td>
<td>0.0 (0.0)</td>
<td>1.8 (0.2)</td>
<td>91 (6.2)</td>
<td>96</td>
<td>227</td>
<td>&gt;980</td>
</tr>
<tr>
<td>CHEAL</td>
<td>2, 3</td>
<td>100.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>2.0 (0.1)</td>
<td>261 (9.8)</td>
<td>261</td>
<td>518</td>
<td>&gt;980</td>
</tr>
<tr>
<td>ECHCG</td>
<td>1, 4</td>
<td>100.0 (0.0)</td>
<td>1.2 (6.0)</td>
<td>1.1 (0.1)</td>
<td>103 (17.3)</td>
<td>101</td>
<td>374</td>
<td>&gt;980</td>
</tr>
<tr>
<td>ECHCG</td>
<td>3</td>
<td>100.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>2.4 (0.1)</td>
<td>462 (12.4)</td>
<td>462</td>
<td>825</td>
<td>&gt;980</td>
</tr>
<tr>
<td>SETVI</td>
<td>1, 3</td>
<td>100.0 (0.0)</td>
<td>0.0 (0.0)</td>
<td>1.4 (0.2)</td>
<td>231 (20.7)</td>
<td>231</td>
<td>613</td>
<td>&gt;980</td>
</tr>
<tr>
<td>SETVI</td>
<td>4, 6</td>
<td>100.0 (0.0)</td>
<td>2.7 (9.1)</td>
<td>1.1 (0.2)</td>
<td>83 (19.5)</td>
<td>79</td>
<td>271</td>
<td>&gt;980</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lamb’s quarters; ECHCG, barnyard grass; Env, environment; PRE, preemergence; SETVI, green foxtail; WAT, weeks after PRE treatment.

\(^b\) Dose response parameters: B, slope of the line around I50; C, lower limit; D, upper limit; I50, rate required for 50% response.

\(^c\) ER50, ER80, and ER95 are the rates required to give 50, 80, and 95% control, respectively, of a given weed species.

Table 2-11. Dose response and segmented linear regression parameters (±SE) for visual weed control evaluations at 7 WAT with saflufenacil/dimethenamid-p applied PRE for Bryanston (2009-2010), Maryhill (2009), and Ridgetown (2009-2010), Ontario.\(^a\)

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env(^d)</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>I50</th>
<th>ER50</th>
<th>ER80</th>
<th>ER95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose response</td>
<td></td>
<td>Dose response</td>
<td>Regression parameters(^b) (±SE)</td>
<td>saflufenacil/dimethenamid-p rate(^c)</td>
<td>g a.i. ha(^{-1})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>100.0</td>
<td>0.6</td>
<td>3.4</td>
<td>469</td>
<td>467</td>
<td>705</td>
<td>&gt;980</td>
</tr>
<tr>
<td>ABUTH 3</td>
<td>100.0</td>
<td>0.6 (0.9)</td>
<td>3.4 (0.2)</td>
<td>469 (9.4)</td>
<td>467 (705)</td>
<td>&gt;980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABUTH 6</td>
<td>100.0</td>
<td>0.8 (1.6)</td>
<td>3.0 (0.3)</td>
<td>203 (8.2)</td>
<td>202 (321)</td>
<td>542</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMASS 1</td>
<td>96.2 (2.8)</td>
<td>0.0</td>
<td>6.3 (0.8)</td>
<td>375 (15.3)</td>
<td>379 (483)</td>
<td>748</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMASS 4, 6</td>
<td>99.3 (5.2)</td>
<td>4.1</td>
<td>129.8</td>
<td>130 (15.1)</td>
<td>130 (131)</td>
<td>133</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMBEL 4, 6</td>
<td>95.6 (5.1)</td>
<td>0.8</td>
<td>2.0</td>
<td>138 (15.3)</td>
<td>143 (304)</td>
<td>&gt;980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHEAL 1,2,3,4,6</td>
<td>100.0</td>
<td>1.4 (2.1)</td>
<td>2.1 (0.3)</td>
<td>320 (20.4)</td>
<td>316 (609)</td>
<td>&gt;980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECHCG 1,3</td>
<td>93.5 (3.5)</td>
<td>0.2</td>
<td>4.1 (0.6)</td>
<td>437 (15.6)</td>
<td>452 (676)</td>
<td>&gt;980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECHCG 4</td>
<td>100.0</td>
<td>2.4 (10.7)</td>
<td>1.0 (0.3)</td>
<td>87 (31.4)</td>
<td>82 (351)</td>
<td>&gt;980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SETVI 1, 3</td>
<td>93.8 (4.0)</td>
<td>0.2</td>
<td>4.1 (0.7)</td>
<td>438 (17.6)</td>
<td>452 (674)</td>
<td>&gt;980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SETVI 4, 6</td>
<td>100.0 (0.0)</td>
<td>3.5</td>
<td>1.3</td>
<td>137 (26.1)</td>
<td>130 (378)</td>
<td>&gt;980</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Segmented Linear

<table>
<thead>
<tr>
<th>Weed</th>
<th>Parameters</th>
<th>a0 (±SE)</th>
<th>b1 (±SE)</th>
<th>br1 (±SE)</th>
<th>j (±SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMBEL</td>
<td>1</td>
<td>3.9x10^-15 (4.5)</td>
<td>-6.1x10^-17 (6.4x10^-2)</td>
<td>0.11 (1.1x10^-2)</td>
<td>222.7 (108.8)</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lamb’s quarters; ECHCG, barnyard grass; Env, environment; PRE, preemergence; SETVI, green foxtail; WAT, weeks after PRE treatment.

\(^b\) Dose-response corresponds to equation 3 and segmented linear corresponds to equation 2a and 2b.

Dose response parameters: B, slope of the line around I50; C, lower limit; D, upper limit; I50, rate required for 50% response.

Segmented linear parameters: a0, intercept of left segment; b1, slope of left segment; br1, slope of right segment; j, junction between left and right segment.

\(^c\) ER50, ER80, and ER95 are the rates required to give 50, 80, and 95% control, respectively, of a given weed species.

Table 2-12. Dose response and segmented linear regression parameters (±SE) for visual weed control evaluations at 11 WAT with saflufenacil/dimethenamid-p applied PRE for Bryanston (2009-2010), Maryhill (2009), and Ridgetown (2009-2010), Ontario.\(^a\)

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env(^d)</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>I50</th>
<th>ER50</th>
<th>ER80</th>
<th>ER95</th>
<th>saflufenacil/dimethenamid-p rate(^c) g a.i. ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose response</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABUTH</td>
<td>6</td>
<td>100.0</td>
<td>0.5</td>
<td>5.1</td>
<td>244</td>
<td>244</td>
<td>320</td>
<td>434</td>
<td></td>
</tr>
<tr>
<td>AMASS</td>
<td>1, 2</td>
<td>73.7</td>
<td>0.7</td>
<td>6.9</td>
<td>489</td>
<td>543</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td></td>
</tr>
<tr>
<td>AMASS</td>
<td>6</td>
<td>99.5</td>
<td>0.0</td>
<td>5.1</td>
<td>130</td>
<td>130</td>
<td>172</td>
<td>237</td>
<td></td>
</tr>
<tr>
<td>AMBEL</td>
<td>4, 6</td>
<td>96.5</td>
<td>0.0</td>
<td>2.6</td>
<td>142</td>
<td>146</td>
<td>262</td>
<td>707</td>
<td></td>
</tr>
<tr>
<td>CHEAL</td>
<td>4, 6</td>
<td>91.3</td>
<td>0.0</td>
<td>3.1</td>
<td>112</td>
<td>119</td>
<td>213</td>
<td>&gt;980</td>
<td></td>
</tr>
<tr>
<td>CHEAL</td>
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<td>78.7</td>
<td>0.3</td>
<td>3.9</td>
<td>469</td>
<td>539</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td></td>
</tr>
<tr>
<td>SETVI</td>
<td>4, 6</td>
<td>95.3</td>
<td>0.0</td>
<td>3.0</td>
<td>141</td>
<td>145</td>
<td>245</td>
<td>955</td>
<td></td>
</tr>
<tr>
<td><strong>Segmented Linear</strong></td>
<td></td>
<td>a0</td>
<td>b1</td>
<td>br1</td>
<td>j</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABUTH</td>
<td>3</td>
<td>-5.5x10(^{-16})</td>
<td>1.3x10(^{-17})</td>
<td>0.12</td>
<td>197.3</td>
<td>602</td>
<td>845</td>
<td>967</td>
<td></td>
</tr>
<tr>
<td>AMBEL</td>
<td>1</td>
<td>6.7x10(^{-16})</td>
<td>-3.6x10(^{-18})</td>
<td>0.10</td>
<td>263.8</td>
<td>766</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td></td>
</tr>
<tr>
<td>ECHCG</td>
<td>1, 3</td>
<td>3.0x10(^{-16})</td>
<td>-4.7x10(^{-17})</td>
<td>0.10</td>
<td>147.7</td>
<td>669</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td></td>
</tr>
<tr>
<td>SETVI</td>
<td>1, 3</td>
<td>-7.1x10(^{-15})</td>
<td>1.9x10(^{-16})</td>
<td>0.10</td>
<td>148.9</td>
<td>674</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lambsquarters; ECHCG, barnyard grass; Env, environment; PRE, preemergence; SETVI, green foxtail; WAT, weeks after PRE treatment.

\(^b\) Dose-response corresponds to equation 3 and segmented linear corresponds to equation 2a and 2b.

Dose response parameters: B, slope of the line around I50; C, lower limit; D, upper limit; I50, rate required for 50% response.

Segmented linear parameters: a0, intercept of left segment; b1, slope of left segment; br1, slope of right segment; j, junction between left and right segment.

\(^c\) ER50, ER80, and ER95 are the rates required to give 50, 80, and 95% control, respectively, of a given weed species.

Table 2-13. Dose response and inverse exponential regression parameters (±SE) for weed density as a percent of the untreated check with saflufenacil/dimethenamid-p applied PRE for Bryanston (2009-2010), Maryhill (2009), and Ridgetown (2009-2010), Ontario.\(^a\)

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env(^d)</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>I50</th>
<th>ER50</th>
<th>ER80</th>
<th>ER95</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dose Response</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABUTH  3</td>
<td>88.6 (7.4)</td>
<td>5.0 (9.1)</td>
<td>6.4 (4.7)</td>
<td>188 (42.8)</td>
<td>183</td>
<td>238</td>
<td>610</td>
<td></td>
</tr>
<tr>
<td>ABUTH 6</td>
<td>100.1 (6.5)</td>
<td>0.0 (0.0)</td>
<td>0.9 (0.3)</td>
<td>21 (7.4)</td>
<td>21</td>
<td>92</td>
<td>489</td>
<td></td>
</tr>
<tr>
<td>AMASS 1, 4, 6</td>
<td>101.1 (11.5)</td>
<td>0.0 (0.0)</td>
<td>1.4 (0.4)</td>
<td>84 (24.9)</td>
<td>85</td>
<td>234</td>
<td>732</td>
<td></td>
</tr>
<tr>
<td>AMBEL 1</td>
<td>131.8 (16.0)</td>
<td>12.1 (32.1)</td>
<td>4.7 (8.0)</td>
<td>279 (97.3)</td>
<td>329</td>
<td>491</td>
<td>&gt;980</td>
<td></td>
</tr>
<tr>
<td>AMBEL 4, 6</td>
<td>99.6 (14.6)</td>
<td>0.0 (0.0)</td>
<td>0.9 (0.5)</td>
<td>25 (18.7)</td>
<td>25</td>
<td>124</td>
<td>758</td>
<td></td>
</tr>
<tr>
<td>CHEAL 2, 3, 4, 6</td>
<td>100.2 (6.8)</td>
<td>0.0 (0.0)</td>
<td>1.3 (0.2)</td>
<td>58 (10.6)</td>
<td>58</td>
<td>171</td>
<td>577</td>
<td></td>
</tr>
<tr>
<td>ECHCG 1</td>
<td>99.3 (20.3)</td>
<td>0.0 (0.0)</td>
<td>1.8 (1.6)</td>
<td>341 (195.2)</td>
<td>338</td>
<td>739</td>
<td>&gt;980</td>
<td></td>
</tr>
<tr>
<td><strong>Inverse Exponential</strong></td>
<td>e</td>
<td>f</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SETVI 1, 6</td>
<td>0.0 (0.0)</td>
<td>168.1 (26.9)</td>
<td>1.9x10(^{-3}) (1.0x10(^{-3}))</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td>&gt;980</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lamb’s quarters; ECHCG, barnyard grass; Env, environment; PRE, preemergence; SETVI, green foxtail.

\(^b\) Dose-response corresponds to equation 3 and Inverse exponential corresponds to equation 4.

Dose response parameters: B, slope of the line around I50; C, lower limit; D, upper limit; I50, rate required for 50% response.

Inverse exponential parameters: e, lower asymptote; f, reduction in y from intercept to e; g, slope of the line.

\(^c\) ER50, ER80, and ER95 are the rates required to give 50, 80, and 95% reduction in density, respectively, of a given weed species.

Table 2-14. Dose response, inverse exponential and linear regression parameters (±SE) for weed dry biomass as a percent of the untreated check with saflufenacil/dimethenamid-p applied PRE for Bryanston (2009-2010), Maryhill (2009), and Ridgetown (2009-2010), Ontario.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env\textsuperscript{d}</th>
<th>Dose Response</th>
<th>Regression parameters\textsuperscript{b} (±SE)</th>
<th>Linear Parameters</th>
<th>saflufenacil/dimethenamid-p rate\textsuperscript{c} g a.i. ha\textsuperscript{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Regression parameters\textsuperscript{b} (±SE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed</td>
<td>Env\textsuperscript{d}</td>
<td>D</td>
<td>C</td>
<td>B</td>
<td>I50</td>
</tr>
<tr>
<td>ABUTH</td>
<td>3</td>
<td>107.5 (14.1)</td>
<td>13.1 (17.2)</td>
<td>4.8 (5.8)</td>
<td>150 (48.4)</td>
</tr>
<tr>
<td>AMASS</td>
<td>1, 4, 6</td>
<td>100.1 (11.8)</td>
<td>0.0 (0.0)</td>
<td>1.4 (0.4)</td>
<td>90 (27.5)</td>
</tr>
<tr>
<td>AMBEL</td>
<td>4, 6</td>
<td>97.3 (21.1)</td>
<td>0.0 (0.0)</td>
<td>1.4 (0.9)</td>
<td>75 (42.1)</td>
</tr>
<tr>
<td>CHEAL</td>
<td>2, 3, 4, 6</td>
<td>111.7 (11.7)</td>
<td>0.0 (0.0)</td>
<td>1.6 (0.6)</td>
<td>164 (43.9)</td>
</tr>
<tr>
<td>ECHCG</td>
<td>1</td>
<td>99.8 (14.7)</td>
<td>0.0 (0.0)</td>
<td>1.2 (0.5)</td>
<td>196 (89.6)</td>
</tr>
</tbody>
</table>

Inverse Exponential

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env\textsuperscript{d}</th>
<th>e</th>
<th>f</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMBEL</td>
<td>1</td>
<td>-5.0x10\textsuperscript{-11} (0.0)</td>
<td>255.2 (61.0)</td>
<td>1.3x10\textsuperscript{-3} (1.2x10\textsuperscript{-3})</td>
</tr>
<tr>
<td>SETVI</td>
<td>1, 6</td>
<td>0.0 (0.0)</td>
<td>163.9 (31.1)</td>
<td>2.1x10\textsuperscript{-3} (1.3x10\textsuperscript{-3})</td>
</tr>
</tbody>
</table>

Linear

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env\textsuperscript{d}</th>
<th>k</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABUTH</td>
<td>6</td>
<td>67.1 (21.2)</td>
<td>-6.7x10\textsuperscript{-2} (5.0x10\textsuperscript{-2})</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lamb’s quarters; ECHCG, barnyard grass; Env, environment; PRE, preemergence; SETVI, green foxtail.

\textsuperscript{b} Dose-response corresponds to equation 3, inverse exponential to equation 4, and linear corresponds to equation 5.

Dose response parameters: B, slope of the line around I50; C, lower limit; D, upper limit; I50, rate required for 50% response.

Inverse exponential parameters: e, lower asymptote; f, reduction in y from intercept to e; g, slope of the line.

Linear parameters: k, y intercept; h, slope of the line.

\textsuperscript{c} ER50, ER80, and ER95 are the rates required to give 50, 80, and 95% reduction in dry weight, respectively, of a given weed species.

<table>
<thead>
<tr>
<th>Weed</th>
<th>Env</th>
<th>Gl vs P30/fbGl</th>
<th>Gl vs P61/fbGl</th>
<th>Gl vs P122/fbGl</th>
<th>Gl vs P245/fbGl</th>
<th>Gl vs P490/fbGl</th>
<th>Gl vs P980/fbGl</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABUTH</td>
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<td>98.3 vs 98.3</td>
<td>98.3 vs 98.3</td>
<td>98.3 vs 98.8</td>
<td>98.3 vs 97.1</td>
<td>98.3 vs 99.0</td>
<td>98.3 vs 99.9*</td>
</tr>
<tr>
<td>ABUTH</td>
<td>6</td>
<td>95.4 vs 97.1</td>
<td>95.4 vs 96.9</td>
<td>95.4 vs 98.5*</td>
<td>95.4 vs 98.8*</td>
<td>95.4 vs 99.9*</td>
<td>95.4 vs 100.0*</td>
</tr>
<tr>
<td>AMASS</td>
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<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
</tr>
<tr>
<td>AMASS</td>
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<td>89.1 vs 90.1</td>
<td>89.1 vs 91.9</td>
<td>89.1 vs 97.6</td>
<td>89.1 vs 95.6</td>
<td>89.1 vs 97.9</td>
</tr>
<tr>
<td>AMASS</td>
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<td>99.9 vs 99.9</td>
<td>99.9 vs 100.0</td>
<td>99.9 vs 100.0</td>
<td>99.9 vs 100.0</td>
<td>99.9 vs 100.0</td>
<td>99.9 vs 100.0</td>
</tr>
<tr>
<td>AMBEL</td>
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<td>99.0 vs 99.0</td>
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<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 98.0</td>
</tr>
<tr>
<td>AMBEL</td>
<td>4, 6</td>
<td>96.4 vs 97.5</td>
<td>96.4 vs 97.6</td>
<td>96.4 vs 99.2</td>
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<td>96.4 vs 99.7</td>
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<tr>
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<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
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<td>99.0 vs 99.0</td>
<td>99.0 vs 98.3</td>
</tr>
<tr>
<td>CHEAL</td>
<td>2, 3</td>
<td>91.2 vs 92.5</td>
<td>91.2 vs 92.6</td>
<td>91.2 vs 93.9</td>
<td>91.2 vs 96.5</td>
<td>91.2 vs 97.6</td>
<td>91.2 vs 99.1</td>
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<tr>
<td>CHEAL</td>
<td>4</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
</tr>
<tr>
<td>CHEAL</td>
<td>6</td>
<td>99.0 vs 99.4</td>
<td>99.0 vs 100.0*</td>
<td>99.0 vs 100.0*</td>
<td>99.0 vs 100.0*</td>
<td>99.0 vs 100.0*</td>
<td>99.0 vs 100.0*</td>
</tr>
<tr>
<td>ECHCG</td>
<td>1</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
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<td>99.0 vs 97.6</td>
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<tr>
<td>ECHCG</td>
<td>3</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0*</td>
<td>99.0 vs 99.0*</td>
<td>99.0 vs 99.9*</td>
</tr>
<tr>
<td>SETVI</td>
<td>1, 3</td>
<td>99.0 vs 98.9</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.0</td>
<td>99.0 vs 99.4</td>
<td>99.0 vs 99.6</td>
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<td>4, 6</td>
<td>99.6 vs 99.2</td>
<td>99.6 vs 99.7</td>
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<td>99.6 vs 99.7</td>
<td>99.6 vs 99.7</td>
<td>99.6 vs 99.7</td>
</tr>
<tr>
<td>Yieldc</td>
<td>1, 3, 4, 6</td>
<td>91.9 vs 91.8</td>
<td>91.9 vs 91.9</td>
<td>91.9 vs 93.1</td>
<td>91.9 vs 95.1</td>
<td>91.9 vs 95.7</td>
<td>91.9 vs 91.0</td>
</tr>
<tr>
<td>Yieldc</td>
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<td>73.1 vs 82.3</td>
<td>73.1 vs 77.8</td>
<td>73.1 vs 81.4</td>
<td>73.1 vs 84.7</td>
<td>73.1 vs 63.7</td>
</tr>
</tbody>
</table>

**Table 2-15.** Contrasts for visual weed control evaluations 11 WAT and soybean yield comparing glyphosate applied POST versus saflufenacil/dimethenamid-p applied PRE at various rates followed by glyphosate applied POST for Bryanston (2009-2010), Maryhill (2009), and Ridgetown (2009-2010), Ontario. 

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*a* Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lamb’s quarters; ECHCG, barnyard grass; Env, environment; Env, Environment: fb, followed by; Gl, glyphosate applied POST at 900 g a.i. ha⁻¹; P###, saflufenacil/dimethenamid-p applied PRE at ### g a.i. ha⁻¹; POST, postemergence; PRE, preemergence; SETVI, green foxtail; WAT, weeks after PRE treatment.


*c* Yield data are percentage of the weed free check.

* Denotes significance at P<0.05.
3.0 Soybean (*Glycine max*) Cultivar Tolerance to saflufenacil

3.1 Abstract

Six field studies were conducted over a two-year period (2009 and 2010) at three Ontario locations to determine the sensitivity of 12 glyphosate resistant soybean cultivars to saflufenacil applied preemergence (PRE). The level of crop injury was dependent on environmental conditions shortly after application. When soybean emergence was delayed due to cool, wet conditions following planting, 52 and 59 g a.i. ha\(^{-1}\) of saflufenacil resulted in 10% injury one week after emergence (WAE) in cultivars OAC Hanover and RCAT Matrix, respectively. In the other environments, greater than 200 g a.i. ha\(^{-1}\) of saflufenacil was required to induce the same level of injury at 1 WAE. Injury decreased with time; however, the more sensitive soybean cultivars were unable to recover from early season injury sustained under adverse environmental conditions. A hydroponic bioassay was developed to screen differences in soybean tolerance to saflufenacil. OAC Hanover was more sensitive than all the other cultivars in both field and hydroponic testing (P<0.05). OAC Hanover height and yield was reduced regardless of environmental conditions. Under cool, wet conditions, 22 g a.i. ha\(^{-1}\) of saflufenacil resulted in a 10% yield reduction, while 46 g a.i. ha\(^{-1}\) was needed under warm dry conditions. All other cultivars required between 82 to 146 g a.i. ha\(^{-1}\) to cause the same level of yield reduction. This research demonstrates that there is a difference in soybean cultivar sensitivity to saflufenacil applied PRE.
3.2 Introduction

Over the past decade, producers have become dependent on glyphosate for weed control in soybean. As a result, herbicide screening for cultivar tolerance to other herbicides has not been routinely conducted in recent years (Poston et al. 2008). Soybean cultivars have displayed differential tolerance to several herbicides, including chlorimuron (Newsom and Shaw 1992), metribuzin (De Weese et al. 1989; Ivany et al. 1992; Mangot et al. 1979), sulfentrazone (Dayan et al. 1997; Hulting et al. 2001; Li et al. 1999, 2000a, 2000b; Swantek et al. 1998), and flumioxazin (Taylor-Lovell et al. 2001). The risk of injury from soil-applied herbicides increases with cool and wet environmental conditions shortly after planting (Hulting et al. 2001; Li et al. 2000b; Niekamp et al. 1999; Poston et al. 2008; Swantek et al. 1998:), since the herbicide is more readily available for plant uptake and cool temperatures decrease the soybean plant’s ability to metabolize the herbicide (Poston et al. 2008).

Saflufenacil is a herbicide used in corn, soybean, and cereals for burndown and residual broadleaf weed control, including acetolactate synthase (ALS), triazine, and glyphosate resistant biotypes (Anonymous 2008; Grossmann et al. 2010; Liebl et al. 2008). Sensitive broadleaf weed species are controlled through the inhibition of protoporphyrinogen IX oxidase (PPO), an important enzyme in the synthesis of chlorophyll (Grossmann et al. 2010). Saflufenacil is readily absorbed by root and shoot tissue of plants. Once absorbed, it is predominantly translocated via xylem tissue, with relatively low movement via the phloem (Bowe et al. 2008). Preemergence (PRE) applications provide control of broadleaf weeds including velvetleaf (*Abutilon therophrasti* Medik.), redroot pigweed (*Amaranthus retroflexus* L.), common ragweed
Sulfentrazone and flumioxazin are two herbicides that also inhibit PPO (Senseman 2007; Taylor-Lovell et al. 2001). Although they have the same mode of action, there are differences in cultivar sensitivity to flumioxazin and sulfentrazone (Taylor-Lovell et al. 2001). Taylor-Lovell et al. (2001) determined in greenhouse testing that sulfentrazone was more injurious than flumioxazin on 40 common soybean cultivars. The cultivars most sensitive to flumioxazin were different from those that were sensitive to sulfentrazone, indicating that soybean tolerance mechanisms may be different for the two herbicides (Taylor-Lovell et al. 2001). Soybean cultivars can be classified as having high, medium, or low tolerance to sulfentrazone (Hulting et al. 2001; Li et al. 1999), with plant height ranging from 0 to 71% of the untreated check for 40 soybean cultivars evaluated (Hulting et al. 2001). Tolerance to sulfentrazone within soybean cultivars appears to be controlled by a single dominant gene, with tolerance being dominant over susceptibility (Swantek et al. 1998).

Soybean tolerance to preplant applications of saflufenacil is considered to be good to excellent at the registered use rate of 18 to 25 g a.i. ha⁻¹ (Anonymous 2010a, 2010b; Hixson et al. 2008). Similarly, Soltani et al. (2010b) found that the soybean cultivar DK 28-52R was tolerant up to 100 g a.i. ha⁻¹ applied PRE. However, studies have reported range in sensitivity among proso millet cultivars to saflufenacil (Lyon and Kniss 2010). It is hypothesized that there is no difference among soybean cultivars in their tolerance to saflufenacil applied PRE. The objective of this study was to determine the tolerance of 12 glyphosate tolerant soybean cultivars grown in Ontario to saflufenacil.
3.3 Materials and Methods

A total of six field research trials were conducted near Bryanston, Maryhill, and Ridgetown, Ontario over a two-year period (2009 to 2010). The soil characteristics for each site are presented in Table 3-1. Seedbed preparation at the Bryanston and Maryhill (2009) sites consisted of spring offset disk, followed by two passes with a cultivator with rolling basket harrows. In 2010, seedbed preparation consisted of an offset disk the previous fall, followed by two passes with a cultivator with rolling basket harrows in the spring. At Ridgetown, seedbed preparation consisted of fall moldboard plowing, followed by two passes with a cultivator with rolling basket harrows in the spring.

Experiments were established as a randomized complete split-plot with 4 replications. Main plots consisted of saflufenacil rate (0, 25, 50, 100, and 200 g a.i. ha\(^{-1}\)), representing 0, 1, 2, 4, and 8 times the maximum registered use rate in soybean, respectively (Anonymous 2010a). Sub-plots consisted of 12 glyphosate tolerant soybean cultivars (one row each of AC Renfrew, OAC Hanover, OAC Raptor, 90B73, AC 0800 RR, DKB 27-51R, Pro 27-51R, RCAT Matrix, HS 11R46, RT 1784A, HS 13RS52 and RCAT Mirra). All sites were fertilized based on soil test results. Soybean was seeded between May 17 and 27 (Table 3-2) at 470 000 seeds ha\(^{-1}\) at Bryanston and Maryhill, and at 480 000 seeds ha\(^{-1}\) at Ridgetown. Plots were 12 m wide and 8 m in length with a row spacing of 75 cm at all locations (two border rows were seeded at both sides of each plot). PRE applications were made within two days of planting (Table 3-2), and plots were maintained weed-free using a combination of glyphosate and hand-weeding as needed. A CO\(_2\) pressurized backpack sprayer was used to deliver 200 L ha\(^{-1}\) of water at 275 kPa with Teejet 110-02 flat-fan nozzle tips (Spraying Systems Co., North Avenue and
Schmale Road, Wheaton, IL 60188) at Bryanston and Maryhill, and 241 kPa with Hypro Ultra low drift 120-02 nozzle tips (Hypro, New Brighton, MN) at Ridgetown.

Visible crop injury was rated on a scale of 0 to 100% (0=no visible crop injury and 100=plant death) weekly for 8 weeks after soybean emergence (WAE). Crop density and dry weight were determined by harvesting 50 cm of each row at 4 WAE. Plants were kiln-dried at approximately 80°C to a constant weight before weighing. Ten random plants were selected in each row to determine average plant height of each cultivar at 4 WAE in 2009, and at 4 and 8 WAE in 2010. Soybean plants were machine harvested at maturity, and moisture was adjusted to 13.0%. Due to uneven emergence at Maryhill in 2010, plant counts were taken for 4 meters of row and used to adjust percent yield reduction relative to the untreated check.

3.3.1 Statistical analysis – Field studies

The PROC MIXED procedure in SAS v. 9.2 (SAS Institute, Cary, NC) was used to determine whether environments could be combined. Saflufenacil rate and soybean cultivar and their interaction were considered fixed effects. Random effects included environment (years and locations), replications (within environment), and the interaction of environment with the fixed effects. Significance of random effects was tested using a Z-test of the variance estimate, and an F-test was used to determine the significance of fixed effects. Data were pooled across all environments if the environment by rate by cultivar interaction was not significant.
Non-linear regression (PROC NLIN in SAS) was used to evaluate the response of crop injury of each cultivar at 1, 2, 4, and 8 WAE. An exponential regression equation was used to describe the percent crop injury as a function of saflufenacil rate:

\[ Y = a * \exp(b * \ln(\text{rate})) \]  \[1\]

where \( Y \) is the percent crop injury, \( a \) is the magnitude constant, and \( b \) is the rate constant.

If Eq. 1 failed to adequately describe the relationship, linear regression was used:

\[ (Y = h * \text{rate} + k) \]  \[2\]

where \( h \) is the slope and \( k \) is the \( Y \) intercept.

The regression equations were used to calculate ER5, 10, and 20 values, which correspond to the effective rates of saflufenacil that caused 5, 10, and 20 percent visual crop injury, respectively.

Height and yield data were converted to a percent reduction of the untreated control for analysis. Linear regression (Eq. 2) was used to determine the percent height and yield reduction of the untreated check.

### 3.3.2 Soybean hydroponic assay

A greenhouse study was developed at BASF Corporation in Raleigh, NC to determine the response of soybean cultivars to saflufenacil. Soybean seeds for each of the 12 cultivars used in the field study were evenly spaced in potting trays with vermiculite. Trays were placed in the greenhouse and watered daily for 2 days or until the hypocotyl reached 3 cm in length. Test tubes with plastic caps were prepared by placing them in a 60 x 35 x 12 cm black wooden box with holes specifically designed to hold the test tube upright. A soldering iron was used to punch a hole in the cap. Combinations of
saflufenacil 70 SC formulation and distilled water were used to create 0, 25, 50, 100, and 200 ppb solutions, which were then added to the prepared test tubes. The series of rates was replicated 6 times for each variety. Seedlings were washed and placed individually into the test tubes with their hypocotyl submerged in solution. The test tubes with seedlings were then placed in a Conviron growth chamber at 20°C, 60% humidity, and ~500 micromoles/m². Seedlings were kept in the dark for the first 9 hours to allow them to become adjusted to their new environment. Following that, 2 cycles per day of 9 hours light, 3 hours darkness occurred for approximately 5 days or until the unifoliate started to unfold in untreated test tubes. Crop injury was evaluated using a scale of 0-100% (0=no injury and 100=complete death). Top growth, primary, and secondary roots as well as hypocotyl necrosis at the solution line were taken into consideration for the evaluated. The experiment was repeated and no significant rate by experimental run interaction was observed when checked using PROC MIXED. Therefore, data were pooled together for analysis.

A four-parameter log-logistic function was used to regress percent crop injury over saflufenacil rate for each cultivar (Seefeldt et al. 1995):

\[ Y = C + \frac{(D-C)}{1 + \exp \left[ B \left( \ln (rate) - \ln (I_{50}) \right) \right]} \]  

where \( Y \) is percent crop injury, \( C \) is the lower limit, \( D \) is the upper limit, \( B \) is the slope of the line, and \( I_{50} \) is the rate required to give 50 percent of the total response between the upper and lower limit.

Comparison of equality-of-slopes between OAC Hanover vs all the other cultivars were made using contrasts in PROC MIXED of SAS. The variables compared consisted...
of percent injury at 1, 2, 4, and 8 WAE, percent height, and yield reduction for the field experiment, and percent injury for the hydroponic experiment.

### 3.4 Results and Discussion

#### 3.4.1 Field Experiment

Environments were combined when there was not an environment by cultivar by rate interaction. Temperatures in 2009 were average to below average in May, and below average in June and July at all locations (Table 3-3) (Environment Canada 2010). At Ridgetown in 2009, precipitation was also much lower than average (Table 3-4), with less than 20 mm of rain within 21 days of the PRE application (Table 3-5) (Farmzone 2010). Precipitation at Bryanston in 2009 was above average, while Maryhill was average (Table 3-4); however, 112.6 and 51 mm of precipitation occurred within the first 7 days after treatment (DAT) at these two locations, respectively (Table 3-5). Due to below average temperatures and excessive moisture at these locations after planting, soybean emergence took 13 and 17 days at Bryanston and Maryhill, respectively, in 2009 (Table 3-2). In 2010, temperatures at all locations were average to above average (Table 3-3), with adequate precipitation at Bryanston and Ridgetown, but only 2.7 mm of precipitation was received at Maryhill within the first 7 DAT (Table 3-4). Higher temperatures, combined with adequate moisture prior to planting and within the first 21 DAT (Table 3-5), resulted in soybean emergence within the 8 days of planting for all sites in 2010 (Table 3-2).

Cultivars are presented in order from lowest to highest crop maturity. Soybean injury consisted of stunting, chlorosis, and necrosis of the stem at the soil surface. More
necrosis of the stem occurred at Bryanston in 2009 at 1 WAE compared to other locations. This was likely due to the excessive rainfall within the first 7 DAT, which resulted in lower rates of saflufenacil required to cause 5, 10, and 20 percent injury across all cultivars. Under cool, wet conditions, OAC Hanover and RCAT Matrix required 52 and 59 g a.i. ha\(^{-1}\) to cause 10% injury respectively, while AC Renfrew and RCAT Mirra required 116 and 123 g a.i. ha\(^{-1}\), respectively, to attain the same level of injury at 1 WAE (Table 3-6). At all other locations, the rate of saflufenacil needed to cause 10% injury was greater than 200 g a.i. ha\(^{-1}\). These results agree with those of Hixson (2008) who found that newly emerged tissue from the soybean seed is the most susceptible to damage by saflufenacil during cool, wet conditions following planting. Since saflufenacil is mobile in the soil, injury observed under cool, wet conditions was primarily contact injury from saflufenacil at the soil surface which increased necrosis on the hypocotyl (Hixson 2008).

At 2 WAE, the amount of rainfall received within the first 7 DAT continued to have an impact on the level of injury for all soybean cultivars. Bryanston (2009), Maryhill (2009), and Ridgetown (2010) received greater than 20 mm of rain within the first 7 DAT (Table 3-5). OAC Hanover and AC 0800RR required 70 and 22 g a.i. ha\(^{-1}\) of saflufenacil respectively, to cause 10% injury in a wet environment (Table 3-7), while AC Renfrew and RCAT Mirra required 122 and 162 g a.i. ha\(^{-1}\), respectively, to cause the same level of injury. Under drier conditions at Bryanston (2010), Maryhill (2010), and Ridgetown (2009), greater than 200 g a.i. ha\(^{-1}\) was required to cause 10% injury for all cultivars. Hixson (2008) found that if saflufenacil remains above the planting depth, less
stunting occurs, which could explain why there is a difference in injury between the locations which had varying levels of rainfall prior to emergence.

At 4 WAE, 35 and 87 g a.i. ha$^{-1}$ of saflufenacil resulted in 10% injury to OAC Hanover in a wet and dry environment, respectively (Table 3-8). By comparison, PRO 27-15, HS 11R46, RCAT Mirra, and AC 0800RR required between 91 and 112 g a.i. ha$^{-1}$ in wet environments, and greater than 200 g a.i. ha$^{-1}$ in drier environments to attain the same level of injury, which was more than double the rate of OAC Hanover regardless of environmental conditions following application. Soltani et al. (2010b) found 6 and 22% injury to soybean cultivar DK 28-52R when saflufenacil was applied PRE at 100 and 200 g a.i. ha$^{-1}$, respectively, at 4 WAE. When comparing the same locations, soybean injury decreased between 4 and 8 WAE for Pioneer 90B73, DKB 27-51R, RCAT Matrix, RT 1784, HS 13RS52, and RCAT Mirra, since higher rates of saflufenacil were required to cause 10% injury for each cultivar (Tables 3-8 and 3-9). These results agree with the findings of Soltani et al. (2010b) who found that soybean injury decreased over time with applications of saflufenacil for one soybean cultivar (DK 28-52R). However, for OAC Hanover, the rates required to cause 10% injury at 4 and 8 WAE were 35 and 38 g a.i. ha$^{-1}$, respectively, which indicates that this cultivar was less able to recover from early season injury in cool, wet conditions (Tables 3-8 and 3-9). Even in drier environments at emergence, 101 g a.i. ha$^{-1}$ of saflufenacil resulted in 10% injury of OAC Hanover at 8 WAE, compared to greater than 200 g a.i. ha$^{-1}$ of for AC Renfrew, Pioneer 90B73, HS 13RS52, and RCAT Mirra (Table 3-9). In addition, RCAT Mirra was best able to recover from early season injury in wetter environments since greater than 200 g a.i. ha$^{-1}$ of saflufenacil was required at 8 WAE to cause 10% injury.
Soybean injury levels are generally higher for sulfentrazone sensitive cultivars under low soil organic matter (Reiling et al. 2006). Hixson (2008) determined that soils with an organic matter content greater than 4% have a higher affinity for saflufenacil, and therefore less herbicide is available for plant uptake. This may explain why minimal soybean injury was observed in dry environments with saflufenacil at 8 times the registered use rate, since the soil at all locations had organic matter content greater than 4% (Table 3-1). Injury appears to be correlated with the amount of rainfall received after application and just prior to soybean emergence. If soybean emergence is delayed due to cool, wet conditions, the potential for injury increases. These results are similar to other studies that found that the closer a PRE application of sulfentrazone was to emergence, the greater the risk of soybean injury (Hulting et al. 2001; Li et al. 2000b; Niekamp et al. 1999; Reiling et al. 2006; Swantek et al. 1998). Since there was a high level of saflufenacil available in the soybean germination zone, this made the herbicide more available for uptake through the hypocotyl. With below normal temperatures and above average rainfall in June and July at Bryanston and Maryhill in 2009, soybean plants were unable to recover from the injury sustained in the cool, wet conditions at planting.

3.4.2 Plant height

Soybean height is important because shorter plants can result in greater losses during harvest. An equality test conducted on the slopes from percent height reduction regression showed that the slopes of the twelve cultivars were not all equal, indicating varying degrees of tolerance to saflufenacil. With the exception of AC 0800RR, environments could be combined for all cultivars at 4 WAE. With a cool, wet spring, 45
g a.i. ha\(^{-1}\) of saflufenacil caused a 10% height reduction of AC 0800RR compared to the untreated check, whereas in drier environments, 131 g a.i. ha\(^{-1}\) was required to reduce height to the same level (Table 3-10). OAC Hanover across all environments had a 10% height reduction at 45 g a.i. ha\(^{-1}\), which is less than 2 times the registered rate. RCAT Mirra required greater than 200 g a.i. ha\(^{-1}\) to cause a 10% height reduction, with all other cultivars ranging from 129 to 182 g a.i. ha\(^{-1}\) for the same level of height reduction (Table 3-10). Saflufenacil applied at 100 and 200 g a.i. ha\(^{-1}\) reduced soybean height 0 and 15%, respectively (Soltani et al. 2010b). Swantek et al. (1998) found an 11% height reduction with sulfentrazone applied at 420 g a.i. ha\(^{-1}\) to the sensitive cultivar KS4895. In greenhouse studies, Hixson (2008) found that soybean height was consistently lower than the untreated check for the cultivar Hutcheson with saflufenacil applied at 40 and 80 g a.i. ha\(^{-1}\).

3.4.3 Yield

Similar to plant height, the twelve cultivars had varying degrees of tolerance to saflufenacil in terms of yield reduction. Under cool, wet conditions, 22 and 45 g a.i. ha\(^{-1}\) caused 10 and 20% yield reduction in OAC Hanover, respectively (Table 3-11). Across all other locations, saflufenacil applied at 46 g a.i. ha\(^{-1}\) reduced yield of OAC Hanover by 10%, which is lower than twice the registered rate. The early season injury in AC 0800RR and HS 11R46 in 2009 at Bryanston was also reflected in yield since 39 and 51 g a.i. ha\(^{-1}\) of saflufenacil, respectively, decreased the yield by 10%. However, under drier conditions, the rate required to reduce yield by 10% increased to 122 and 124 g a.i. ha\(^{-1}\) for AC 0800RR and HS 11R46, respectively. The rate of saflufenacil that caused a 10%
yield reduction across all environments in PRO 27-15 and RCAT Mirra was 159 and 145 g a.i. ha\(^{-1}\), respectively. All other cultivars needed between 82 and 112 g a.i. ha\(^{-1}\) to cause the same level of yield reduction, which is greater than two times the registered use rate. Lyon and Kniss (2010) found that proso millet plants were able to recover from early season stand loss and leaf injury to produce grain yields that were no different from the untreated check. However, these results suggest that under adverse environment conditions the more sensitive soybean cultivars are unable to recover from early season injury.

3.4.4 Hydroponic experiment

Li et al. (1999) demonstrated that hypocotyl and root length reduction of germinal seedlings can be used to predict soybean cultivar response to sulfentrazone. Injury from saflufenacil consisted of reduction in top growth, primary and secondary root development, as well as hypocotyl necrosis at the solution line. Hixson (2008) found that soybean injury was most severe when shoots, roots, and seeds were directly exposed to saflufenacil, which may explain why greater injury was observed under hydroponic conditions compared to the field study. The hydroponic results from this experiment confirm that OAC Hanover was more sensitive than the other cultivars tested. As the most sensitive cultivar, OAC Hanover required only 1 ppb of saflufenacil to cause 10% injury, while the next sensitive cultivar required 5 times this amount to cause the same level of injury (Table 3-12). All other cultivars required between 16 to 37 ppb of saflufenacil to cause 10% injury. The hydroponic experiment corroborates the field studies that there is a range in tolerance among soybean cultivars to saflufenacil.
3.5 Conclusion

Results from this experiment are similar to those of Niekamp et al. (1999) who found that poor growing conditions following planting resulted in greater soybean injury from sulfentrazone and flumioxazin. Saflufenacil applied PRE can cause injury and yield reduction under adverse environmental conditions in sensitive soybean cultivars. OAC Hanover was more sensitive to saflufenacil than the other cultivars tested in this study. Therefore, the hypothesis that there is no difference among soybean cultivars in their sensitivity to saflufenacil applied PRE is rejected. Planting soybean cultivars that are tolerant to saflufenacil should be recommended in order to minimize the risks associated with crop sensitivity. This research demonstrates that there is a difference in soybean cultivar tolerance to saflufenacil and further studies will need to be conducted to determine the degree of sensitivity.
Table 3-1. Soil characteristics for each location, including soil type, percent composition of sand, silt, clay and organic matter, pH, and CEC.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Soil type</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>OM&lt;sup&gt;a&lt;/sup&gt;</th>
<th>pH</th>
<th>CEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston</td>
<td>2009</td>
<td>Silty Loam</td>
<td>32</td>
<td>51</td>
<td>17</td>
<td>5.1</td>
<td>7.4</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Silty Loam</td>
<td>32</td>
<td>51</td>
<td>17</td>
<td>5.1</td>
<td>6.8</td>
<td>22</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>Sandy Loam</td>
<td>58</td>
<td>37</td>
<td>5</td>
<td>4.4</td>
<td>6.8</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Sandy Loam</td>
<td>58</td>
<td>37</td>
<td>5</td>
<td>4.4</td>
<td>6.8</td>
<td>14</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>Clay Loam</td>
<td>33</td>
<td>33</td>
<td>34</td>
<td>5.7</td>
<td>6.6</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Sandy Clay Loam</td>
<td>55</td>
<td>24</td>
<td>21</td>
<td>4.0</td>
<td>7.0</td>
<td>18</td>
</tr>
</tbody>
</table>

<sup>a</sup> Abbreviations: OM, organic matter; CEC, cation exchange capacity.
Table 3-2. Soybean planting, emergence and harvest and herbicide application dates in each year at each location for saflufenacil applied PRE.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Planting</th>
<th>Application</th>
<th>Emergence</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston</td>
<td>2009</td>
<td>21-May</td>
<td>22-May</td>
<td>3-Jun</td>
<td>19-Oct</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>17-May</td>
<td>19-May</td>
<td>25-May</td>
<td>24-Sept</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>22-May</td>
<td>23-May</td>
<td>8-Jun</td>
<td>20-Oct</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>18-May</td>
<td>20-May</td>
<td>27-May</td>
<td>1-Oct</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>21-May</td>
<td>23-May</td>
<td>27-May</td>
<td>20-Oct</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>27-May</td>
<td>28-May</td>
<td>1-Jun</td>
<td>7-Oct</td>
</tr>
</tbody>
</table>

a Abbreviations: PRE, preemergence.
Table 3-3. Mean and 30 year average temperatures for Bryanston, Maryhill, and Ridgetown, Ontario from May to August in 2009 and 2010.\(^a\)

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>May</th>
<th></th>
<th>June</th>
<th></th>
<th>July</th>
<th></th>
<th>August</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>30 year avg</td>
<td>Mean</td>
<td>30 year avg</td>
<td>Mean</td>
<td>30 year avg</td>
<td>Mean</td>
<td>30 year avg</td>
</tr>
<tr>
<td>Bryanston(^b)</td>
<td>2009</td>
<td>13.0</td>
<td>13.0</td>
<td>17.5</td>
<td>18.0</td>
<td>18.3</td>
<td>20.5</td>
<td>19.7</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>15.2</td>
<td>13.0</td>
<td>19.1</td>
<td>18.0</td>
<td>22.0</td>
<td>20.5</td>
<td>21.7</td>
<td>19.5</td>
</tr>
<tr>
<td>Maryhill(^c)</td>
<td>2009</td>
<td>11.9</td>
<td>12.9</td>
<td>16.4</td>
<td>18.0</td>
<td>17.3</td>
<td>20.2</td>
<td>18.7</td>
<td>19.3</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>14.0</td>
<td>12.9</td>
<td>17.6</td>
<td>18.0</td>
<td>21.2</td>
<td>20.2</td>
<td>20.4</td>
<td>19.3</td>
</tr>
<tr>
<td>Ridgetown(^d)</td>
<td>2009</td>
<td>13.0</td>
<td>13.8</td>
<td>17.3</td>
<td>19.3</td>
<td>18.5</td>
<td>21.6</td>
<td>19.6</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>15.1</td>
<td>13.8</td>
<td>19.4</td>
<td>19.3</td>
<td>22.4</td>
<td>21.6</td>
<td>21.7</td>
<td>20.6</td>
</tr>
</tbody>
</table>

\(^a\) Distance of weather station from location: Bryanston 10 km; Maryhill 6 km; Ridgetown, 1 km.

\(^b\) Mean temperature data from Environment Canada, London Ontario Airport.

\(^c\) Mean temperature data from Environment Canada, Kitchener Waterloo Airport.

\(^d\) Mean temperature data from University of Guelph, Ridgetown Campus.
Table 3-4. Mean and 30 year average precipitation data for Bryanston, Maryhill, and Ridgetown, Ontario from May to August in 2009 and 2010

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>May Mean</th>
<th>30 year avg</th>
<th>June Mean</th>
<th>30 year avg</th>
<th>July Mean</th>
<th>30 year avg</th>
<th>August Mean</th>
<th>30 year avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryanston</td>
<td>2009</td>
<td>156.6</td>
<td>83.0</td>
<td>110.1</td>
<td>87.0</td>
<td>95.7</td>
<td>82.0</td>
<td>94.7</td>
<td>85.0</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>57.2</td>
<td>83.0</td>
<td>140.7</td>
<td>87.0</td>
<td>128.0</td>
<td>82.0</td>
<td>13.0</td>
<td>85.0</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>79.0</td>
<td>85.0</td>
<td>84.0</td>
<td>81.0</td>
<td>114.5</td>
<td>85.0</td>
<td>108.0</td>
<td>89.0</td>
</tr>
<tr>
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<td>2010</td>
<td>67.1</td>
<td>85.0</td>
<td>130.7</td>
<td>81.0</td>
<td>129.3</td>
<td>85.0</td>
<td>27.7</td>
<td>89.0</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>30.6</td>
<td>80.1</td>
<td>61.4</td>
<td>73.4</td>
<td>31.6</td>
<td>76.8</td>
<td>91.0</td>
<td>88.8</td>
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<tr>
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<td>122.2</td>
<td>80.1</td>
<td>84.5</td>
<td>73.4</td>
<td>136.0</td>
<td>76.8</td>
<td>26.0</td>
<td>88.8</td>
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</table>

* Distance of weather station less than 1 km from location; 30 year average precipitation data from Farmzone 2010.
Table 3-5. Amount of precipitation for 0-7 DBP, 0-7 DAT, and 0-21 DAT for Bryanston, Maryhill, and Ridgetown, Ontario in 2009 and 2010.\(^a\)

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>0-7 DBP</th>
<th>0-7 DAT</th>
<th>0-21 DAT</th>
</tr>
</thead>
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<tr>
<td>Bryanston</td>
<td>2009</td>
<td>4.8</td>
<td>112.6</td>
<td>132.4</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>13.0</td>
<td>8.0</td>
<td>113.7</td>
</tr>
<tr>
<td>Maryhill</td>
<td>2009</td>
<td>6.5</td>
<td>51.0</td>
<td>73.0</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>6.8</td>
<td>2.1</td>
<td>87.9</td>
</tr>
<tr>
<td>Ridgetown</td>
<td>2009</td>
<td>1.8</td>
<td>7.8</td>
<td>19.4</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>3.1</td>
<td>20.2</td>
<td>73.9</td>
</tr>
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</table>

\(^a\) Abbreviations: DAT, days after preemergence treatment; DBP, days before planting.
Table 3-6. Exponential regression parameters (±SE) for percent soybean injury at 1 WAE for Bryanston, Maryhill, and Ridgetown, Ontario in 2009 and 2010. a

<table>
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<tr>
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<th>Regression parameters b (±SE)</th>
<th>Saflufenacil rate c</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>AC Renfrew</td>
<td>1</td>
<td>3.9×10^{-7} (2.8×10^{-6})</td>
<td>3.6 (1.4)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>3.2×10^{-4} (1.9×10^{-3})</td>
<td>1.7 (1.1)</td>
</tr>
<tr>
<td>OAC Hanover</td>
<td>1</td>
<td>1.3×10^{-2} (2.2×10^{-2})</td>
<td>1.7 (0.3)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>2.9×10^{-5} (1.3×10^{-4})</td>
<td>2.3 (0.8)</td>
</tr>
<tr>
<td>OAC Raptor</td>
<td>1</td>
<td>5.8×10^{-5} (2.3×10^{-4})</td>
<td>2.6 (0.7)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>4.9×10^{-6} (4.3×10^{-5})</td>
<td>2.5 (1.7)</td>
</tr>
<tr>
<td>Pioneer 90B73</td>
<td>1</td>
<td>3.6×10^{-3} (9.5×10^{-3})</td>
<td>1.8 (0.5)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>4.3×10^{-4} (2.5×10^{-3})</td>
<td>1.6 (1.1)</td>
</tr>
<tr>
<td>AC 0800RR</td>
<td>1</td>
<td>9.8×10^{-4} (2.8×10^{-3})</td>
<td>2.1 (0.6)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>8.2×10^{-6} (6.2×10^{-5})</td>
<td>2.3 (1.4)</td>
</tr>
<tr>
<td>DKB 27-51R</td>
<td>1</td>
<td>3.1×10^{-3} (9.5×10^{-3})</td>
<td>1.9 (0.6)</td>
</tr>
<tr>
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<td>23456</td>
<td>8.9×10^{-9} (6.4×10^{-8})</td>
<td>2.1 (1.4)</td>
</tr>
<tr>
<td>PRO 27-15</td>
<td>1</td>
<td>3.1×10^{-3} (9.4×10^{-3})</td>
<td>1.9 (0.6)</td>
</tr>
<tr>
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<td>1.4 (1.1)</td>
</tr>
<tr>
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<td>1.5 (0.5)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>2.1×10^{-6} (2.2×10^{-5})</td>
<td>2.7 (2.1)</td>
</tr>
<tr>
<td>HS 11R46</td>
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<td>2.5 (0.5)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>8.3×10^{-9} (2.7×10^{-8})</td>
<td>0.7 (0.7)</td>
</tr>
<tr>
<td>RT 1784A</td>
<td>1</td>
<td>9.6×10^{-3} (1.7×10^{-2})</td>
<td>1.7 (0.3)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>8.2×10^{-6} (6.3×10^{-5})</td>
<td>2.4 (1.5)</td>
</tr>
<tr>
<td>HS 13RS52</td>
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<td>2.7×10^{-3} (5.2×10^{-3})</td>
<td>1.9 (0.4)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>2.1×10^{-9} (4.9×10^{-8})</td>
<td>3.9 (4.4)</td>
</tr>
<tr>
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<td>1</td>
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<td>3.2 (1.9)</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>3.2×10^{-10} (1.1×10^{-8})</td>
<td>4.2 (6.4)</td>
</tr>
</tbody>
</table>

a Abbreviations: Env, environment; WAE, weeks after crop emergence.
b Exponential corresponds to equation 1. Parameters: a, magnitude constant; b, rate constant.
c ER5, ER10, and ER20 are the rates required to give 5, 10, and 20% crop injury, respectively.
* Denotes significant difference when compared to all other cultivars combined (P<0.05).
Table 3-7. Exponential regression parameters (±SE) for percent soybean injury at 2 WAE for Bryanston, Maryhill, and Ridgetown, Ontario in 2009 and 2010.\(^a\)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Env</th>
<th>a</th>
<th>b</th>
<th>ER5</th>
<th>ER10</th>
<th>ER20</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Renfrew</td>
<td>1</td>
<td>7.1x10(^{-8})</td>
<td>(5.6x10(^{-8}))</td>
<td>3.9</td>
<td>(1.5)</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>1.3x10(^{-3})</td>
<td>(4.5x10(^{-3}))</td>
<td>1.6</td>
<td>(0.7)</td>
<td>170</td>
</tr>
<tr>
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<td>126</td>
<td>1.0x10(^{-2})</td>
<td>(1.7x10(^{-2}))</td>
<td>1.6</td>
<td>(0.3)</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>345</td>
<td>5.9x10(^{-3})</td>
<td>(1.7x10(^{-3}))</td>
<td>1.3</td>
<td>(0.6)</td>
<td>153</td>
</tr>
<tr>
<td>OAC Raptor</td>
<td>12</td>
<td>4.0x10(^{-3})</td>
<td>(1.3x10(^{-3}))</td>
<td>1.7</td>
<td>(0.6)</td>
<td>65</td>
</tr>
<tr>
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<td>3456</td>
<td>2.6x10(^{-3})</td>
<td>(1.3x10(^{-3}))</td>
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<td>(0.9)</td>
<td>196</td>
</tr>
<tr>
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<td>1.9x10(^{-3})</td>
<td>(6.5x10(^{-3}))</td>
<td>1.6</td>
<td>(0.3)</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>3456</td>
<td>3.9x10(^{-4})</td>
<td>(2.0x10(^{-4}))</td>
<td>1.7</td>
<td>(1.0)</td>
<td>&gt;200</td>
</tr>
<tr>
<td>AC 0800RR</td>
<td>126</td>
<td>3.2x10(^{-3})</td>
<td>(1.8x10(^{-3}))</td>
<td>2.6</td>
<td>(1.1)</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>345</td>
<td>2.2x10(^{-3})</td>
<td>(9.7x10(^{-3}))</td>
<td>1.7</td>
<td>(0.9)</td>
<td>&gt;200</td>
</tr>
<tr>
<td>DKB 27-51R</td>
<td>126</td>
<td>1.6x10(^{-3})</td>
<td>(5.8x10(^{-3}))</td>
<td>1.8</td>
<td>(0.7)</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>345</td>
<td>1.3x10(^{-8})</td>
<td>(1.7x10(^{-8}))</td>
<td>3.6</td>
<td>(2.5)</td>
<td>&gt;200</td>
</tr>
<tr>
<td>PRO 27-15</td>
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<td>2.1x10(^{-5})</td>
<td>(1.1x10(^{-5}))</td>
<td>2.8</td>
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<td>23456</td>
<td>4.1x10(^{-4})</td>
<td>(1.3x10(^{-4}))</td>
<td>1.6</td>
<td>(0.6)</td>
<td>&gt;200</td>
</tr>
<tr>
<td>RCAT Matrix</td>
<td>126</td>
<td>6.8x10(^{-5})</td>
<td>(3.2x10(^{-5}))</td>
<td>2.4</td>
<td>(0.9)</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>345</td>
<td>9.9x10(^{-5})</td>
<td>(6.2x10(^{-5}))</td>
<td>1.9</td>
<td>(1.2)</td>
<td>&gt;200</td>
</tr>
<tr>
<td>HS 11R46</td>
<td>1</td>
<td>2.1x10(^{-3})</td>
<td>(5.0x10(^{-3}))</td>
<td>2.3</td>
<td>(0.5)</td>
<td>74</td>
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<td>(3.6x10(^{-7}))</td>
<td>2.9</td>
<td>(1.4)</td>
<td>&gt;200</td>
</tr>
<tr>
<td>RT 1784A</td>
<td>1</td>
<td>4.9x10(^{-3})</td>
<td>(9.3x10(^{-3}))</td>
<td>1.8</td>
<td>(0.4)</td>
<td>49</td>
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<tr>
<td></td>
<td>23456</td>
<td>5.7x10(^{-7})</td>
<td>(5.2x10(^{-7}))</td>
<td>3.0</td>
<td>(1.7)</td>
<td>190</td>
</tr>
<tr>
<td>HS 13RS52</td>
<td>1</td>
<td>3.5x10(^{-3})</td>
<td>(5.8x10(^{-3}))</td>
<td>1.9</td>
<td>(0.3)</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>1.9x10(^{-7})</td>
<td>(2.3x10(^{-7}))</td>
<td>3.2</td>
<td>(2.4)</td>
<td>&gt;200</td>
</tr>
<tr>
<td>RCAT Mirra</td>
<td>1</td>
<td>5.1x10(^{-4})</td>
<td>(1.5x10(^{-4}))</td>
<td>1.9</td>
<td>(0.6)</td>
<td>113</td>
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<td>(4.7x10(^{-8}))</td>
<td>3.5</td>
<td>(2.9)</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: Env, environment; WAE, weeks after crop emergence.
\(^b\) Exponential corresponds to equation 1. Parameters: a, magnitude constant; b, rate constant.
\(^c\) ER5, ER10, and ER20 are the rates required to give 5, 10, and 20% crop injury, respectively.
\(^*\) Denotes significant difference when compared to all other cultivars combined (P<0.05).
Table 3-8. Exponential and linear regression parameters (±SE) for percent soybean injury at 4 WAE for Bryanston, Maryhill, and Ridgetown, Ontario in 2009 and 2010.\(^a\)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Env(^d)</th>
<th>a</th>
<th>b</th>
<th>ER5</th>
<th>ER10</th>
<th>ER20</th>
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<td>Regression parameters(^b) (±SE)</td>
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<tr>
<td></td>
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<td>Exponential</td>
<td>Linear</td>
<td></td>
<td></td>
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<tr>
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<td>1</td>
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<td>(3.1x10(^{-8}))</td>
<td>4.4</td>
<td>(0.9)</td>
<td>106</td>
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<tr>
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<td>(8.4x10(^{-4}))</td>
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<td>(1.3)</td>
<td>144</td>
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<td>(0.2)</td>
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<td>(1.4x10(^{-2}))</td>
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<td>(0.3)</td>
<td>56</td>
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<td>(0.4)</td>
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<td>(1.9x10(^{-10}))</td>
<td>3.9</td>
<td>(3.8)</td>
<td>165</td>
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<td>(5.8x10(^{-4}))</td>
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<td>(1.5)</td>
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<td>(1.9x10(^{-10}))</td>
<td>3.9</td>
<td>(3.8)</td>
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<td>(0.3)</td>
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<tr>
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<td>(9.3x10(^{-10}))</td>
<td>2.3</td>
<td>(0.9)</td>
<td>80</td>
</tr>
<tr>
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<td>(3.3x10(^{-3}))</td>
<td>1.6</td>
<td>(0.2)</td>
<td>35</td>
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<tr>
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<td>(1.5)</td>
<td>162</td>
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<td>(2.9x10(^{-3}))</td>
<td>1.6</td>
<td>(0.5)</td>
<td>45</td>
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<tr>
<td></td>
<td>3456</td>
<td>2.4 x10(^{-3})</td>
<td>(3.6 x10(^{-4}))</td>
<td>3.5</td>
<td>(2.8)</td>
<td>&gt;200</td>
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<td>(2.0x10(^{-4}))</td>
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<td>(0.5)</td>
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<tr>
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<td>(3.5x10(^{-7}))</td>
<td>2.4</td>
<td>(1.3)</td>
<td>&gt;200</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Env(^d)</th>
<th>a</th>
<th>b</th>
<th>ER5</th>
<th>ER10</th>
<th>ER20</th>
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</thead>
<tbody>
<tr>
<td>PRO 27-15</td>
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<td>1.1x10(^{-2})</td>
<td>(2.9x10(^{-3}))</td>
<td>&gt;200</td>
<td>&gt;200</td>
<td>&gt;200</td>
</tr>
<tr>
<td>HS 11R46</td>
<td>3456</td>
<td>8.9 x10(^{-3})</td>
<td>(3.6x10(^{-4}))</td>
<td>&gt;200</td>
<td>&gt;200</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: Env, environment; WAE, weeks after crop emergence.

\(^b\) Exponential corresponds to equation 1 and linear corresponds to equation 2.

Exponential parameters: a, magnitude constant; b, rate constant.

Linear parameter: b1, slope.

\(^c\) ER5, ER10, and ER20 are the rates required to give 5, 10, and 20% crop injury, respectively.


\(^*\) Denotes significant difference when compared to all other cultivars combined (P<0.05).
<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Env&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Regression parameters&lt;sup&gt;b&lt;/sup&gt; (±SE)</th>
<th>Saflufenacil rate&lt;sup&gt;c&lt;/sup&gt;</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Exponential</td>
<td></td>
<td>ER5</td>
<td>ER10</td>
</tr>
<tr>
<td>AC Renfrew</td>
<td>12</td>
<td>1.3x10&lt;sup&gt;-4&lt;/sup&gt; (4.4x10&lt;sup&gt;-4&lt;/sup&gt;)</td>
<td>2.4 (0.6)</td>
<td>79</td>
<td>105</td>
</tr>
<tr>
<td>OAC Hanover&lt;sup&gt;*&lt;/sup&gt;</td>
<td>12</td>
<td>1.0x10&lt;sup&gt;-1&lt;/sup&gt; (8.5x10&lt;sup&gt;-2&lt;/sup&gt;)</td>
<td>1.3 (0.2)</td>
<td>22</td>
<td>38</td>
</tr>
<tr>
<td>OAC Raptor</td>
<td>3456</td>
<td>4.8x10&lt;sup&gt;-3&lt;/sup&gt; (9.0x10&lt;sup&gt;-3&lt;/sup&gt;)</td>
<td>1.7 (0.4)</td>
<td>66</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>6.7x10&lt;sup&gt;-4&lt;/sup&gt; (2.3x10&lt;sup&gt;-3&lt;/sup&gt;)</td>
<td>1.9 (0.7)</td>
<td>121</td>
<td>176</td>
</tr>
<tr>
<td>Pioneer 90B73</td>
<td>12</td>
<td>4.9x10&lt;sup&gt;-2&lt;/sup&gt; (8.2x10&lt;sup&gt;-2&lt;/sup&gt;)</td>
<td>1.2 (0.3)</td>
<td>43</td>
<td>75</td>
</tr>
<tr>
<td>AC 0800RR</td>
<td>1</td>
<td>8.7x10&lt;sup&gt;-4&lt;/sup&gt; (2.9x10&lt;sup&gt;-4&lt;/sup&gt;)</td>
<td>2.5 (0.6)</td>
<td>31</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>1.3x10&lt;sup&gt;-2&lt;/sup&gt; (3.5x10&lt;sup&gt;-2&lt;/sup&gt;)</td>
<td>1.2 (0.5)</td>
<td>134</td>
<td>&gt;200</td>
</tr>
<tr>
<td>PRO 27-15</td>
<td>1</td>
<td>7.8x10&lt;sup&gt;-5&lt;/sup&gt; (3.5x10&lt;sup&gt;-3&lt;/sup&gt;)</td>
<td>2.2 (1.1)</td>
<td>160</td>
<td>&gt;200</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>1.3x10&lt;sup&gt;-2&lt;/sup&gt; (3.5x10&lt;sup&gt;-2&lt;/sup&gt;)</td>
<td>2.2 (1.1)</td>
<td>68</td>
<td>95</td>
</tr>
<tr>
<td>RCAT Matrix</td>
<td>1</td>
<td>4.5x10&lt;sup&gt;-2&lt;/sup&gt; (1.5x10&lt;sup&gt;-2&lt;/sup&gt;)</td>
<td>2.2 (0.6)</td>
<td>76</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>4.0x10&lt;sup&gt;-4&lt;/sup&gt; (2.2x10&lt;sup&gt;-4&lt;/sup&gt;)</td>
<td>2.3 (1.1)</td>
<td>171</td>
<td>&gt;200</td>
</tr>
<tr>
<td>HS 11R46</td>
<td>12</td>
<td>1.8x10&lt;sup&gt;-4&lt;/sup&gt; (1.7x10&lt;sup&gt;-4&lt;/sup&gt;)</td>
<td>3.2 (1.8)</td>
<td>110</td>
<td>138</td>
</tr>
<tr>
<td>RT 1784A</td>
<td>1</td>
<td>2.6x10&lt;sup&gt;-6&lt;/sup&gt; (9.7x10&lt;sup&gt;-7&lt;/sup&gt;)</td>
<td>1.8 (0.7)</td>
<td>63</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>6.4x10&lt;sup&gt;-6&lt;/sup&gt; (4.9x10&lt;sup&gt;-6&lt;/sup&gt;)</td>
<td>2.6 (1.4)</td>
<td>189</td>
<td>&gt;200</td>
</tr>
<tr>
<td>HS 13RS52</td>
<td>1</td>
<td>2.0x10&lt;sup&gt;-6&lt;/sup&gt; (6.5x10&lt;sup&gt;-7&lt;/sup&gt;)</td>
<td>1.9 (0.6)</td>
<td>59</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>8.3x10&lt;sup&gt;-6&lt;/sup&gt; (5.8x10&lt;sup&gt;-6&lt;/sup&gt;)</td>
<td>2.4 (1.3)</td>
<td>&gt;200</td>
<td>&gt;200</td>
</tr>
<tr>
<td>RCAT Mirra</td>
<td>12</td>
<td>4.9x10&lt;sup&gt;-2&lt;/sup&gt; (7.8x10&lt;sup&gt;-2&lt;/sup&gt;)</td>
<td>9.9 (0.3)</td>
<td>107</td>
<td>&gt;200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Linear</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AC Renfrew</td>
<td>3456</td>
<td>2.2x10&lt;sup&gt;-2&lt;/sup&gt; (3.8x10&lt;sup&gt;-3&lt;/sup&gt;)</td>
<td>b1</td>
<td>&gt;200</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Pioneer 90B73</td>
<td>3456</td>
<td>2.8x10&lt;sup&gt;-2&lt;/sup&gt; (5.1x10&lt;sup&gt;-3&lt;/sup&gt;)</td>
<td></td>
<td>176</td>
<td>&gt;200</td>
</tr>
<tr>
<td>HS 11R46</td>
<td>3456</td>
<td>8.2x10&lt;sup&gt;-3&lt;/sup&gt; (1.6x10&lt;sup&gt;-3&lt;/sup&gt;)</td>
<td></td>
<td>&gt;200</td>
<td>&gt;200</td>
</tr>
<tr>
<td>RCAT Mirra</td>
<td>3456</td>
<td>4.2x10&lt;sup&gt;-3&lt;/sup&gt; (1.0x10&lt;sup&gt;-3&lt;/sup&gt;)</td>
<td></td>
<td>&gt;200</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>

<sup>a</sup> Abbreviations: Env, environment; WAE, weeks after crop emergence.

<sup>b</sup> Exponential corresponds to equation 1 and linear corresponds to equation 2.

Exponential parameters: a, magnitude constant; b, rate constant.

Linear parameter: b1, slope.

<sup>c</sup> ER5, ER10, and ER20 are the rates required to give 5, 10, and 20% crop injury, respectively.


<sup>*</sup> Denotes significant difference when compared to all other cultivars combined (P<0.05).
Table 3-10. Linear regression parameters (±SE) for percent soybean height reduction at 4 WAE for Bryanston, Maryhill, and Ridgetown, Ontario in 2009 and 2010.\(^a\)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Env(^d)</th>
<th>Regression parameter(^b) (±SE)</th>
<th>Saflufenacil rate(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>b1</td>
<td>ER5</td>
</tr>
<tr>
<td>AC Renfrew</td>
<td>123456</td>
<td>7.8 x10(^{-2}) (8.3x10(^{-3}))</td>
<td>65</td>
</tr>
<tr>
<td>OAC Hanover(^*)</td>
<td>123456</td>
<td>2.2 x10(^{-1}) (1.2x10(^{-2}))</td>
<td>23</td>
</tr>
<tr>
<td>OAC Raptor</td>
<td>123456</td>
<td>7.6 x10(^{-2}) (1.1x10(^{-2}))</td>
<td>66</td>
</tr>
<tr>
<td>Pioneer 90B73</td>
<td>123456</td>
<td>6.8 x10(^{-2}) (8.2x10(^{-3}))</td>
<td>73</td>
</tr>
<tr>
<td>AC 0800RR</td>
<td>1</td>
<td>2.2 x10(^{-1}) (2.2x10(^{-2}))</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>7.7 x10(^{-2}) (8.0x10(^{-3}))</td>
<td>65</td>
</tr>
<tr>
<td>DKB 27-51R</td>
<td>123456</td>
<td>1.0 x10(^{-1}) (9.5x10(^{-3}))</td>
<td>49</td>
</tr>
<tr>
<td>PRO 27-15</td>
<td>123456</td>
<td>7.5 x10(^{-2}) (6.9x10(^{-3}))</td>
<td>67</td>
</tr>
<tr>
<td>RCAT Matrix</td>
<td>123456</td>
<td>5.5 x10(^{-2}) (6.8x10(^{-3}))</td>
<td>91</td>
</tr>
<tr>
<td>HS 11R46</td>
<td>123456</td>
<td>6.1 x10(^{-2}) (7.2x10(^{-3}))</td>
<td>83</td>
</tr>
<tr>
<td>RT 1784A</td>
<td>123456</td>
<td>7.5 x10(^{-2}) (8.6x10(^{-3}))</td>
<td>66</td>
</tr>
<tr>
<td>HS 13RS22</td>
<td>123456</td>
<td>5.9 x10(^{-2}) (7.1x10(^{-3}))</td>
<td>84</td>
</tr>
<tr>
<td>RCAT Mirra</td>
<td>123456</td>
<td>3.4 x10(^{-2}) (5.0x10(^{-3}))</td>
<td>145</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: Env, environment; WAE, weeks after crop emergence.

\(^b\) Linear corresponds to equation 2. Parameters: b1, slope.

\(^c\) ER5, ER10, and ER20 are the rates required to give 5, 10, and 20% reduction in plant height, respectively.


\(^*\) Denotes significant difference when compared to all other cultivars combined (P<0.05).
Table 3-11. Linear regression parameters (±SE) for percent soybean yield reduction of the untreated check for Bryanston, Maryhill, and Ridgetown, Ontario in 2009 and 2010.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Env\textsuperscript{d}</th>
<th>Regression parameter\textsuperscript{b} (±SE)</th>
<th>Saflufenacil rate\textsuperscript{c}</th>
<th>ER5</th>
<th>ER10</th>
<th>ER20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>\textsuperscript{b1}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AC Renfrew</td>
<td>123456</td>
<td>9.7 x 10^{-2} (1.1 x 10^{-2})</td>
<td>52</td>
<td>103</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3456</td>
<td>2.2 x 10^{-1} (1.7 x 10^{-2})</td>
<td>23</td>
<td>46</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>OAC Hanover\textsuperscript{*}</td>
<td>12</td>
<td>4.5 x 10^{-1} (2.2 x 10^{-2})</td>
<td>11</td>
<td>22</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3456</td>
<td>2.2 x 10^{-1} (1.7 x 10^{-2})</td>
<td>41</td>
<td>82</td>
<td>165</td>
<td></td>
</tr>
<tr>
<td>OAC Raptor</td>
<td>123456</td>
<td>1.2 x 10^{-1} (1.3 x 10^{-2})</td>
<td>56</td>
<td>112</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>Pioneer 90B73</td>
<td>123456</td>
<td>9.0 x 10^{-2} (1.0 x 10^{-2})</td>
<td>23</td>
<td>46</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>AC 0800RR</td>
<td>1</td>
<td>2.6 x 10^{-1} (3.6 x 10^{-2})</td>
<td>20</td>
<td>39</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>8.2 x 10^{-2} (1.3 x 10^{-2})</td>
<td>61</td>
<td>122</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>DKB 27-51R</td>
<td>123456</td>
<td>1.1 x 10^{-1} (1.1 x 10^{-2})</td>
<td>44</td>
<td>88</td>
<td>177</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>8.1 x 10^{-2} (1.5 x 10^{-2})</td>
<td>62</td>
<td>124</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>PRO 27-15</td>
<td>123456</td>
<td>6.3 x 10^{-2} (9.2 x 10^{-3})</td>
<td>79</td>
<td>158</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>RCAT Matrix</td>
<td>123456</td>
<td>9.2 x 10^{-2} (1.2 x 10^{-2})</td>
<td>54</td>
<td>108</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>2.0 x 10^{-1} (1.9 x 10^{-2})</td>
<td>25</td>
<td>51</td>
<td>101</td>
<td></td>
</tr>
<tr>
<td>HS 11R46</td>
<td>1</td>
<td>2.0 x 10^{-1} (1.9 x 10^{-2})</td>
<td>25</td>
<td>51</td>
<td>101</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23456</td>
<td>8.1 x 10^{-2} (1.5 x 10^{-2})</td>
<td>62</td>
<td>124</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>RT 1784A</td>
<td>123456</td>
<td>9.3 x 10^{-2} (1.1 x 10^{-2})</td>
<td>54</td>
<td>107</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>HS 13RS52</td>
<td>123456</td>
<td>9.7 x 10^{-2} (1.2 x 10^{-2})</td>
<td>52</td>
<td>104</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>RCAT Mirra</td>
<td>123456</td>
<td>6.9 x 10^{-2} (1.0 x 10^{-2})</td>
<td>72</td>
<td>145</td>
<td>&gt;200</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} Abbreviations: Env, environment; WAE, weeks after crop emergence.

\textsuperscript{b} Linear corresponds to equation 2. Parameters: b1, slope.

\textsuperscript{c} ER5, ER10, and ER20 are the rates required to give 5, 10, and 20\% reduction in crop yield, respectively.


\textsuperscript{*} Denotes significant difference when compared to all other cultivars combined (P<0.05).
**Table 3-12.** Dose response regression parameters (±SE) for percent soybean injury of hydroponic screening conducted at BASF Corporation (2011). Data was pooled for 2 runs.  

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Regression parameters(^b) (±SE)</th>
<th>Saflufenacil rate(^c) (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>AC Renfrew</td>
<td>89.7 (5.5)</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>OAC Hanover(^*)</td>
<td>100.0 (15.4)</td>
<td>0.0 (3.0)</td>
</tr>
<tr>
<td>OAC Raptor</td>
<td>95.9 (5.7)</td>
<td>2.1 (3.1)</td>
</tr>
<tr>
<td>Pioneer 90B73</td>
<td>100.0 (0.0)</td>
<td>0.2 (6.3)</td>
</tr>
<tr>
<td>AC 0800RR</td>
<td>81.6 (5.3)</td>
<td>4.0 (3.2)</td>
</tr>
<tr>
<td>DKB 27-51R</td>
<td>100.0 (0.0)</td>
<td>2.2 (4.1)</td>
</tr>
<tr>
<td>PRO 27-15</td>
<td>92.2 (4.9)</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>RCAT Matrix</td>
<td>100.0 (0.0)</td>
<td>4.3 (3.9)</td>
</tr>
<tr>
<td>HS 11R46</td>
<td>100.0 (0.0)</td>
<td>2.4 (4.6)</td>
</tr>
<tr>
<td>RT 1784A</td>
<td>91.4 (5.6)</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>HS 13RS52</td>
<td>100.0 (0.0)</td>
<td>2.6 (3.8)</td>
</tr>
<tr>
<td>RCAT Mirra</td>
<td>100.0 (0.0)</td>
<td>4.3 (3.9)</td>
</tr>
</tbody>
</table>

\(^a\) Abbreviations: Env, environment; ppb, parts per billion in solution.

\(^b\) Dose-response corresponds to equation 3. Parameters: B, slope of the line around I50; C, lower limit; D, upper limit; I50, rate required for 50% response.

\(^c\) ER5, ER10, and ER20 are the rates required to give 5, 10, and 20% crop injury, respectively.

\(^*\) Denotes significant difference when compared to all other cultivars combined (P<0.05).
4.0 General Discussion

4.1 Contribution

With the increased use of glyphosate resistant crops in Ontario, there has been an over-reliance on the use of glyphosate as a sole means of weed control. This research provides information on saflufenacil and saflufenacil/dimethenamid-p when used as a set-up treatment prior to an in-crop application of a registered herbicide in soybean. The data from this study does not support the hypothesis that there is no difference among weed species to applications of saflufenacil/dimethenamid-p applied PRE. Although there were no yield benefits with the addition of saflufenacil/dimethenamid-p applied PRE followed by glyphosate POST compared to a single application of glyphosate POST in soybean, results may have been different if glyphosate resistant biotypes were present. Saflufenacil can provide an alternative mode of action to control ALS, triazine, and glyphosate resistant broadleaf weeds, and also increase the control of broadleaf weeds that require a higher rate of glyphosate. Glyphosate is a valuable tool in Canadian agriculture and it is important to use glyphosate judiciously to ensure that it remains an effective weed management tool for many years. The use of saflufenacil as a soil-applied herbicide prior to crop emergence would provide residual control of broadleaf weeds and possibly eliminate the need for a second herbicide application in-crop, saving the grower both time and additional application costs.

To date, no studies have been published on cultivar tolerance to saflufenacil and weed control with saflufenacil/dimethenamid-p in soybean. Based on the data from this experiment, the hypothesis there is no difference among soybean cultivars in their sensitivity to saflufenacil applied PRE is rejected. By identifying soybean cultivars that
are more sensitive to saflufenacil, growers can select alternate cultivars more tolerant to saflufenacil, thereby reducing the potential of injury if adverse environmental conditions occur after planting. This research demonstrates that there is a difference among soybean cultivars in their sensitivity to saflufenacil, though further studies will need to be conducted in order to determine the degree of sensitivity.

4.1 Limitations

This research demonstrated that there was a difference among soybean cultivars to saflufenacil, however only 12 different glyphosate resistant soybean cultivars were evaluated. A limitation of this study is the lack of public data on the soybean germplasm from various seed companies. With several seed companies marketing multiple soybean cultivars on the market, it is difficult to acquire data on the germplasm of soybean cultivars due to confidential information. The high rate of turn-over of glyphosate resistant cultivars on the market makes it difficult to conduct field trials over multiple years on the same cultivar under various environmental conditions. It is also important to examine conventional and identity preserve (IP) soybean cultivars. Measuring electrolytic leakage from excised roots has been used to determine soybean cultivar sensitivity to sulfentrazone (Li et al. 2000a). However, the use of this method does not reflect the expected cultivar-based differences (Li et al. 2000a). Therefore, the development of a simple and rapid assay to accurately predict soybean cultivar tolerance to saflufenacil is necessary.
4.2 Future Research

This study outlines some important information for growers on the tolerance of soybean cultivars to saflufenacil, as well as the level of weed control achieved when saflufenacil/dimethenamid-p is applied as a set-up treatment for a planned POST glyphosate application in soybean. A hydroponic screening test similar to the one used in this study could be used by breeders to select soybean lines that are more tolerant to saflufenacil, to reduce the potential risk of soybean injury under various environmental conditions. The hydroponic screening test should also incorporate lower rates of saflufenacil in the solution to achieve a more accurate dose response to determine the degree of tolerance. Root growth and hypocotyl length measurements should also be incorporated into this test to determine if cultivar response is manifested during germination and prior to emergence.

Furthermore, it is important to investigate the mechanism of soybean cultivar tolerance. Such mechanisms could include differential rates of metabolism, absorption and/or translocation. In addition, soybean injury is influenced by soil factors including texture, OM, CEC, pH (Hixson 2008) and environmental conditions, as shown in this research. Understanding the interaction between soil factors and environmental conditions after application, including the timing of rain events, as well as the impact of temperature, is necessary to determine when the soybean plant is most sensitive to applications of saflufenacil. When the premix of saflufenacil/dimethenamid-p is applied as a set-up treatment in soybean, it is important to determine if the dimethenamid-p component of this formulation increases the potential for crop injury or has an additive
effect on sensitive soybean cultivars if cool and wet environmental conditions occur after application.

This research also demonstrated that there was no yield benefit with the addition of saflufenacil/dimethenamid-p applied PRE followed by glyphosate POST in soybean compared to a single POST application of glyphosate. However, it is important to conduct this research in the presence of glyphosate resistant weed species to demonstrate the yield benefit of a PRE application of saflufenacil/dimethenamid-p followed by glyphosate POST in glyphosate tolerant soybean. More research will need to be conducted in order to determine if there is the potential to increase the rate of saflufenacil/dimethenamid-p above the current registered rate so that the length of residual weed control can be increased.
5.0 Literature Cited


Buzzell, R.I. and A.S. Hamill. 1988. Improved tolerance of soybean (Glycine max) to metribuzin. Weed Technol. 2:170-171,


6.0 Appendix 1: SAS Codes to Analyze Biologically Effective Rate of saflufenacil/dimethenamid-p in Soybean Data

libname Sasdata "C:\Documents and Settings\miller5\My Documents\School\Data\SAS Data Set";
*Biological Effective Rate of BAS 781 in soybean;
*Env: 1 and 4 (Bryanston), 2 and 5 (Maryhill), 3 and 6 (Ridgetown);
*Year: 2009, 2010;
*Injury1, Injury2, Injury4 weeks after treatment: crop injury;
*XXXXXX2,XXXXXX4,XXXXXX7,XXXXXX11,XXXXXX15: weed control at 2, 4, 7, 11, and 15 weeks after treatment;
*XXXXXdens and XXXXXdw: weed density and dryweight per sq. meter at 56 DAE;
*cheal, amass, ambel, setvi, echcg, abuth, solpt;
*yield in T/ha;

data first;
set Sasdata.efficacy;

if env=5 then delete;
if setvi2=2000 then delete;
if echcg4=2000 then delete;
if echcg7=2000 then delete;
if echcg11=2000 then delete;
if echcg15=2000 then delete;
if echcgden=2000 then delete;
if echcgwt=2000 then delete;
if pechcgden=2000 then delete;
if pechcgwt=2000 then delete;

if trt=1 then rate=.1;
*if trt=1 then delete;
if trt=2 then delete;
*if trt=9 then rate=.1;
*if trt=9 then delete;
*if trt=1 then delete;

**for density and dry weights;
*if trt=2 then delete;
*if trt<9 then delete;

**for control regressions;
*if trt=2 then delete;
*if env=1 then delete;
*if env=2 then delete;
*if env=3 then delete;
*if env=4 then delete;
*if env=6 then delete;

**for contrasts;
*if trt>8 then delete;

*title2 'amass2';
*analvar=amass2;

*title2 'amass2 (log transformation)';
*analvar=log(amass2+1);

*title2 'amass2 (Square root transformation)';
*analvar=sqrt(amass2+0.5);

/*
**Use following adjustment for arcsine square root trans;
title2 'amass2 (arcsine sqrt transformation)';
analvar1=amass2;
if analvar1=100 then analvar1=100-0.01;
if analvar1=0 then analvar1=0+0.01;
analvar2=analvar1/100;
analvar=arsin(sqrt(analvar2));
*/
*indvar=rate;

*indvar=log(rate);
run;

proc sort data=first;
by env trt rep;
run;

**use trt for contrasts;
**use rate for regression;

proc mixed covtest;
class env trt rep;
model analvar=trt / ddfm=satterth outp=second;
**satterthwaite method for degrees of freedom;
*random env env*trt rep(env);

**single environment;
random rep;

parms/nobound;

lsmeans trt;
run;

/*
 ** Residual analysis;

proc plot;
plot resid*pred resid*trt resid*env resid*rep/vref=0;
run;

proc univariate normal;
var resid;
run;

proc rank normal=blom out=two;
var resid;
ranks zvar;
run;

proc plot;
plot resid*zvar='*';
run;
*/

/**exponential response for Injury;
 **if trt=1 then rate=1;
 **use log(rate);

proc nlin;
parameters
a=0.1
b=3;

model analvar=a*exp(b*indvar);
run;
*/

/**
 **segmented regression;
 **a=left intercept, b1=slope of left segment;
**br1=slope of right segment, j=junction of two lines;**
**use indvar=rate;**
proc nlin method=marquardt;
bounds a0>=0;
parameters a0=0
    b1=.01
        br1=.5
    j=200;
*left segment;
if indvar<=j then do;
    model analvar=a0+b1*indvar;
    der.a0=1;
    der.b1=indvar;
    der.br1=0;
    der.j=0;
end;
*right segment;
if indvar>j then do;
*else do;
model analvar=a0+b1*j+br1*(indvar-j);
    der.a0=1;
    der.b1=j;
    der.br1=indvar-j;
    der.j=b1-br1;
end;
run;
*
/*
** dose response for control ratings;**
**use log(rate);**
**if trt=1 then rate=.1;**

proc nlin;
bounds c>=0;
bounds d<=100;
parameters
d=100
c=0
i50=150
b=2;
if rate=0.1 then predict=c;
else predict=c+(d-c)/(1+exp(-b*(indvar-log(i50))));
model analvar=predict;
run;
*/

/**
** dose response for density and dry weight ratings;
**use log(rate);
**if trt=1 then rate=.1;
**add to parameter list if hormesis present: h=1;
proc nlin;
bounds c>=0;
*bounds h>=0;
parameters
d=100
c=0
i50=100
b=2;

if rate=0.1 then predict=d;
else predict=c+(d-c)/(1+exp(b*(indvar-log(i50))));
*else predict=c+(d-c+h*rate)/(1+exp(b*(indvar-log(i50))));
model analvar=predict;

run;
*/

/*
** density and dry weight inverse exponential;
**if trt=1 then rate=0.1;
**use rate;

proc nlin;
bounds a>=0;
parameters
a=0
b=150
c=.2;

predict=a+b*exp(-c*indvar);
model analvar=predict;

run;
*/

/*
** linear regression dry weight;
**use rate;
**if trt=1 then rate=0.1;
proc nlin;
parameters
a=100
b=5;
model analvar=indvar*b+a;
run;
*/

proc mixed covtest;
class env trt rep;
model analvar=trt / ddfm=satterth outp=second;
**satterthwaite method for degrees of freedom;
*random env env*trt rep(env);

**single environment;
random rep;

parms/nobound;

* delete trt 1 and 2 before running contrasts;
contrast 'gly vs res30+gly'   trt 0 0 0 0 0 0 1 -1 0 0 0 0 0
contrast 'gly vs res61+gly'   trt 0 0 0 0 0 0 1 0 -1 0 0 0 0
contrast 'gly vs res122+gly'  trt 0 0 0 0 0 0 1 0 0 -1 0 0 0
contrast 'gly vs res245+gly'  trt 0 0 0 0 0 0 1 0 0 0 -1 0 0
contrast 'gly vs res490+gly'  trt 0 0 0 0 0 0 1 0 0 0 0 -1
contrast 'gly vs res980+gly'  trt 0 0 0 0 0 0 1 0 0 0 0 0 -1

lsmeans trt;
run;

/*
*Means and Std Errors;
proc summary mean stderr;
*by trt;

*var injury1 injury2 injury4
cheal2 cheal4 cheal7 cheal11 cheal15
amass2 amass4 amass7 amass11 amass15
ambel2 ambel4 ambel7 ambel11 ambel15
setvi2 setvi4 setvi7 setvi11 setvi15
echcg2 echcg4 echcg7 echcg11 echcg15
abuth2 abuth4 abuth7 abuth11 abuth15
solpt15

101
chealden cheekwt
amassden amasswt
ambelden ambelwt
setviden setviwt
echcgden echcgwt
abuthden abuthwt
solptden solptwt
yield;

*output mean=minjury1 minjury2 minjury4
mcheal2 mcheal4 mcheal7 mcheal11 mcheal15
mamass2 mamass4 mamass7 mamass11 mamass15
mambel2 mambel4 mambel7 mambel11 mambel15
msetvi2 msetvi4 msetvi7 msetvi11 msetvi15
mehcgl2 mehcgl4 mehcgl7 mehcgl11 mehcgl15
mabuth2 mabuth4 mabuth7 mabuth11 mabuth15
msolpt15
mchealden mchealwt
mamassden mamasswt
mambelden mambelwt
msetviden msetviwt
mehcgden mehcgwt
mabuthden mabuthwt
msolptden msolptwt
myield

stderr=seinjury1 seinjury2 seinjury4
secheal2 secheal4 secheal7 secheal11 secheal15
seamass2 seamass4 seamass7 seamass11 seamass15
seambel2 seambel4 seambel7 seambel11 seambel15
sesetvi2 sesetvi4 sesetvi7 sesetvi11 sesetvi15
seehcgl2 seehcgl4 seehcgl7 seehcgl11 seehcgl15
seaabuth2 seaabuth4 seaabuth7 seaabuth11 seaabuth15
sesolpt15
sechealden sechealwt
seamassden seamasswt
seambelden seambelwt
sesetviden sesetviwt
seehcglden seehcglwt
seaabuthden seaabuthwt
sesolptden sesolptwt
seyield;

run;

proc print;
*var minjury1 seinjury1 minjury2 seinjury2 minjury4 seinjury4 mcheal2 secheal2 mcheal4 secheal4 mcheal7 secheal7 mcheal11 secheal11 mcheal15 secheal15 mamass2 seamass4 mamass4 seamass7 mamass11 seamass11 mamass15 seamass15 mambel2 seambel2 mambel4 seambel4 mambel7 seambel7 mambel11 seambel11 mambel15 seambel15 msetvi2 sesetvi2 msetvi4 sesetvi4 msetvi7 sesetvi7 msetvi11 sesetvi11 msetvi15 sesetvi15 mechcg2 seechcg2 mechcg4 seechcg4 mechcg7 seechcg7 mechcg11 seechcg11 mechcg15 seechcg15 mabuth2 seabuth2 mabuth4 seabuth4 mabuth7 seabuth7 mabuth11 seabuth11 mabuth15 seabuth15 msolpt15 sesolpt15 mchealden sechealden mchealwt sechealwt mamassden seamassden mamasswt seamasswt mambelden seambelden mambelwt seambelwt msetviden sesetviden msetviwt sesetviwt mechcgden seechcgden mechcgwt seechcgwt mabuthden seabuthden mabuthwt seabuthwt msolptden sesolptden msolptwt sesolptwt myield seyield;

*by trt;
run;
*/
Appendix 2: SAS Codes to Analyze Soybean Cultivar Tolerance to Saflufenacil - Field Study Data

libname SasData "C:\Documents and Settings\miller5\My Documents\School\Data\SAS Data Set";
*Tolerance of soybean to saflufenacil;
*Env: 1 and 4 (Bryanston), 2 and 5 (Maryhill), 3 and 6 (Ridgetown);
*Year: 2009, 2010;
*Trt: 1-5, Rep: 1-4;
*Var 1-12;
*Injury1, Injury2, Injury3 Injury4 Injury5 Injury6 Injury7 Injury8 Injury9 weeks after treatment: crop injury;
*dens pden wt pwt : density and dryweight per sq. 0.5 meter at 28 DAE;
*height1 pheight1 height2 pheight2 : plant height at 28 and 56 DAE;
*count4m : plant counts per 4m of row;
*yield pyield padjyield in T/ha;

data first;
set SasData.tolerance;

*if count4m=2000 then delete;
*if adjYield=2000 then delete;

*if trt=1 then rate=.1;
*if trt=1 then delete;

*if env=1 then delete;
*if env=2 then delete;
*if env=3 then delete;
*if env=4 then delete;
*if env=5 then delete;
*if env=6 then delete;

if var=1 then delete;
if var=2 then delete;
if var=3 then delete;
if var=4 then delete;
if var=5 then delete;
if var=6 then delete;
if var=7 then delete;
if var=8 then delete;
if var=9 then delete;
if var=10 then delete;
if var=11 then delete;
if var=12 then delete;
title2 'Injury1';
analvar= Injury1;

*title2 'injury1 (log transformation)';
*analvar=log(injury1+1);

*title2 'injury1 (Square root transformation)';
*analvar=sqrt(injury1+0.5);

**Use following adjustment for arcsine square root trans;
/*title2 'injury1 (arcsine sqrt transformation)';
analvar1=injury1;
if analvar1=100 then analvar1=100-0.01;
if analvar1=0 then analvar1=0+0.01;
analvar2=analvar1/100;
analvar=arsin(sqrt(analvar2));
*/

indvar=rate;

*indvar=log(rate+0.1);
run;

proc sort data=first;
by env trt rep;
run;

**use rate for regression;
proc mixed covtest;
class env rate rep;
model analvar=rate/ ddfm=satterth outp=second;
**satterthwaite method for degree of freedom;
random env env*rate rep(env);

**single environment;
*random rep;

parms/nobound;

lsmeans rate;
run;

/*
** Residual analysis;
proc plot;
plot resid*pred resid*rate resid*env resid*rep/vref=0;
rn;

proc univariate normal;
var resid;
rn;

proc rank normal=blom out=two;
var resid;
ranks zvar;
rn;

proc plot;
plot resid*zvar='*';
rn; */

/*
** exponential regression;
**if trt=1 then rate=0.1;
**use rate;

proc nlin;
bounds a>=0;
parameters
a=.01
b=1;

predict=a*exp(b*log(indvar));
model analvar=predict;

run;
*/

/*
**linear regression ;
**use rate;
**if trt=1 then rate=0.1;
proc nlin;
bounds 100<=a<=100;
parameters
a=100
b=-.02;
model analvar=indvar*b+a;
run;
*/
libname SasData "C:\Documents and Settings\miller5\My Documents\School\Data\SAS Data Set";
*Tolerance of soybean to saflufenacil hydroponic screen;
*Env: 1 and 2 is run 1 and 2;
*Trt: 1-5, Rep: 1-6;
*Var 1-12;
*Injury1;

data first;
set Sasdata.Hydroponic;

*if rate=0 then rate=.1;
*if rate=0 then delete;

*if env=1 then delete;
*if env=2 then delete;

if var=1 then delete;
if var=2 then delete;
if var=3 then delete;
if var=4 then delete;
if var=5 then delete;
if var=6 then delete;
if var=7 then delete;
if var=8 then delete;
if var=9 then delete;
if var=10 then delete;
if var=11 then delete;
if var=12 then delete;

title2 'injury1';
analvar=injury1;

*title2 'injury1 (log transformation)';
*analvar=log(injury1+1);

*title2 'injury1 (Square root transformation)';
*analvar=sqrt(injury1+0.5);

/*
**Use following adjustment for arcsine square root trans;
title2 'injury1 (arcsine sqrt transformation)';
analvar1=injury1;
if analvar1=100 then analvar1=100-0.01;
if analvar1=0 then analvar1=0+0.01;
analvar2=analvar1/100;
analvar=arsin(sqrt(analvar2));
*/

*indvar=rate;
*indvar=log(rate);
run;

proc sort data=first;
by env rate rep;
run;

**use rate for regression;

proc mixed covtest;
class env rate rep;
model analvar=rate/ ddfm=satterth outp=second;
**satterthwaite method for degrees of freedom;
random env env*rate  rep(env);

**single environment;
*random rep;

parms/nobound;

lsmeans rate;
run;

*/
** Residual analysis;

proc plot;
plot resid*pred resid*rate resid*env resid*rep/vref=0;
run;

proc univariate normal;
var resid;
run;

proc rank normal=blom out=two;
var resid;
ranks zvar;
run;
proc plot;
plot resid*zvar='*';
run;
*/
/*
 ** dose response for hydroponic injury;
 ** use log(rate);
 ** if rate=1 then rate=.1;

proc nlin;
bounds c>=0;
bounds d<=100;
parameters
d=100
c=0
i50=50
b=2;

if rate=0.1 then predict=c;
else predict=c+(d-c)/(1+exp(-b*(indvar-log(i50))));
model analvar=predict;

run;
*/
/*
proc sort data=first;
by var env rep;
run;

** use rate for regression;

proc mixed covtest;
class env var rep;
model analvar=var/ ddfm=satterth outp=second;
** satterthwaite method for degrees of freedom;
random env env*var rep(env);

parms/nobound;
* delete trt 1;
contrast 'var2 vs varall' var 1 -1 1 1 1 1 1 1 1 1 1 1;
lsmeans var;

run;
*/