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EVALUATION OF NIGHTSHADE (*Solanum spp.*) AND
GROUNDCHERRY SPECIES (*Physalis spp.*) RESPONSE TO
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EVALUATION OF NIGHTSHADE (*Solanum spp.*) AND GROUNDCHERRY SPECIES (*Physalis spp.*) RESPONSE TO HERBICIDES

By

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ABSTRACT

EVALUATION OF NIGHTSHADE (*Solanum spp.*) AND GROUNDCHERRY SPECIES (*Physalis spp.*) RESPONSE TO HERBICIDES

By

Vijaikumar Pandian

Solanaceous weeds such as eastern black nightshade (*Solanum ptycanthum*), hairy nightshade (*Solanum sarrachoides*), and horsenettle (*Solanum carolinense*) are serious weeds in tomato production in Michigan. Groundcherries, such as clammy groundcherry (*Physalis heterophylla*) and smooth groundcherry (*Physalis subglabrata*) are usually less troublesome weeds in tomatoes. Studies were conducted in the field and greenhouse to determine nightshade and groundcherry response to herbicides. Germination studies were conducted in growth chambers to determine the influence of temperature on germination of nightshade and groundcherry populations collected in Michigan. Post-transplant application of S-metalochlor (1.8 kg/ha), and dimethenamid-P (1.09 kg/ha) and pre-transplant application of flumioxazin (0.05 kg/ha), and oxyfluorfen (0.28 kg/ha) in the field gave 95% control of eastern black nightshade with no tomato injury. Postemergence application of pyridate (1.01 kg/ha) gave 60% control of eastern black nightshade in field with no crop injury. There was variation in dose response of eastern black nightshade populations to sulfosulfuron, halosulfuron, and metribuzin in the greenhouse. There was variation in dose response of hairy nightshade populations to halosulfuron. Eastern black nightshade had a higher germination rate than horsenettle, hairy nightshade, smooth and clammy groundcherries at 28/20 °C. An eastern black nightshade population from Oceana County germinated at a wider range of temperatures from 28/20° C to 15/10 ° C.

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CHAPTER 1

LITERATURE REVIEW

Introduction:

Eastern black nightshade (*Solanum ptycanthum* Dun.) is native to North America and is found mostly east of the Rocky Mountains (Ogg et al., 1981). Eastern black nightshade is one of the most troublesome weeds in soybean (*Glycine max L.*), tomato (*Lycopersicon esculentum L.*), pepper (*Capsicum annuum L.*), field bean (*Phaseolus vulgaris L.*), and corn (*Zea mays L.*) in central and north eastern America (Ogg et al., 1981). In Nebraska, economic losses due to eastern black nightshade infestation in soybean fields have been estimated at 12% of total state soybean income (Burgert et al., 1973). Eastern black nightshade causes a major problem in soybean harvesting operations by forming a sticky mass which can quickly plug combine screens and rotors. Mature berries often stain soybean during harvest and thereby reduce the bean quality. Eastern black nightshade causes a major problem in fresh pea harvesting operations. Immature berries of eastern black nightshade are similar in size, shape and color to pea, which makes separation of pea and nightshade fruit difficult during harvest. During processing, the immature berries turn black and reduce the pea quality (Majek, 1981). Perez and Masiunas (1990) estimated 60% yield loss in transplanted tomato with four eastern black nightshade plants per m^2. Also, eastern black nightshade is an alternate host for many tomato pests and diseases.

Taxonomic characteristics:

The *Solanum nigrum* (nightshade) complex consists of approximately 30 species. In the U.S there are 11 recognized species (Schilling, 1981) of Solanum with four species in the *Solanum nigrum* complex recognized as troublesome weeds in a variety of crops (Heiser et al, 1979). These species include hairy nightshade (*Solanum sarrachoides* Sendtner), eastern black nightshade, black nightshade (*Solanum nigrum*) and American black nightshade (*Solanum americanum* Mill.) (Ogg et al., 1981). These closely related species are difficult to separate in taxonomic classification. There are four primary reasons for difficulty in taxonomic identification and separation of the species (Ogg et al., 1981). First and most obvious, is the similarity in gross morphology among species. Second, these species are highly phenotypically plastic. When grown under different environmental conditions, they vary considerably in many taxonomic characteristics that are frequently used for identification. Third, genetic variation in certain species is large and is expressed as numerous geographic types within a single species. Fourth, there has been extensive nomenclature confusion within the group. Hence there is a need to understand some of the key taxonomic characteristics of eastern black nightshade.

The following description of eastern black nightshade was based on work by Bassett & Munro (1984), Ogg et al., (1981), and Schilling (1981).

Eastern black nightshade (Chromosome no. 2n= 24):

Eastern black nightshade is an annual, rarely a short-lived perennial, up to 1m high, erect, sparsely or freely branching plant. The stems are green or greenish purple, round or angular, and subglabrous. The lower surfaces of the young seedling leaves are purple in color. Leaves are up to 10 cm long and 9 cm broad, triangular-ovate or elliptic and acute. The surfaces are subglabrous with few eglandular hairs. The inflorescence is umbellate, up to six flowers and the calyx is 1-3 mm long at anthesis and the lobes adhere to the mature berry. Corolla is stellate, white with a yellow star, about 8 mm broad. Anthers are 1-2 mm long and yellow. Mature berries are globosely, shiny, and purplish black. The berries contain 6-15 sclerotic granules and up to 100 seeds. The seeds are 1.5 - 1.8 mm long and 1.3 mm wide, light brown in color.

Eastern black nightshade is most frequently confused with American black nightshade and black nightshade because of their similar appearance.

History:

Eastern black nightshade is a native of North America and was falsely identified in Michigan as black nightshade until the 1980's (Vandeventer et al., 1982). Eastern black nightshade was first collected in Michigan in 1896 in Grand Rapids by J.S. Haddick and H.C.Skeels (MSU herbarium).

Seed production and dispersal characteristics:

The time period from germination to fruiting of eastern black nightshade can be completed within 6 weeks; however, flowering can last for several months (Ogg et al., 1981). Eastern black nightshade produces viable seeds within 4 weeks of anthesis (Quakenbush and Anderson, 1984). Eastern black nightshade plants can produce many berries and viable seeds within a short period of time. Each eastern black nightshade plant produces 50 to 100 berries (Bassett and Munro, 1984) and each berry may contain 110 to 150 seeds (Majek, 1981; Roberts and Lockett, 1978). In another study, Stoller and Myers (1989a) reported that eastern black nightshade produced 50,000 seeds per plant under full sunlight and 20,000 seeds per plant with soybean interference. Eastern black nightshade seeds have viability of 90% in soil for 5 years. Viability drops successively to 73, 27 and 2% over the next three years (Dorph-Petersen, 1924).

Berries and seeds of eastern black nightshade are easily dispersed by rodents, birds, livestock, man and along water courses (Salisbury, 1961; Burgert et al., 1973; Kelley & Bruns, 1975; Roberts & Lockett, 1978). During soybean harvesting operations, berries are crushed and the sticky seeds are easily disseminated by the harvesting equipment throughout the field.

GERMINATION CHARACTERISTICS:

The invasion success of a colonizing weed species depends on the ability of its seed to germinate in new habitats (Groves, 1986). Many germination studies have been done to estimate the colonization potential of eastern black nightshade and to predict time of emergence in the field. Hermanutz and Weaver (1990) observed that the ruderal eastern black nightshade populations of northern range germinated faster than agrestal eastern black nightshade populations, though both populations had similar base temperatures. This genetic variability in germination parameters across temperature may have profound impact on future range of expansion. Hermanutz and Weaver (1991) observed that eastern black nightshade germinates more slowly over a wider range of temperature than hairy nightshade, and may have prolonged germination during the growing season. Hence, eastern black nightshade can produce more seeds and seedlings per year and can be more dominant than hairy nightshade with respect to colonization.

Reports in general suggest that alternating temperature from 20 to 30 C causes maximum germination of eastern black nightshade. However under darkness, very poor germination of eastern black nightshade occurs (Thomson and Witt, 1987; Hermanutz and Weaver, 1990). Germination of eastern black nightshade is region specific and varies under different environmental conditions (Hermanutz and Weaver, 1990). In general, eastern black nightshade emerges in the late spring and continues until mid summer when the daily maximum air temperature approaches 20 C (Ogg and Dawson, 1984; Roberts and Lockett, 1978). In addition, shallow tillage can stimulate overall emergence of eastern black nightshade in field conditions (Ogg and Dawson, 1984).

Growth and physiological characteristics:

Eastern black nightshade has a dichotomous branching pattern, but the forks are unequal in length. This unequal fork results in a spreading growth habit for eastern black nightshade and greater leaf area (McGiffen et al., 1992) and thereby it forms a dense canopy to intercept more light (McGiffen & Masiunas, 1992). The plant also responds to self-shading by increasing specific leaf area, and forms thinner leaves. Thinner leaves can result in decreased respiration rate and more carbon assimilation per quantum of light (Stoller & Myers, 1989b). Thus, by adapting to self-shading, eastern black nightshade maintains a dense canopy that can shade the growth of other plants and increase the efficiency of competitiveness.

In addition to self-shading, eastern black nightshade also responds to the shading effect of the crop canopy by allocating more biomass to leaves and less biomass to berries, lowering respiration rate, and increasing specific leaf area and light absorption efficiency. This physiological adaptation to shade increases the efficient utilization of photosynthetic active radiation (PAR) (Stoller & Meyer, 1989a).

Interference in tomato growth and development:

Tomato is one of the most important vegetable crops in Michigan. Bridges (1992) estimated the annual tomato yield loss due to weeds in Michigan was about 6.4 million dollars in fresh market tomatoes and 11.9 million dollars in processing tomatoes. Eastern black nightshade is one of the major competitive weeds in Michigan tomatoes.

Reports of tomato yield loss from nightshade interference vary widely. In southern France, 20 black nightshade plants per meter of row caused 73% reduction in transplanted tomato yield (Maillet and Abdel-Fatah, 1983). In southern Italy, eight black nightshades plants per meter caused similar yield reduction of about 73% (Damato and Montemurro, 1986). And in Canada, a mixture of 20 eastern black nightshades and hairy nightshade plants per meter of row decreased transplanted tomato yield by 20 to 60% and direct-seeded tomato yield by about 95% (Weaver et al., 1987).

Perez and Masiunas (1990) observed that the critical stage for control of eastern black nightshade is within 6 weeks after tomato transplantation. Eastern black nightshade begins to interfere with tomato from 4 to 8 weeks after tomato transplanting (Perez & Masiunas, 1990; Weaver and Tan, 1983). This critical period coincides with the full bloom stage of tomato (Friesen, 1979; Perez & Masiunas, 1990). So, if unchecked within 6 weeks, three eastern black nightshade plants per m^2 can reduce tomato yield by 60%. During this critical period of tomato interference, eastern black nightshade grew much faster and taller than tomato, competing for light by overtopping tomato's canopy (Weaver and Tan, 1983). Thus eastern black nightshade reduces the availability of PAR to tomato, which is necessary for its flower and fruit development.

Eastern black nightshade also competes with tomato for water and nutrients. Wahle and Masiunas (2003), observed that eastern black nightshade responds to high levels of nitrogen (N). Eastern black nightshade attained maximum growth at 12 weeks after planting and fresh mass increased with N up to 336 kg N/ha. Similar observations were reported by Bassett and Munro (1985), and Gonzalec et al., (1996). Thus eastern black nightshade can be more competitive with tomato in accumulation of N for its growth and development.

Tan and Weaver (1996) reported that eastern black nightshade possesses more stomata (particularly on the lower leaf surface) than hairy nightshade. This causes an increase in transpiration rate under ample water and light conditions. Hence, due to high transpiration rate, eastern black nightshade competes strongly with tomato for water which may cause rapid depletion of soil water resources.

Alternate host to pest and diseases:

Nightshade acts as an alternate host to many pests and diseases in *Solanaceous* crops. Colorado potato beetle (*Leptinotarsa decemlineata* Say) feeds on nightshades (Brown et al., 1980). *Rhizoctonia solani* frequently colonizes the roots of nightshade in potato fields, contributing to the transmission of the disease from one season to another (Ogg, 1989). Nightshades are an excellent host of late blight (*Phytophthora infestans*) (Vartanian and Ends, 1985) and powdery mildew (*Oidium lycopersicum*) (Lamondia et al., 1999) which are common diseases in tomato. Perennial eastern black nightshade acts as an overwintering host for cucumber mosaic virus in pepper (Hobbs et al., 2000). Eastern black nightshade can also host nematodes like *Heterodera glycines* (Wong and Tylka., 1994), and *Globodera tabacum* (Lamondia, 1996).

Difficult to control in tomato:

Eastern black nightshade and tomato have similar herbicide susceptibilities, growth habitat and physiology (McGiffen and Masiunas, 1991; Perez and Masiunas, 1990; Weaver et al., 1987). Hence it is difficult to find a selective herbicide to control eastern black nightshade without injuring tomato. Currently, there are few registered herbicides for use in tomato which limits the control options of weeds like nightshades. Metolachlor is currently registered for use in tomato and gives good control of eastern black nightshade preemergence (Gaynor et al., 1993). Currently there are no registered herbicides available which will control eastern black nightshade postemergence in tomato.

Metribuzin is registered for broadleaf weed control in tomato, but does not control eastern black nightshade (Ackley et al., 1997). A combination of metribuzin and pyridate controlled eastern black nightshade, but caused unacceptable injury to tomato (McGiffen and Masiunas, 1991). DCPA and chloramben herbicides are no longer registered for use in tomato due to a potential leaching effect in the soil (Perez and Masiunas, 1990). Rimsulfuron, a sulfonylurea herbicide, is used in tomato production worldwide (Reinke et al., 1991), but lacks persistence and does not control black nightshades. Some tomato cultivars are also sensitive to rimsulfuron (Bewick et al., 1991).

Chang and Masiunas (1992) characterized some of the somoclones of eastern black nightshade tolerant to acifluorfen, oxyfluorfen, diquat and paraquat and suggested the tolerance of nightshade to the diphenyl ether and bipyridylium salt herbicides could be a problem in field situations. The reliance on a few active ingredients (and sites of action) for nightshade management in field crops has resulted in herbicide resistance problems. Biotypes of eastern black nightshade resistant to acetolactate synthesis (ALS) inhibitor herbicides such as imazethapyr, imazamox and primisulfuron-methyl have been reported in Wisconsin (Volenberg et al., 2000), Indiana, and Illinois (Milliman et al., 2003).

Many fresh market tomato growers have adopted the plasticulture production system to achieve earlier harvest and increase high quality fruit yield (Brown et al., 1991; Wein and Minotti, 1987) and to reduce the weeds. In a plasticulture production system, fumigation by methyl bromide has been successfully used to control many weeds. The phaseout of methyl bromide by 2005 in the U.S (EPA, 1998), has further limited the options for weed control in tomatoes. Hence, there are no alternate methods to control eastern black nightshade in tomato.

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CHAPTER 2

POTENTIAL HERBICIDES TO CONTROL EASTERN BLACK NIGHTSHADE (*Solanum ptycanthum*) IN TOMATO (*Lycopersicon esculentum*)

Abstract. Eastern black nightshade (*Solanum ptycanthum* Dun.) is a troublesome weed in tomato production. Eastern black nightshade and tomato share similar herbicide susceptibilities due to a close genetic relationship. The objective of this study was to evaluate potential herbicides to control eastern black nightshade in tomato. Field studies showed that post-transplant application of S-metalochlor (1.8 kg/ha), dimethenamid-P (1.1 kg/ha) and pre-transplant application of flumioxazin (0.052 kg/ha), and oxyfluorfen (0.28 kg/ha) gave at least 95% control of eastern black nightshade with negligible or no crop injury and no yield reduction. Postemergence application of pyridate controlled 60% control of eastern black nightshade with no crop injury and resulted in yield of 85% of the weeded control. Pre-transplant and postemergence application of sulfentrazone gave fair control of eastern black nightshade, but caused crop injury of at least 20%. Post-directed application of carfentrazone (0.18 kg/ha) and flumioxazin (0.052 kg/ha) caused unacceptable crop injury to tomato. In greenhouse studies, sulfosulfuron (0.034 kg/ha) did not control eastern black nightshade sufficiently and did not cause injury to tomato. However, eastern black nightshade has shown a difference in response to sulfosulfuron applied during the spring and summer seasons. Eastern black nightshade showed more sensitivity to sulfosulfuron during the spring season than during the summer season.
Key words: Tomato, eastern black nightshade (*Solanum ptycanthum*), dimethenamid-P, S-metolachlor, sulfosulfuron, flumioxazin, oxyfluorfen, sulfentrazone, pyridate, carfentrazone.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetable crops in Michigan. Interference of weeds in tomato causes yield reduction and low quality of tomatoes (Friesen, 1979; McGiffen et al., 1992). Eastern black nightshade (*Solanum ptycanthum* Dun.) is a troublesome weed in tomato throughout the northeastern United States. Eastern black nightshade interferes with tomato within 4 to 8 weeks after crop establishment (Perez and Masiunas, 1990; Weaver and Tan, 1983), coinciding with the full bloom stage of tomato (Friesen, 1979). Eastern black nightshade overtops the tomato canopy resulting in a decrease photosynthetic active radiation (PAR), flower abortion and less fruit set (Mc Giffen et al., 1992). Four eastern black nightshade plants per meter square can cause a yield reduction of 80% in direct seeded tomatoes and 25 to 60% in transplanted tomatoes (Perez and Masiunas, 1990).

Eastern black nightshade is difficult to control in tomato because eastern black nightshade and tomato share a close genetic relationship, having similar herbicide susceptibilities, growth habitat and physiology (McGiffen et al., 1992; Perez and Masiunas, 1990; Weaver et al., 1987). There are few registered herbicides in tomato (Ackley et al., 1997). Metolachlor is currently the only registered herbicide to control eastern black nightshade preemergence in tomato and no postemergence herbicides are registered for eastern black nightshade control in tomato.

Metribuzin is registered for control of broadleaf weeds in tomato but it doesn't control eastern black nightshade (Ackley et al., 1997). Combinations of metribuzin and pyridate controlled eastern black nightshade, but caused unacceptable injury to tomato (McGiffen and Masiunas, 1991). DCPA and chloramben are no longer registered for use in tomatoes (Perez and Masiunas, 1990). Rimsulfuron, a sulfonylurea herbicide is used in tomato production worldwide (Reinke et al., 1991), but it lacks persistence and does not control black nightshade. Besides, some tomato cultivars are sensitive to rimsulfuron (Bewick et al., 1995).

The reliance on a few active ingredients (and sites of action) for nightshade management in field crops has resulted in herbicide-resistant weed problems. Biotypes of eastern black nightshade resistant to ALS inhibitor herbicides such as imazethapyr, imazamox and primisulfuron-methyl have been reported from Wisconsin (Volenberg et al., 2000), Indiana and Illinois (Milliman et al., 2003).

Many fresh market tomato growers have adopted the plasticulture production system to achieve earlier harvest, increase high quality fruit yield (Brown et al., 1991; Wein and Minotti, 1987) and to reduce weeds. In the plasticulture production system, fumigation by methyl bromide successfully controls many weeds. The phase out of methyl bromide by 2005 in the U.S (EPA, 1998) has further limited the options for control of eastern black nightshade in tomatoes.

Due to the prevalence and strong interference of eastern black nightshade in tomato growth and development, and the necessity for alternate herbicides to establish an effective management system in tomato, field studies were conducted to evaluate the efficacy of potential herbicides to control eastern black nightshade in tomato.

MATERIALS AND METHODS

FIELD STUDY:

Field experiments were conducted in 2002, 2003 and 2004 to evaluate the potential herbicides to control eastern black nightshade in tomato. The research was conducted at Michigan State University's Horticulture Teaching and Research Center (HTRC), East Lansing, Michigan. The soil type at the research center was Marlette fine sandy loam. In 2002 and 2004, the experimental site had very high eastern black nightshade pressure. The 2003 site had low to moderate eastern black nightshade pressure but there was sufficient pressure for herbicide evaluation.

Field preparation:

The fields were plowed using a moldboard plow at the end of the previous fall season. In mid spring, the fields were worked with a field cultivator to enhance the soil aeration and decomposition of the previous residues. The field was fertilized with N: P_2O_5:K_2O ratio of 19:19:19 at rates of 250 kg/ha, 312 kg/ha, 300 kg/ha in 2002, 2003 and 2004 respectively.

Transplanting:

The tomato cultivar Pikrite[1] was used in this research. The seeds were sown in flats in the greenhouse and were grown for about 30 days and then transferred to a shade house for 10 days before being transplanted into the field. Forty-day-old tomato seedlings were transplanted with a Mechanical Transplanter Model 4000[2] with two rows 90cm apart per plot with 60 cm spacing between seedlings in 2002, 2004 and 45 cm spacing in 2003.

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[1]Harris Moran Seed Co., P.O.Box 4938, Modesto, CA 95352.
[2]Mechanical Transplanter Company, S.Central at U.S. 31, Holland, Michigan.

Application methods:

Herbicide plot size was 2.4m X 10.6m in 2002 and 2003 and 2.5m X 7.8m per treatment in 2004. The design of the experiment was a randomized complete block design with four replications. The herbicides were applied as pre-transplant, post-transplant, postemergence and post-directed applications. The list of the various herbicides applied at different application timings are listed in Table 2. Weeded control plot was hand weeded once in a week and continued till end of the last visual rating.

The herbicides were sprayed using a CO_2 backpack sprayer with a four nozzle boom with FF8002 nozzles. Treatments were applied at the rate of 187L/ha at a pressure of 207 kPa and at the speed of 5.12 Kph. In case of post-directed applications, herbicides were applied using a two nozzle shielded boom with FF11002 nozzles.

Visual rating:

Three visual ratings were recorded for all applications at regular intervals of 7, 14, and 21 days after the respective dates of application. The crop and weed injury level were scaled from 1 to 10, with one being no injury and 10 being complete death of the plant. The visual scale was converted to percent for analysis.

Yield:

Tomato harvest began when there was visible red color on the fruit. All fruit with red color were harvested once per week beginning in mid August and harvest continued until frost killed the plants in late September. In 2003, both marketable and unmarketable tomato fruit yield was recorded.

Statistical Analysis:

The data were subjected to analysis of variance by using the SAS program (SAS, 1990). The means were separated by using Fisher's Protected LSD at α =0.05 significance level. Because of interactions between years the results of eastern black nightshade control, crop injury and yield are presented by year wise.

GREENHOUSE STUDY:

Greenhouse experiments were conducted twice in 2003 during the early spring season and the mid summer season to determine the dose response of eastern black nightshade and tomato to sulfosulfuron and sulfentrazone.

Pre treatment of nightshade seeds:

Nightshade seeds were extracted from berries collected from the Horticulture Teaching and Research Center (HTRC) at East Lansing, Michigan during 2002. The nightshade seeds were subjected to cold treatment (-20 C) for 2 months and then stored in the incubator (28 C). Study conducted by Basett and Munro (1984) observed that addition of 500 ppm gibberelic acid (GA_3) and 0.2% potassium nitrate (KNO_3) enhances germination of black nightshade. A similar preliminary study was conducted in a growth chamber in 2002 to determine effects of GA_3 and KNO_3 at different concentration on germination of eastern black nightshade seeds. Our preliminary study observed that 1000 ppm GA_3 and 0.1% potassium nitrate for 10-12 hours enhanced 75% germination of eastern black nightshade and hence was used as a pre treatment to trigger germination before being sown in the flats.

Sowing and transplanting:

Nightshade seeds were sown in flats containing Baccto soil mix[3]. Nightshade plants emerged within a week after sowing. During the early spring season, supplemental light of 750 to 800 uM/m^2/s photosynthetic photon flux for 14 hours per day were provided over the flats. A constant temperature of 24^0 C was maintained in the greenhouse. Pikrite tomato seeds were sown at the same time in a flat.

Seedlings of nightshade and tomato were transplanted at the cotyledon stage in 1 liter (L) pots filled with Baccto soil mix. During the early spring season, transplanted seedlings were provided with supplemental lights, using high pressure sodium vapor lamps. In mid summer season, transplanted seedlings were not provided with supplemental light.

Treatment application:

Herbicide treatments were applied with a moving track sprayer[4] with a single 80015E flat-fan nozzle[5] calibrated to deliver 187L/ha at a pressure of 207 kPa. Herbicides were applied to eastern black nightshade at the 5-6 leaf stage (5 cm in height) and to tomato plants at 25 to 30 cm in height. Sulfosulfuron was applied at 0.0086 kg /ha, 0.0173 kg /ha, 0.034 kg /ha, 0.069 kg /ha and 0.13 kg /ha concentration. Sulfentrazone was applied at 0.028 kg /ha, 0.056 kg /ha, 0.11 kg ai/ha, 0.22 kg /ha, and 0.44 kg /ha. The treated nightshade and tomato seedlings were then returned to the greenhouse and provided the respective light and temperature conditions.

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[3]Baccto Soil Mix. Michigan Peat Co., P.O.Box 980129, Houston, TX 0129.
[4]Allen Machine works, 607 E Miller, Midland, MI 48640.
[5]Teejet flat fan tips. Spraying Systems Co., North Ave., Schmale Rd., Wheaton, IL 60188.

The treated plants were arranged in randomized complete block design with four replications per treatment. The four replications are placed in different benches, which were facing north-south direction.

Visual rating and harvesting of biomass:

Visual ratings were taken at 7, 14 and 21 days after treatment (DAT). Visual ratings were scaled from 1 (no injury) to 10 (complete death) and were then converted to percent. All aboveground plant tissue was harvested 22 DAT and fresh weights were recorded. The plant tissues were then dried at 60 C for 6 days and their dry weights were recorded. Herbicide effects were calculated in terms of GR_{50}, which describes the herbicide required for 50% dry weight reduction from untreated control.

Statistical analysis:

All the dry biomass data were subjected to ANOVA and interaction effects were determined. The data collected from both seasons were pooled together if there were no interactions. If there was an interaction, the data from the summer season and spring season are presented separately.

Nonlinear regression parameters were predicted from four replications using the polynomial quadratic model by using Sigma plot version 8 software[6]. This model uses the following equation to relate dry biomass as a percentage of reduction from the control y to the herbicide rate x.

$y= a+ bx+ cx^2$. In this equation a, b, c is constant

[6]Sigma plot version 8.02, SPSS Inc., 233 South Wacker Drive, Chicago, IL 60606.

RESULTS AND DISCUSSION

FIELD STUDY:

Pre-transplant herbicide:

Pre-transplant (PRT) application of protoporphyrinogen oxidase (PROTOX) inhibitors like flumioxazin, oxyfluorfen, and sulfentrazone consistently resulted in at least 95% control of eastern black nightshade in all three years (Table 2). Flumioxazin and oxyfluorfen did not cause any crop injury and the effect on yield varied across the years (Table 5). In 2002, neither flumioxazin nor oxyfluorfen reduced yield. In 2003, lack of rainfall during the growing season (July – August) resulted in blossom end rot, causing a significant reduction in yield of marketable tomatoes in all the plots. Hence there was no difference in treatment effect on yield among the pre-transplant herbicide plots in 2003. In 2004, flumioxazin yielded 127% of the weeded control and oxyfluorfen yielded 75% of the weeded control (Table 5).

PRT application of sulfentrazone controlled eastern black nightshade but caused significant crop injury that ranged from 18-25% in 2002 and 2004. In general, the crop injury was relatively high during the first week after treatment (WAT) causing necrotic spots and curling of leaves. Sulfentrazone caused a significant yield reduction in 2004 and yielded 53% of the weeded control (Table 5).

Metribuzin did not control eastern black nightshade (Table 2), and did not cause any visual injury symptoms or yield reduction in tomato in all three years when applied PRT (Table 5). However, metribuzin controlled other broadleaf weeds in tomatoes such as common lambsquarters and redroot pigweed.

PRT application of sulfosulfuron in 2004 resulted in 75% control of eastern black nightshade (Table 2) and yield was 126% of the weeded control (Table 5). However in 2003, sulfosulfuron PRT did not control eastern black nightshade. We have no explanation for the difference in level of control between years.

Post-transplant herbicide:

There was no significant interaction between treatments and years in 2002 and 2004 with respect to post-transplant (POT) herbicide effects on eastern black nightshade. Sulfosulfuron gave at least 90% control of eastern black nightshade in 2002 and 2004 but failed to control nightshade in 2003 (Table 3). Sulfosulfuron did not cause any crop injury and resulted in a significant yield increase in all three years (Table 6).

Rimsulfuron, applied POT failed to control eastern black nightshade (Table 3) in all three years and did not cause any visual injury to tomato.

Seedling shoot inhibitors such as S-metolachlor and dimethenamid-P gave 100% control of eastern black nightshade in all three years when applied POT (Table 3). Activity of S-metolachlor and dimethenamid-P against eastern black nightshade was effective from first WAT and had a consistent prolong effect even after 6 WAT. Neither S-metolachlor nor dimethenamid-P caused significant crop injury in tomato in all three years.

Napropramide was applied POT in 2002 and 2003 only. Though napropramide belongs to the amide group and has the same mode of action as of S-metolachor and dimethenamid-P, it did not control eastern black nightshade in 2002 or 2003 (Table 3) and therefore napropramide was dropped from the 2004 experiment.

Postemergence herbicide:

Rimsulfuron and halosulfuron postemergence (POST) did not control eastern black nightshade, nor did they injure tomato in any year (Table 4).

POST application of sulfosulfuron did not control eastern black nightshade in 2003 or 2004 (Table 4). There was no crop injury in all three years with a slight yield reduction in 2004, resulting in yield of 87% of the weeded control (Table 7).

Sulfentrazone POST at 0.11 kg/ha and 0.22 kg/ha gave 56% and 92% control of eastern black nightshade respectively in 2002 (Table 4). However in 2003, sulfentrazone 0.11 kg/ha and 0.22 kg/ha gave 75% and 56% control of eastern black nightshade respectively, with no significant crop injury and similar yield reduction for both rates (Table 4,7). In 2004, there was no dose response effect from sulfentrazone and both rates gave at least 90% control of eastern black nightshade (Table 4). Both rates of sulfentrazone caused significant crop injury and yield reduction in 2004. Although it gives fair to good eastern black nightshade control, sulfentrazone probably is too injurious to tomato for POST application. Typical injury symptoms were necrosis and curling and cupping of leaves.

Metribuzin POST had no effect on eastern black nightshade and did not cause any yield reduction or crop injury in all three years. Pyridate gave 61% and 67% control of eastern black nightshade in 2002 and 2003, respectively (Table 4). Pyridate did not cause any crop injury (Table 4) and yield was 83% and 85% of the weeded control in 2002 and 2003 (Table 7).

Post-directed herbicides:

Carfentrazone controlled eastern black nightshade but caused unacceptable crop injury when applied post-directed (PODIR) (Table 4). In 2002, carfentrazone water dispersable granule (WDG) application gave 80% control of eastern black nightshade but caused 36% crop injury and yielded 57% of weeded control (Table 7). Carfentrazone emulsifiable concentrate (EC) was used in 2003 and 2004 because the WDG was discontinued by the manufacturer. The carfentrazone EC formulation caused 75% and 67% injury to tomato in 2003 and 2004 and resulted in yield of 67% and 22% of weeded control (Table 7). Flumioxazin PODIR gave fair to excellent control of eastern black nightshade in all three years. It caused no significant yield reduction in 2002 and 2003, but caused 39% crop injury in 2004 (Table 4). This resulted in a yield of only 13% of the weeded control in 2004 (Table 7). Flumioxazin appears to be too toxic to tomato for PODIR application, unless a safer method of application can be devised.

GREENHOUSE STUDY:

Dose response of sulfosulfuron:

There was a significant difference in dose response of eastern black nightshade to sulfosulfuron, between spring and summer season experiment (Figure 1). In the early spring experiment, there was no dose response to sulfosulfuron. All the treatments caused a dry weight reduction of at least 70% from the untreated control. In the summer season experiment there was a strong dose response (R^2= 0.79) of eastern black nightshade to sulfosulfuron, with a GR_{50} of 0.079 kg/ha (Table 8). In the early spring experiment, all eastern black nightshade plants flowered during the second week after treatment. This may have made the plants more susceptible to the herbicide. Early flowering of eastern black nightshade might have been a response to the short days and reduced temperature in the greenhouse in early spring. In the summer season experiment, the plants did not flower until four weeks after treatment. Even though sulfosulfuron caused reduction in dry weight at all rates in the spring experiment, it did not give sufficient control of eastern black nightshade at 0.034 kg/ha or 0.069 kg/ha in the summer experiment.

Dose response of sulfentrazone:

The GR_{50} values for sulfentrazone were similar for the two seasons. GR_{50} values were 0.18 kg/ha in spring and 0.14 kg/ha in summer (Table 8). There was a dose response of eastern black nightshade to sulfentrazone and at 0.44 kg/ha dry weight reduction was 80% in spring and 95% in summer.

The results from the field and greenhouse studies have shown that POT application of s-metalochlor and dimethanamid-P and PRT application of flumioxazin and oxyfluorfen controlled eastern black nightshade with negligible or no crop injury. Eastern black nightshade was not controlled sufficiently by sulfosulfuron. Sulfentrazone gave good eastern black nightshade control but caused unacceptable crop injury.

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Table 1. List of treatments, application methods and the rates applied in field experiments during 2002, 2003, and 2004 to evaluate control of eastern black nightshade in transplanted tomato.

Application day	Application method	Application stage	Herbicide	Form conc. & type	Rate kg ai/ha
June 7, 2002	Pre-transplant	Before	Flumioxazin	51 WG	0.052
June 1, 2003		transplanting	Metribuzin	75 DF	0.56
June 7, 2004		tomato seedlings	Oxyfluorfen	2 L	0.28
			Sulfentrazone	75 DF	0.33
			Sulfosulfuron***	75 WG	0.034
June 8, 2002	Post-transplant	After transplanting	Dimethenamid-P	6 EC	1.1
June 2, 2003		of tomato seedlings	Napropramide**	50 DF	2.24
June 7, 2004			Rimsulfuron	25 DF	0.034
			S-metolachlor	7.62 EC	1.8
			Sulfosulfuron	75 WG	0.034
July 11, 2002	Post -emergence	Nightshades are 3-	Halosulfuron*	75 WG	0.034
July1, 2003		4 leaf stage at a	Metribuzin	75 DF	0.28
July1, 2004		height of 2.5-5 cm	Pyridate**	3.75 EC	1.01
			Rimsulfuron	25 DF	0.034
			Sulfentrazone	75 DF	0.11
			Sulfentrazone	75 DF	0.22
			Sulfosulfuron*	75 WG	0.034
July 19, 2002	Post-directed	Nightshades are 3-	Carfentrazone*	40 WG	0.18
July 1, 2003		4 leaf stage at a	Carfentrazone*	2 EC	0.18
July1, 2004		height of 2.5-5 cm	Flumioxazin*	51 WG	0.052

*Nonionic Surfactant (NIS) of 0.5% V/V was included with the respective treatment.

** The given treatment was applied 2002, 2003 only

*** The given treatment was applied 2003, 2004 only

Table 2. Pre transplant (PRT) treatment effects on eastern black nightshade (SOLPT) and crop injury rated at six weeks after treatment in 2002, 2003 and 2004.

Treatments	Rate kg ai/ha	SOLPT control (%)			Crop injury (%)		
		2002	2003	2004	2002	2003	2004
Weeded control		100a	100a	100a	0a	0	0b
Oxyfluorfen	0.28	100 a	100 a	100 a	6 a	0	3 b
Metribuzin	0.56	22.0 b	0 c	0 c	3 a	0	0 b
Sulfentrazone	0.33	100 a	100 a	100 a	18 b	0	25 a
Flumioxazin	0.052	94 a	100 a	94 a	11 a, b	0	3 b
Sulfosulfuron	0.034	NA	33 b	75 b	NA	0	0 b
Lsd		17	23	8	9	NS	15

Values followed by the same letter in the same column are not statistically significant at α =0.05.
NA - non availability of data
NS- non significance of mean

Table 3. Post transplant (POT) treatment effects on eastern black nightshade (SOLPT) and crop injury rated at six weeks after treatment in 2002, 2003 and 2004.

Treatments	Rate Kg ai/ha	SOLPT control (%) 2002	SOLPT control (%) 2003	SOLPT control (%) 2004	Crop injury (%) 2002	Crop injury (%) 2003	Crop injury (%) 2004
Weeded control		100a	100a	100a	0	0	0
Napropramide	2.24	6 b	0 b	NA	3	0	NA
S-metolachlor	1.8	100 a	100 a	100 a	11	0	0
Rimsulfuron	0.034	11 b	0 b	0 c	3	0	0
Sulfosulfuron	0.034	97 a	25 c	89 b	6	0	0
Dimethenamid- P	1.1	100 a	100 a	100 a	6	0	0
Lsd		14	30	9	NS	NS	NS

Values followed by the same letter in the same column are not statistically significant at α =0.05
NA – Treatment not included in that respective year
NS- non significance of mean

Table 4. post emergence (POST) and post directed (PODIR) treatment effects on eastern black nightshade (SOLPT) and crop injury rated at three weeks after treatment in 2002, 2003 and 2004.

Treatments	Rate Kg ai/ha	SOLPT control (%)			Crop injury (%)		
		2002	2003	2004	2002	2003	2004
POST							
Weeded control		100a	100a	100a	0	0	0a
Rimsulfuron	0.034	6	0 c	25 b	3	0	0 a
Sulfosulfuron*	0.034	67 a, b	6 c	11 b	7	0	0 a
Halosulfuron*	0.034	11 c	0 c	0 b	3	11	0 a
Metribuzin	0.28	11 c	0 c	0 b	3	0	0 a
Sulfentrazone	0.11	56 b	75 b	94 a	11	0	11 b
Sulfentrazone	0.22	92 a	56 b	100 a	8	7	22 c
Pyridate	1.01	61 b	67 b	NA	0	0	NA
Lsd		31	41	29	NS	NS	10
PODIR							
Weeded control		100	100	100	0b	0b	0c
Carfentrazone*	0.18	83	100	100	36 a	75 a	67 a
Flumioxazin*	0.052	64	100	100	6 b	14 b	39 b
Lsd		NS	NS	NS	11	16	6

Values followed by the same letter in the same column in each application method are not statistically significant at $\alpha = 0.05$.
*Nonionic Surfactant of 0.5% V/V was included with herbicide
NA – Treatment not included in that respective year
NS- non significance of mean

Table 5. Effect of pre-transplant (PRT) treatments on tomato yield from 2002-2004.

Treatments	Rate kg ai/ha	Yield (kg/plot) 2002	2003	2004	Yield as % of weeded control 2002	2003	2004
Weeded control		146	39 c	85 a, b	100	100	100
Oxyfluorfen	0.28	125	61 a, b	63 b, c	86	156	75
Metribuzin	0.56	148	55 a, b	86 b, a	101	141	101
Sulfentrazone	0.33	124	70 a	45 c	85	179	53
Flumioxazin	0.052	122	67 a	108 a	84	172	127
Sulfosulfuron	0.034	NA	52 a, b	107 a	NA	133	126
Lsd		37	23	30			

Values followed by the same letter in the same column are not statistically significant at α =0.05
NA – Treatment not included in that respective year
NS- non significance of mean

Table 6. Effect of post-transplant (POT) treatments on tomato yield from 2002-2004.

Treatments	Rate Kg ai/ha	Yield (kg/plot)			Yield as % of weeded control		
		2002	2003	2004	2002	2003	2004
Weeded control		146 a,b	39	85	100	100	100
Napropramide	2.24	131 a, b	58	NA	90	149	NA
S-metolachlor	1.8	123 b	39	98	84	100	115
Rimsulfuron	0.034	132 a, b	40	114	90	103	134
Sulfosulfuron	0.034	169 a	54	120	116	138	141
Dimethenamid-P	1.1	152 a, b	60	86	104	154	101
Lsd		45	NS	NS			

Values followed by the same letter in the same column are not statistically significant at α =0.05
NA- Treatment not included in that respective year
NS- non significance of mean

Table 7. Effect of post emergence (POST) and post directed (PODIR) treatments on tomato yield from 2002-2004.

Treatments	Rate Kg ai/ha	Yield (kg/plot) 2002	Yield (kg/plot) 2003	Yield (kg/plot) 2004	Yield as % of weeded control 2002	Yield as % of weeded control 2003	Yield as % of weeded control 2004
POST							
Weeded control		146 a	39 a, b	85 a	100	100	100
Rimsulfuron	0.034	140 a,b	30 b	72 a,b	96	77	85
Sulfosulfuron*	0.034	138 a,b	51 a,b	74 a,b	95	131	87
Halosulfuron*	0.034	123a,b, c	47 a, b	68 b,c	84	121	80
Metribuzin	0.28	138 a, b	52 a, b	90 a	95	133	106
Sulfentrazone	0.11	88 c	37 a, b	39 c	60	95	46
Sulfentrazone	0.22	102 b, c	62 a	40 c	70	159	47
Pyridate	1.01	121a,b,c	33 b	NA	83	85	NA
Lsd		40	27	35			
PODIR							
Weeded control		146 a	39	85 a	100	100	100
Carfentrazone*	0.18	83 b	26	19 b	57	67	22
Flumioxazin*	0.052	120 a, b	54	11 b	82	138	13
Lsd		43	NS	22			

Values followed by the same letter in the same column in each application method are not statistically significant at α =0.05.
*Nonionic Surfactant of 0.5% V/V was included with herbicide
NA - Treatment not included in that respective year
NS- non significance of mean

Table 8. Polynomial quadratic equations, R^2 values*, GR_{50} values to determine the response of eastern black nightshade (SOLPT) and tomato to sulfosulfuron**, sulfentrazone treatments applied during two different season.

Treatment	Time of application	Leaf stage/ height	r^2	$y= a+bx+c x^2$	GR_{50} (kg/ha)
Sulfosulfuron**	SOLPT-Early Spring	6 Leaf/ 5 cm	0.038	$y= 71.08-79.29x-677.20 x^2$	<0.0086
	SOLPT-Mid summer	6 Leaf/ 5 cm	0.79	$y= -5.37+758.89x-805.84 x^2$	0.079
	Tomato***	25-30 cm	0.21	$y= -4.44+442.56x-1969.71 x^2$	>0.13
Sulfentrazone	SOLPT-Early Spring	6 Leaf/ 5 cm	0.85	$y= -17.50+472.51x-583.78 x^2$	0.18
	SOLPT-Mid summer	6 Leaf/ 5 cm	0.82	$y= -17.36+567.59x-712.38x^2$	0.14
	Tomato***	25-30 cm	0.32	$y=-11.11+418.01x-658.58 x^2$	0.22

* All R^2 values are significant at $\alpha < 0.01$
**Nonionic Surfactant of 0.5% V/V was included with herbicide
*** Interactions between two seasons are not significant and the data are pooled together

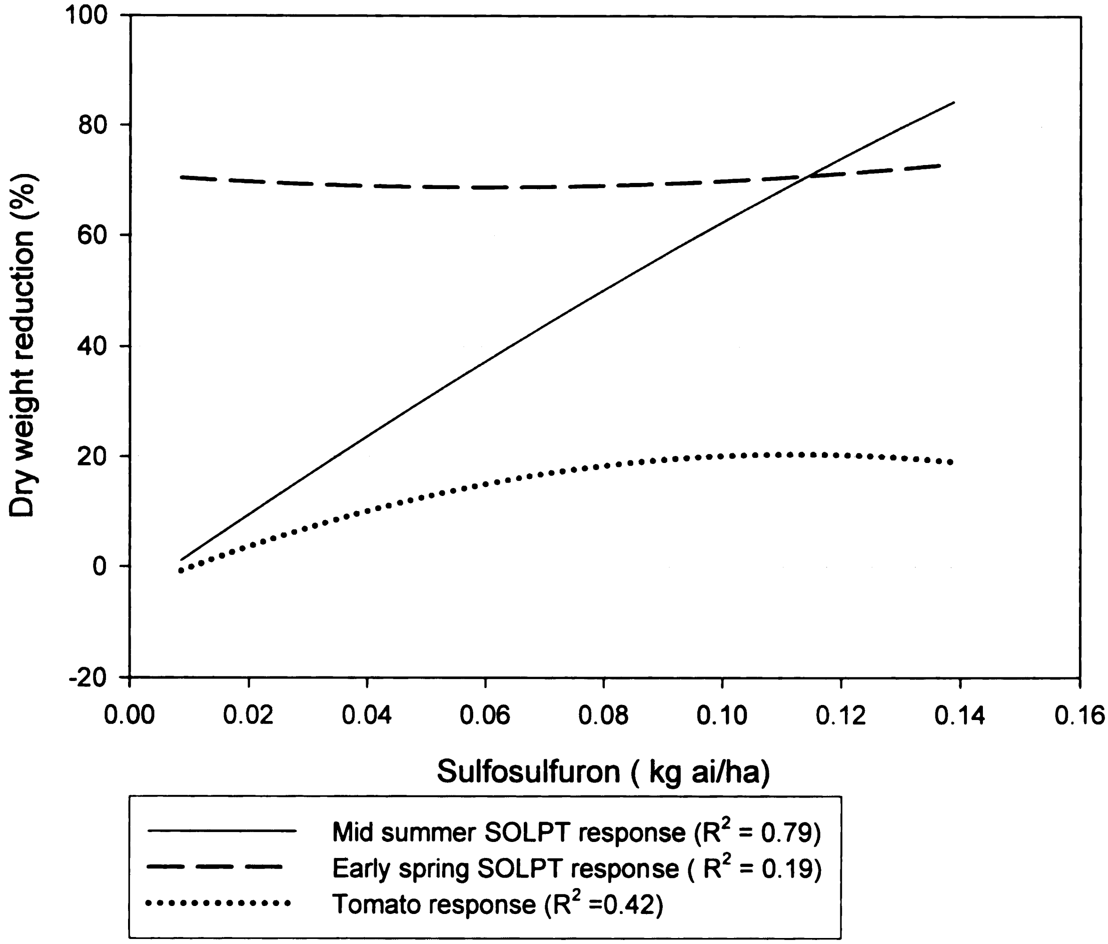

Figure 1. Polynomial quadratic comparison of eastern black nightshade (SOLPT) response to sulfosulfuron at 0.0086 kg/ha, 0.0173 kg/ha, 0.034 kg/ha, 0.069 kg/ha and 0.13 kg/ha concentrations applied during early 2003 spring and mid summer season in greenhouse.

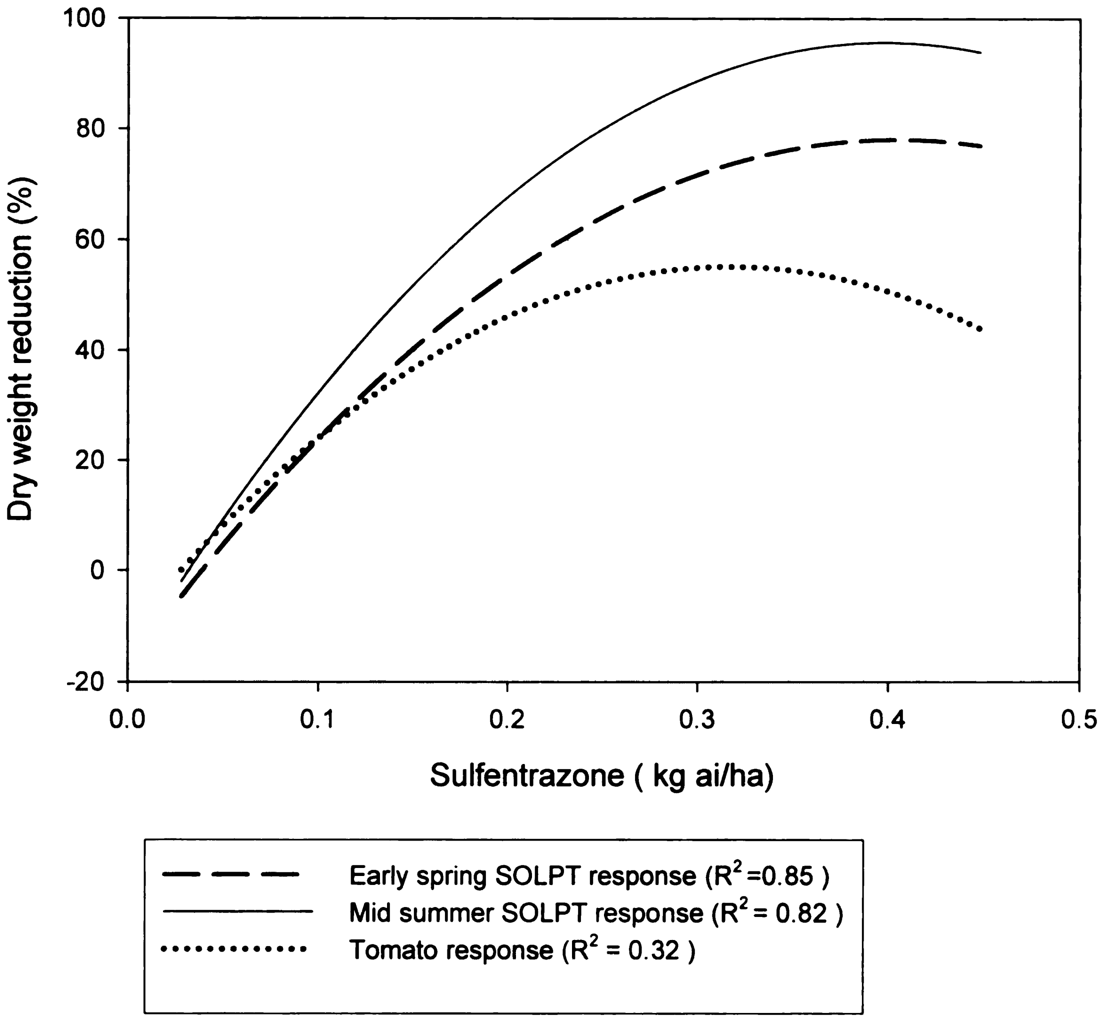

Figure 2. Polynomial quadratic comparison of eastern black nightshade (SOLPT) response to sulfentrazone at 0.028 kg /ha, 0.056 kg /ha, 0.11 kg ai/ha, 0.22 kg /ha, and 0.44 kg /ha concentrations applied during early 2003 spring and mid summer season in greenhouse.

CHAPTER 3

VARIATION IN HERBICIDE RESPONSE AMONG NIGHTSHADE (*Solanum* spp) AND GROUNDCHERRY (*Physalis* spp) SPECIES AND WITHIN NIGHTSHADE POPULATIONS

Abstract. Greenhouse experiments were conducted in 2003 and 2004 to determine the variation in herbicide response among nightshade and groundcherry species and within nightshade populations in Michigan. Eastern black nightshade populations had a wider range of variation than hairy nightshade and horsenettle population to metribuzin, sulfentrazone and halosulfuron. Among the 12 eastern black nightshade populations screened for herbicide response, the Ingham2 population had greater tolerance to herbicides than the other populations. A wide range of variation was noted among hairy nightshade populations in response to halosulfuron. Among the eight populations of hairy nightshade, the Macomb1 and Bay2 population was more tolerant than the other populations to halosulfuron. There was no significant difference in herbicide tolerance among horsenettle populations. Among nightshade and groundcherry species, eastern black nightshade was the only species that had a high range of tolerance to metribuzin. Clammy groundcherry was more tolerant to sulfentrazone than eastern black nightshade, hairy nightshade, horsenettle and smooth groundcherry. Smooth groundcherry was more tolerant to pyridate than eastern black nightshade, hairy nightshade, horsenettle and clammy groundcherry.

Key words: Eastern black nightshade (*Solanum ptycanthum*), hairy nightshade (*Solanum sarrachoides*), horsenettle (*Solanum carolinense*), smooth groundcherry (*Physalis subglabrata*), clammy groundcherry (*Physalis heterophylla*)

INTRODUCTION

Weeds in the nightshade family (Solanaceae) are difficult to control in vegetable cropping systems throughout the northeastern United States. Solanaceous weeds such as eastern black nightshade (*Solanum ptycanthum*), hairy nightshade (*Solanum sarrachoides*) and horsenettle (*Solanum carolinense*) are more troublesome in tomato, potato and pepper than clammy groundcherry (*Physalis heterophylla*) and smooth groundcherry (*Physalis subglabrata*). Nightshade causes direct yield losses due to plant competition with the crop and indirect yield losses by hosting a number of pests of *Solanaceous* crops. Perez and Masiunas (1990) estimated that four eastern black nightshade plants per square meter reduced yield by 60% in transplanted tomato by interfering with tomato growth within 4 to 8 weeks after crop establishment. In potato, hairy nightshade acts as an alternate host to potato leaf roll virus (Thomas, 2002) and *Rhizoctonia solani* (Ogg, 1989) and contributes to the transmission of diseases from one season to the next, leading to indirect yield reduction of potato. Similarly, horsenettle acts as an important reservoir of Colorado potato beetle (Covarrubias et al., 1996) causing indirect yield reduction in potato.

Since nightshade and tomato belong to the same botanical family, nightshades and tomato have a close genetic relationship and share similar growth habitats, physiology and herbicide susceptibilities (McGiffen & Masiunas, 1991; Perez & Masiunas, 1990; Weaver et al., 1987). Hence nightshades are difficult to control in tomato. In addition, there are few registered postemergence herbicides for nightshade control in tomatoes.

The similarities of closely related nightshade species has led to improper identification of nightshades in the past and has caused confusion with regard to the response of nightshades to herbicides. The revision of taxonomic descriptions by Schilling (1981), reports on nightshade species variation in response to herbicides (Ogg, 1986) and the difference in germination response to differing cultural practices (Ogg et al., 1981; Holm et al., 1977) has lead to accurate identification of nightshade species.

Differences in eastern black nightshade and hairy nightshade response to acifluorfen (Majek, 1981), chlorsulfuron (Ogg et al., 1981) and rimsulfuron (Ackley, 1997) have been reported. Recently eastern black nightshade biotypes resistant to ALS inhibitors have been reported in Wisconsin (Volenberg et al., 2000), Indiana and Illinois (Milliman et al., 2003). Furthermore, there are reports substantiating herbicide variation among accessions of eastern black nightshade (Ogg, 1986). There are no reports in variation in herbicide response among hairy nightshade and horsenettle populations. Richman et al. (1995) reported phylogenetic differences in two populations of horsenettle but there was no report on herbicide sensitivity in horsenettle populations.

The objective of this study was to determine any variation in sensitivity among nightshade and groundcherry species to herbicides and also to determine variation in herbicide sensitivity within the populations of nightshade species.

MATERIALS AND METHODS

Greenhouse experiments were conducted in 2003 and 2004 to evaluate the herbicide dose response among eastern black nightshade, hairy nightshade, horsenettle, smooth groundcherry and clammy groundcherry populations collected in Michigan.

Collection of berries:

In 2002, 11 populations of eastern black nightshade, seven populations of hairy nightshade, four populations of horsenettle and one population each of clammy groundcherry and smooth groundcherry were collected from locations in Michigan. Location, soil type, associated crops, and dates of collection of the weed populations are listed in Tables 1-4. The berries of ten nightshade plants in each field were randomly collected and bagged together.

Processing of berries:

The berries of these weeds were crushed and soaked in water for one night. Fruit juices were removed by wrapping in cheese cloth and squeezing by hand. Then the seeds in the cheese cloth were washed repeatedly and air dried for a week. The seeds were stored for two months at -20°C and then stored in incubator at 28° C to overcome dormancy.

Pre treatment of seeds:

A preliminary study was conducted in a growth chamber in 2002 to determine effects of germination enhancing chemicals on these seeds. Soaking seed in Gibberrellic acid (GA_3) at 1000 ppm and 0.1% potassium nitrate (KnO_3) for 10-12 hours resulted in at least 75% germination. Therefore seeds were pretreated overnight with 1000 ppm GA_3

and 0.1% KNO_3 to enhance germination. The pretreated seeds were allowed to air dry and then were sown in the flats containing Baccto[1] soil mix.

Sowing and transplanting:

Seeds were sown during the first week of June in the greenhouse and transferred to 1L pots, when the seedlings had 2 to 3 true leaves. The seedlings were maintained in the pots until the four to six leaf stages, and then were subjected to postemergence herbicide treatments.

Treatments and application:

The herbicide treatments and concentrations are listed in Table 5. The 1 X rates for the herbicide treatments in Table 5 were used in the field experiment in 2002, 2003 and 2004. All the weed populations were sprayed in three consecutive days, by using a single tip track sprayer[3] with an 80015E flat-fan nozzle[2] calibrated to deliver 187 L/ha at a pressure of 207 kPa. The treated nightshade populations were placed in the greenhouse and were arranged in randomized complete block design with four replications per treatment. The four replications are placed in different benches, which were facing north-south direction.

Visual rating and biomass measurements:

Visual ratings were taken at 1, 2 and 3 weeks after treatment (WAT). Visual ratings were scaled from 1 (no injury) to 10 (complete death) and then converted to a percentage for statistical analysis. Plants were harvested by clipping at the stem base region at 3 WAT and the fresh weights were recorded. The plants were air dried at 60^0C for a week and

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[1]Baccto Soil Mix. Michigan Peat Co., P.O.Box 980129, Houston, TX 0129.
[2]Teejet flat fan tips. Spraying Systems Co., North Ave., Schmale Rd., Wheaton, IL 60188.
[3]Allen Machine works, 607 E Miller, Midland, MI 48640.

then weighed again. The plant weights were then converted to percent of reduction from the untreated control.

Statistical analysis:

The two years data were subjected to ANOVA to determine the significance of year x year interactions and data were combined together over years if there was no year effect. Using a log-logistic model (Seefeldt et al., 1995), a non linear regression curve was developed by using Table curve[4] and Sigma plot version 8 software[5]. The following log-logistic equation, relates the percent of dry biomass reduction from the control y to the herbicide rate x (Seefeldt et al., 1995).

$$y = C + \frac{D - C}{1 + (x/GR_{50})^{b}}$$

In this equation, C is the lower response limit, D is the upper response limit, b is the slope and GR_{50} is the rate which resulted in a 50% reduction in biomass.

[4]Jandel Scientific, Table Curve 2D v. 3.1, 2591 Kerner Boulevard, San Rafael, CA 94901.

[5]Version 8.02, SPSS Inc., 233 South Wacker Drive, Chicago, IL 60606.

RESULTS AND DISCUSSION

Response of eastern black nightshade populations to herbicides:

Eastern black nightshade populations had a wide range of variation in response to metribuzin at rates higher than 0.28 kg/ha. Dose response curves for the 12 populations in response to metribuzin are presented in Figures 1a, 1b, and 1c. Among the 12 populations, the Newaygo2 and Monroe4 populations were the most susceptible to metribuzin with a 50% growth reduction (GR_{50}) at 0.31 kg/ha (Figure1a). Oceana1, Ingham1, Ingham2, Bay1 and Monroe2 populations had high tolerance to metribuzin at 1.12 kg/ha and could not fit the log logistic equation (Table 6). In general, all eastern black nightshade populations were tolerant to metribuzin at the normal dose rate of 0.28 kg/ha.

Sulfentrazone, a protoporphyrinogen oxidase inhibitor, reduced the dry weight of all eastern black nightshade populations. However, populations varied in their susceptibility to sulfentrazone (Figures 2a, 2b, 2c, 2d). Newago2 was the most susceptible among the eastern black nightshade populations with a GR_{50} of 0.036 kg/ha (Table 7). Ingham1 & Ingham2 populations were the most tolerant of sulfentrazone (Figure 2c) with a GR_{50} =0.22 kg/ha which is twice the standard rate. The Ingham2 R/S (Resistance/ Susceptible) ratio was calculated at about 6 times more tolerant than the Newago2 (Figure2d). Eastern black nightshade populations within counties other than Monroe had similar responses. Among Monroe populations, Monroe1 was 60% more tolerant than Monroe2 (Table 7). Log-logistic equations could not be obtained for the monroe4 population response to sulfentrazone due to high degree of non homogenous data.

Eastern black nightshade populations other than Macomb3 and Macomb1 were tolerant to halosulfuron. However, there was a wide range of variation among the populations above the rate of 0.034 kg/ha except in Macomb3 and Macomb1 populations (Figures 3a, 3b, 3c). Macomb3 and Macomb1 populations were the most susceptible to halosulfuron with a GR_{50} less than the normal rate of 0.034 kg/ha (Table 8). In contrast, the Macomb2 population was 6 times more tolerant to halosulfuron than Macomb3, and 4 times more tolerant than the Macomb1 population (Figure 3c). The Ingham2 population was very highly tolerant to halosulfuron and could not fit the log logistic equation (Table 8). A GR_{50} value could not be obtained for other populations such as Bay1, Ingham1, Monroe2, Mason1 and Newago2 due to high degree of tolerance to halosulfuron.

There was a wide range of variation among eastern black nightshade populations to sulfosulfuron (Figures 4a, 4b, 4c). The Monroe2 population was highly susceptible to sulfosulfuron, with a GR_{50} of 0.032 kg/ha. The Oceana1 population was the most tolerant to sulfosulfuron among the eastern black nightshade populations (Figure 4d). The GR_{50} value for the Oceana1 population could not be calculated and also had a low R square value due to high tolerance (Table 9). The Macomb3 population possessed GR_{50} of 0.10 kg/ha which was two times more tolerant than the highly susceptible Macomb2 population.

Most of the populations of eastern black nightshade had a high degree of sensitivity to pyridate (Table 10) and there was no wide variation among eastern black nightshade populations susceptibility to pyridate (Figure 5a). Ingham2 and Oceana1 were susceptible to pyridate at 0.44 kg/ha and 0.36 kg/ha respectively (Table 10). Mason1, Ingham1, and Bay1 populations were susceptible at 0.29 kg/ha. Other eastern black nightshade populations were highly sensitive to pyridate even at the very low rate of 0.225 kg/ha and hence log-logistic equation could not be applied.

In conclusion, the Ingham2 population had greater tolerance to all herbicides than the other eastern black nightshade populations. The Oceana1 population was more tolerant to sulfosulfuron and metribuzin than other eastern black nightshade populations. Past cultural practices by using herbicides in Ingham2 and Oceana1 for many years may be the reason for greater tolerance to herbicides.

Response of hairy nightshade populations to herbicides:

In general, hairy nightshade populations were highly susceptible to metribuzin (Figure 5b, 5c). The Montcalm1 population was the most susceptible among the 7 populations with a GR_{50} of 0.10 kg/ha (Table 11). The Macomb1 population was twice as tolerant compared to the Montcalm1 population with a GR_{50} of 0.23 kg/ha (Figure 5d).

Most of the hairy nightshade populations were highly susceptible to sulfentrazone (Figure 6a, 6b, Table 12). The Presque2 and Presque3 populations were the most susceptible among the hairy nightshade populations with a GR_{50} less than 0.028 kg/ha. The Macomb1 population was the most tolerant to sulfentrazone compared to other hairy nightshade populations with a GR_{50} of 0.10 kg/ha, and was four times more tolerant than the Presque2 and Presque3 populations (Figure 6c).

Hairy nightshade populations were highly susceptible sulfosulfuron (Figures 7a, 7b) and the range of susceptibility varied from <0.0086 kg/ha to 0.037 kg/ha. Log-logistic equations could not be obtained for the Presque1 and Montcalm2 populations due to a high degree of susceptibility to sulfosulfuron. In general, the Presque2, Presque3, and Presque4 populations were similar in dose response to sulfosulfuron (Table13) with a

GR_{50} of 0.0099 kg/ha. The Macomb1 and Montcalm1 populations were more tolerant to sulfosulfuron compared to other hairy nightshade populations with a GR_{50} of 0.037 kg/ha. The Macomb1 and Montcalm1 populations were 4 times more tolerant to sulfosulfuron than the Presque2, Presque3, Presque4 populations (Figure 7c).

Hairy nightshade populations had a wide range of variation in response to halosulfuron (Figure 8a). The Presque2 population was the most susceptible among the hairy nightshade populations with GR_{50} of 0.021 kg/ha. The Macomb1 and Bay2 populations were tolerant to halosulfuron. Due to the high degree of tolerance, GR_{50} values could not be calculated (Figure 8b). The Presque4 population (GR_{50} = 0.077 kg/ha) was three times more tolerant than the Presque2 population (Table14). Presque1 and Montcalm1 populations could not be analyzed for response to halosulfuron, due to the high degree of non homogenous variability in the data which could not be transformed.

All hairy nightshade populations were sensitive to pyridate at 0.225 kg/ha and data could not be fitted to a log logistic equation (Table 15).

Among all hairy nightshade populations, the Macomb1 population was more tolerant than the other hairy nightshade populations in response to all of the herbicides.

Response of horsenettle populations to herbicides:

Horsenettle populations were very susceptibile to halosulfuron (Figure 9). Among the four populations, Monroe5 was highly susceptible and a GR_{50} value could not be obtained. Besides the Monroe5 population, Berrien2 was very sensitive with GR_{50} of 0.0086 kg/ha (Table16).

Narrow range of variation was observed among horsenettle populations in response to sulfentrazone (Figure10). Among the four horsenettle populations, Montcalm3 was the most susceptible to sulfentrazone with GR_{50} of 0.012 kg/ha. Vanburen1 was the most tolerant among the four populations with a GR_{50} of 0.35 kg/ha which was three times more tolerant than Berrien2 and 30 times more tolerant than Montcalm3 populations in response to sulfentrazone (Table 17).

Horsenettle populations were highly susceptible to sulfosulfuron. A narrow range of variation was observed among the four horsenettle populations in response to sulfosulfuron. (Table 18). Vanburen1 was the most susceptible to sulfosulfuron and had GR_{50} less that 0.0086 kg/ha. All horsenettle populations were very sensitive below the normal dose of 0.034 kg/ha (Figure 11).

Horsenettle populations had a narrow range of variation in response to pyridate. All of the horsenettle populations were sensitive to pyridate at rate less than 0.5 kg/ha (Figure12). The Monroe5 population was the most sensitive among the horsenettle populations, (Table 19) with a GR_{50} less than 0.252 kg/ha.

All horsenettle populations also had a high degree of sensitivity to metribuzin even at the lowest rate and hence the log logistic equation could not be developed (Table 20).

In general, there was not much variation in tolerance among the four horsenettle populations to herbicides.

Response of clammy groundcherry to herbicides:

The Newago1 population had a high tolerance to sulfentrazone and a GR_{50} could not be obtained at the given rates (Table 21). The low susceptibility of Newago1 population to sulfentrazone might be due to the presence of dense pubescence on the leaves that might have prevented the entry of sulfentrazone into the cuticle of the leaves.

However, the Newago1 population was sensitive to sulfosulfuron, metribuzin and pyridate. Due to the high degree of non homogenous variability in data with respect to the halosulfuron treatment, a log logistic curve could not be applied.

Response of smooth groundcherry to herbicides:

The Ingham3 population was very sensitive to sulfentrazone treatment with a GR_{50} of 0.104 kg/ha. There was a high degree of sensitivity to metribuzin in the Ingham3 population and log logistic curve could not be developed due to a high degree of sensitivity (Table 22). The Ingham3 population was also susceptible to halosulfuron at 0.038 kg/ha and pyridate at 1.39 kg/ha (Table 22). With respect to sulfosulfuron, Ingham3 possessed fair tolerance, with a GR_{50} of 0.091 kg/ha.

The results of this study indicate that nightshade and groundcherry species respond differently to a wide variety of herbicides (Table 23). Past cultural practices in using herbicides for many years might be the reason for higher tolerance among eastern black nightshade populations and some hairy nightshade populations to herbicides. Eastern black nightshade populations in particular have a wide range of variation to herbicides (Table 23). Eastern black nightshade populations such as Ingham2 and Oceana1 may possess multiple resistant characteristics to triazine and sulfonylurea herbicides and might be likely to build resistance to other herbicides. Studies conducted by Vollenberg et al., (2000) and Milliman et al., (2003) have reported ALS resistant eastern black nightshade in agronomic crops. These results indicate that eastern black nightshade may become an increasingly troublesome weed among Solanaceous species in tomato and likely to build resistance to many herbicides.

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Table 1. Eastern black nightshade (SOLPT) populations collected from various regions in Michigan; including location, current crop and soil properties.

SOLPT Population	Location (Michigan)	Current Crop	Soil Properties			
			Soil Type	pH	Organic Content (%)	$N(NO_3)$ (ppm)
Newago2	T12N, R14W Sec : 17, Sheridan twp	Tomato	Loamy sand	5.7	2.98	18.6
Ingham1	T3N, R1W Sec : 12, Delhi twp	Tomato	Sandy loam	7.1	2.14	5.7
Ingham2	T1N, R2E Sec : 35, Stockbridge twp	Potato	organic	4.7	32.41	45.3
Oceana1	T15N, R17W Sec : 32, Hart twp	Asparagus	Loamy sand	5.9	1.91	9.1
Mason1	T18N, R17W Sec : 29 Riverton twp	Snap bean	Sandy clay loam	7	2.62	51.1
Monroe2*	T7S, R6E Sec : 21, Dundee twp	Tomato	-	-	-	-
Monroe4	T7S, R6E Sec : 21, Dundee twp	Pepper	Clay loam	6.8	2.98	5.8
Macomb1	T3N, R13E Sec : 17, Macomb twp	Tomato	Sandy loam	5.7	1.52	11.1
Macomb2	T4N, R13E Sec : 5, Ray twp	Tomato	Sandy clay Loam	7	3.57	17.2
Macomb3	T5N, R13E Sec : 32, Armada twp	Tomato	Loamy sand	5.3	2.34	32.9
Bay1**	T15N, R3E Sec : 22, Garfield twp	Potato	-	7.3	2.21	14.2

*Soil properties of the given population is not available
** Soil type of the given population is not available

Table 2. Hairy nightshade (SOLSA) populations collected from various regions in Michigan; including location, current crop and soil properties.

SOLSA Population	Location (Michigan)	Current Crop	Soil Properties			
			Soil Type	pH	Organic Content (%)	N(NO_3) (ppm)
Montcalm1	T12N, R6W Sec : 34, Home twp	Potato	Sandy loam	6.2	3.1	14.6
Montcalm2*	T11N, R9W Sec : 25, Maple valley twp	A[1]	Sandy loam	6.1	1.17	-
Macomb1	T3N, R13E Sec : 17, Macomb twp	Tomato	Sandy loam	5.7	1.52	11.1
Presque1	T34N, R5E Sec : 2, Belknap twp	Potato	Sandy loam	7.6	1.4	15.9
Presque2	T34N, R6E Sec : 30, S.Pulawski twp	Dry bean	Loam	7	3.03	8.5
Presque3	T34N, R5E Sec : 21, Belknap twp	Dry bean	Sandy clay loam	7.8	3.43	6.1
Presque4**	T34N, R6E Sec : 30, S.Pulawski twp	Dry bean	-	-	-	-
Bay2	T15N, R3E Sec : 22, Garfield twp	Potato	Sandy loam	7.3	2.21	14.2

* Nitrogen content of the given population is not available

** Soil properties of the given population is not available

A[1] The given population is collected from agrestal region (uncultivated/ undisturbed region)

Table 3. Horsenettle (SOLCA) populations collected from various regions in Michigan; including location, current crop and soil properties.

SOLCA Population	Location (Michigan)	Current. Crop	Soil Properties			
			Soil type	pH	Organic Content (%)	N (NO_3) (ppm)
Berrien2	T5S, R18W Sec : 15, Sodus twp	A[1]	Sandy loam	6.2	1.71	43
Vanburen1	T3S, R16W Sec : 1, Hartford twp	Tomato	Sandy loam	6.5	1.71	14.3
Montcalm3	T10N, R8W Sec : 5	Snapbean	Sandy loam	5.4	2.07	14.8
Monroe5*	T7S, R6E Sec : 30, Dundee twp	Soybean				

A[1] The given population is collected from agrestal region (uncultivated/ undisturbed region

*Soil properties of the given population is not available

Table 4. Clammy groundcherry (PHYHE) and smooth groundcherry (PHYSU) populations collected from various regions in Michigan; including location, current crop and soil properties.

Species	Location (Michigan)	Assoc. Crop	Soil Properties			
			Soil Type	pH	Organic Content (%)	$N(NO_3)$ (ppm)
PHYHE (Newago1)	T12N, R14W Sec : 36, Sheridan twp	Tomato	Loamy sand	6.2	2.05	8.6
PHYSU (Ingham3)	T2N, R2W Sec : 14, Aurelius twp	Onion	organic	6.6	71.77	102.1

Table 5. Treatments applied at various concentrations to eastern black nightshade, hairy nightshade, horsenettle, smooth groundcherry and clammy groundcherry populations.

Treatments	0.25X (kg ai/ha)	0.5X (kg ai/ha)	1X (kg ai/ha)	2X (kg ai/ha)	4X (kg ai/ha)
Metribuzin	0.070	0.14	0.28	0.56	1.12
Sulfentrazone	0.028	0.056	0.112	0.224	0.448
Sulfosulfuron	0.0086	0.0173	0.0347	0.0694	0.1388
Halosulfuron	0.0086	0.0173	0.0347	0.0694	0.1388
Pyridate	0.252	0.50	1.01	2.02	4.04

Table 6. Log logistic equations, R^2 values and GR_{50} values for eastern black nightshade (SOLPT) populations in response to metribuzin treatment.

SOLPT Population	R^{2a}	Log-logistic equation	GR_{50}(kg ai/ha)
Monroe4	0.78	$y= 0 + 74.86/[1+(x/0.31)^{-18.01}]$	0.31
Newaygo2	0.53	$y= 0+ 76.89/[1+(x/0.31)^{-1.76}]$	0.31
Mason1	0.66	$y= 0+ 86.71/[1+(x/0.50)^{-0.74}]$	0.50
Monroe1	0.82	$y= 0+84.85/[1+(x/0.60)^{-19.49}]$	0.60
Macomb2	0.61	$y= 0+93.79/[1+(x/0.61)^{-1.95}]$	0.61
Macomb1	0.74	$y= 0+87.19/[1+(x/0.67)^{-1.10}]$	0.67
Macomb3	0.72	$y= 0+70.80/[1+(x/0.82)^{-1.37}]$	0.82
Oceana1[b]			>1.12
Ingham1[b]			>1.12
Ingham2[b]			>1.12
Bay1[b]			>1.12
Monroe2[b]			>1.12

[a] All R^2 values are significant at $\alpha < 0.01$.

[b] Populations were highly tolerant and could not fit in to the equation and have low R^2.

Table 7. Log logistic equations, R^2 values and GR_{50} values for eastern black nightshade (SOLPT) populations in response to sulfentrazone treatment.

SOLPT Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Newago2	0.36	$y= 0+88.11/[1+(x/0.036)^{-0.33}]$	0.036
Macomb1	0.90	$y= 0+ 102.84/[1+(x/0.066)^{-1.79}]$	0.066
Macomb2	0.76	$y= 0+ 95.09/[1+(x/0.07)^{-1.94}]$	0.07
Macomb3	0.78	$y= 0+ 86.68/[1+(x/0.07)^{-1.61}]$	0.07
Monroe2	0.45	$y= 0+80.18/[1+(x/0.091)^{-0.35}]$	0.091
Oceana1	0.75	$y= 0+79.60/[1+(x/0.091)^{-5.51}]$	0.091
Mason1	0.91	$y= 0+ 94.01/[1+(x/0.12)^{-3.36}]$	0.12
Bay1	0.82	$y= 0+101.69/[1+(x/0.14)^{-3.09}]$	0.14
Monroe1	0.79	$y= 0+ 98.46/[1+(x/0.15)^{-0.74}]$	0.15
Ingham2	0.67	$y= 0+95.76/[1+(x/0.22)^{-19.89}]$	0.22
Ingham1	0.65	$y= 0+ 81.17/[1+(x/0.22)^{-0.74}]$	0.22
Monroe4[b]			

[a] All R^2 values are significant at $\alpha< 0.01$

[b] Population has huge variability in data which could not be transformed for analysis

Table 8. Log logistic equations, R^2 values and GR_{50} values for eastern black nightshade (SOLPT) populations in response to halosulfuron treatment.

SOLPT Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Macomb3	0.53	$y= 0+77.67/[1+(x/0.019)^{-2.34}]$	0.019
Macomb1	0.74	$y= 0+83.42[1+(x/0.027)^{-8.36}]$	0.027
Monroe4	0.36	$y= 0+60.99/[1+(x/0.041)^{-1.82}]$	0.041
Oceana1	0.63	$y= 0+82.16/[1+(x/0.11)^{-2.82}]$	0.11
Ingham1	0.44	$y= 0+56.63/[1+(x/0.086)^{-25.69}]$	0.086
Macomb2	0.60	$y= 0+63.33/[1+(x/0.11)^{-1.38}]$	0.11
Monroe1	0.70	$y= 0+61.36/[1+(x/0.12)^{-3.13}]$	0.12
Newago2 [b]			>0.138
Monroe2 [b]			>0.138
Bay1 [b]			>0.138
Ingham2 [b]			>0.138
Mason1 [c]			

[a] All R^2 values are significant at α <0.01

[b] Population were highly tolerant and could not fit logistic equation

[c] Population has huge variability in data which could not be transformed for analysis

Table 9. Log logistic equations, R^2 values and GR_{50} values for eastern black nightshade (SOLPT) populations in response to sulfosulfuron treatment.

SOLPT Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Monroe2	0.83	$y= 0+67.74[1+(x/0.032)^{-3.8}]$	0.032
Monroe1	0.73	$y= 0+54.62[1+(x/0.038)^{-8.62}]$	0.038
Bay1	0.74	$y= 0+66.95[1+(x/0.040)^{-8.52}]$	0.04
Macomb2	0.73	$y= 0+74.34[1+(x/0.053)^{-1.20}]$	0.053
Macomb1	0.76	$y= 0+91.24[1+(x/0.062)^{-0.75}]$	0.062
Monroe4	0.70	$y= 0+80.99[1+(x/0.066)^{-0.71}]$	0.066
Ingham1	0.71	$y= 0+83.81[1+(x/0.074)^{-1.12}]$	0.074
Newaygo2	0.75	$y= 0+92.84[1+(x/0.077)^{-1.05}]$	0.077
Mason1	0.79	$y= 0+69.32[1+(x/0.07)^{-1.23}]$	0.079
Ingham2	0.88	$y= 0+85.70[1+(x/0.074)^{-1.66}]$	0.099
Macomb3	0.54	$y= 0+52.64[1+(x/0.10)^{-1.07}]$	0.10
Oceana1 [b]			>0.138

[a] All R^2 values are significant at $\alpha < 0.01$

[b] Population were highly tolerant and could not fit logistic equation

Table 10. Log logistic equations, R^2 values and GR_{50} values for eastern black nightshade (SOLPT) populations in response to pyridate treatment.

SOLPT Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Monroe2 [b]			<0.22
Monroe4 [b]			<0.22
Monroe1 [b]			<0.22
Newaygo2 [b]			<0.22
Macomb3 [b]			<0.22
Macomb2 [b]			<0.22
Macomb1 [b]			<0.22
Mason1	0.60	$y= 0+99.04[1+(x/0.29)^{-3.02}]$	0.29
Ingham1	0.70	$y= 0+99.16[1+(x/0.29)^{-2.69}]$	0.29
Bay1	0.69	$y= 0+100.00[1+(x/0.29)^{-3.45}]$	0.29
Oceana1	0.60	$y= 0+98.59[1+(x/0.36)^{-2.32}]$	0.36
Ingham2	0.82	$y= 0+100.00 [1+(x/0.44)^{-4.75}]$	0.44

[a] All R^2 values are significant at $\alpha < 0.01$

[b] Population were highly sensitive and could not fit logistic equation

Table 11. Log logistic equations, R^2 values and GR_{50} values for hairy nightshade (SOLSA) populations in response to metribuzin treatment.

SOLSA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Montcalm1	0.71	$y= 0+ 82.17/[1+(x/0.10)^{-4.89}]$	0.10
Montcalm2	0.85	$y= 0+ 100.81/[1+(x/0.15)^{-2.06}]$	0.15
Presque2	0.90	$y=0+ 102.23/[1+(x/0.16)^{-2.73}]$	0.16
Presque3	0.88	$y=0+ 96.85/[1+(x/0.19)^{-4.81}]$	0.19
Presque4	0.92	$y=0+ 100.40/[1+(x/0.19)^{-5.33}]$	0.19
Presque1	0.91	$y=0+ 99.97/[1+(x/0.20)^{-5.40}]$	0.20
Bay2	0.88	$y=0+ 100.00/[1+(x/0.20)^{-2.87}]$	0.20
Macomb1	0.86	$y=0+ 95.47/[1+(x/0.23)^{-5.60}]$	0.23

[a] All R^2 values are significant at $\alpha < 0.01$.

Table 12. Log logistic equations, R^2 values and GR_{50} values for hairy nightshade (SOLSA) populations in response to sulfentrazone treatment.

SOLSA Population	R^2	Log-logistic equation	GR_{50} (kg ai/ha)
Presque2 [b]			<0.028
Presque3 [b]			<0.028
Presque1	0.82	$y= 0+ 100.59/[1+(x/0.04)^{-0.77}]$	0.045
Montcalm2	0.83	$y= 0+ 97.07/[1+(x/0.061)^{-2.22}]$	0.061
Montcalm1	0.77	$y= 0+94.82/[1+(x/0.09)^{0.05}]$	0.061
Presque4	0.86	$y= 0+ 103.69/[1+(x/0.066)^{-1.67}]$	0.066
Bay2	0.81	$y= 0+ 82.56/[1+(x/0.070)^{-10.91}]$	0.070
Macomb1	0.69	$y= 0+ 101.54/[1+(x/0.10)^{-0.81}]$	0.10

[a] All R^2 values are significant at $\alpha < 0.01$.

[b] Population were highly sensitive and could not fit logistic equation

Table 13. Log logistic equations, R^2 values and GR_{50} values for hairy nightshade (SOLSA) populations in response to sulfosulfuron treatment.

SOLSA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Montcalm2 [b]			<0.0086
Presque1 [b]			<0.0086
Presque2	0.60	$y= 0+ 86.06/[1+(x/0.0099)^{-8.61}]$	0.0099
Presque3	0.81	$y= 0+ 101.92/[1+(x/0.0099)^{-1.39}]$	0.0099
Presque4	0.84	$y= 0+ 97.84/[1+(x/0.0099)^{-4.22}]$	0.0099
Bay2	0.91	$y= 0+ 95.22/[1+(x/0.031)^{-1.43}]$	0.031
Macomb1	0.87	$y= 0+ 74.75/[1+(x/0.037)^{-21.72}]$	0.037
Montcalm1	0.84	$y= 0+ 101.96/[1+(x/0.037)^{-1.91}]$	0.037

[a] All R^2 values are significant at $\alpha < 0.01$.

[b] Population were highly sensitive and could not fit logistic equation.

Table 14. Log logistic equations, R^2 values and GR_{50} values for hairy nightshade (SOLSA) populations in response to halosulfuron treatment.

SOLSA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Presque2	0.59	$y= 0+ 68.69/[1+(x/0.021)^{-2.48}]$	0.021
Presque3	0.28	$y= 0+ 67.39/[1+(x/0.57)^{-0.37}]$	0.057
Montcalm2	0.70	$y= 0+ 79.06/[1+(x/0.073)^{-0.87}]$	0.073
Presque4	0.62	$y= 0+ 79.58/[1+(x/0.077)^{-0.79}]$	0.077
Bay2 [b]	0.31		>0.138
Macomb1 [b]	0.21		>0.138
Presque1 [c]			
Montcalm1 [c]			

[a] All R^2 values are significant at $\alpha < 0.01$.

[b] Population were highly tolerant and could not fit logistic equation

[c] Population has huge variability in data which could not be transformed for analysis

Table 15. Log logistic equations, R^2 values and GR_{50} values for hairy nightshade (SOLSA) populations in response to pyridate treatment.

SOLSA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Montcalm1 [b]			<0.22
Montcaml2 [b]			<0.22
Presque2 [b]			<0.22
Presque3 [b]			<0.22
Presque4 [b]			<0.22
Presque1 [b]			<0.22
Bay2 [b]			<0.22
Macomb1 [b]			<0.22

[a] All R^2 values are significant at $\alpha < 0.01$

[b] Population were highly sensitive and could not fit logistic equation

Table 16. Log logistic equations, R^2 values and GR_{50} values for horsenettle (SOLCA) populations in response to halosulfuron treatment.

SOLCA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Monroe5[b]			<0.0086
Berrien2	0.83	$y= 0+ 100.85/[1+(x/0.086)^{-2.50}]$	0.0086
Montcalm3	0.60	$y= 0+ 95.53/[1+(x/0.016)^{-0.38}]$	0.016
Vanburen1	0.42	$y= 0+ 88.70/[1+(x/0.036)^{-0.47}]$	0.036

[a] All R^2 values are significant at $\alpha < 0.01$.

[b] Population were highly sensitive and could not fit logistic equation

Table 17. Log logistic equations, R^2 values and GR_{50} values for horsenettle (SOLCA) populations in response to sulfentrazone treatment.

SOLCA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Montcalm3	0.68	$y = 0 + 80.81/[1+(x/0.012)^{-1.54}]$	0.012
Berrien2	0.88	$y = 0 + 70.70/[1+(x/0.12)^{-15.16}]$	0.12
Monroe5	0.85	$y = 0 + 88.92/[1+(x/0.19)^{-2.85}]$	0.19
Vanburen1	0.43	$y = 0 + 65.07/[1+(x/0.35)^{-1.10}]$	0.35

[a] All R^2 values are significant at $\alpha < 0.01$.

Table 18. Log logistic equations, R^2 values and GR_{50} values for horsenettle (SOLCA) populations in response to sulfosulfuron treatment.

SOLCA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Vanburen1 [b]			<0.0086
Montcalm3	0.68	$y= 0+ 80.81/[1+(x/0.012)^{-1.54}]$	0.012
Berrien2	0.49	$y= 0+ 80.83/[1+(x/0.020)^{-0.30}]$	0.020
Monroe5	0.50	$y= 0+ 88.91/[1+(x/0.031)^{-0.42}]$	0.031

[a] All R^2 values are significant at $\alpha < 0.01$.

[b] Population were highly sensitive and could not fit logistic equation

Table 19. Log logistic equations, R^2 values and GR_{50} values for horsenettle (SOLCA) populations in response to pyridate treatment.

SOLCA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Monroe5 [b]			<0.252
Berrien2	0.90	$y= 0+ 103.29/[1+(x/0.40)^{-1.71}]$	0.40
Vanburen1	0.90	$y= 0+ 93.38/[1+(x/0.40)^{-2.63}]$	0.40
Montcalm3	0.70	$y= 0+ 98.44/[1+(x/0.51)^{-1.01}]$	0.51

[a] All R^2 values are significant at $\alpha < 0.01$

[b] population were highly sensitive and could not fit logistic equation.

Table 20. Log logistic equations, R^2 values and GR_{50} values for horsenettle (SOLCA) populations in response to metribuzin treatment.

SOLCA Population	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Monroe5 [b]			<0.070
Berrien2 [b]			<0.070
Vanburen1 [b]			<0.070
Montcalm3 [b]			<0.070

[a] All R^2 values are significant at $\alpha < 0.01$

[b] Population were highly sensitive and could not fit logistic equation

Table 21. Log logistic equations, R^2 values and GR_{50} values for clammy groundcherry (PHYHE) population in response to sulfosulfuron, metribuzin, pyridate, sulfentrazone treatment.

PHYHE Population	Treatments	R^{2a}	Log-logistic equation	GR_{50} (kg ai/ha)
Newago1	Sulfosulfuron	0.54	$y= 0+ 82.19/[1+(x/0.028)^{-0.42}]$	0.028
	Metribuzin	0.73	$y= 0+ 96.67/[1+(x/0.42)^{-0.72}]$	0.42
	Pyridate	0.62	$y= 0+ 84.71/[1+(x/0.67)^{-1.00}]$	0.67
	Sulfentrazone [b]			>0.44
	Halosulfuron [c]			

[a] All R^2 values are significant at $\alpha < 0.01$

[b] Population were tolerant to the treatment and could not fit logistic equation

[c] Population has huge variability in data which could not be transformed for analysis

Table 22. Log logistic equations, R^2 values[a] and GR_{50} values for smooth groundcherry (PHYSU) population in response to sulfosulfuro, pyridate, sulfentrazone treatment.

PHYSU Population	Treatments	R^2	Log-logistic equation	GR_{50} (kg ai/ha)
Ingham3	Halosulfuron	0.58	$y = 0 + 83.22/[1+(x/0.038)^{-1.39}]$	0.038
	Sulfosulfuron	0.61	$y = 0 + 72.71/[1+(x/0.091)^{-0.90}]$	0.091
	Sulfentrazone	0.76	$y = 0 + 102.21/[1+(x/0.104)^{-2.10}]$	0.104
	Pyridate	0.69	$y = 0 + 98.83/[1+(x/1.39)^{-0.70}]$	1.39
	Metribuzin[b]			<0.070

[a] All R^2 values are significant at $\alpha < 0.01$

[b] Population were highly sensitive to the treatment and could not fit logistic equation

Table 23. Range of GR_{50} values between populations of eastern black nightshade (SOLPT), hairy nightshade (SOLSA), horsenettle (SOLCA), clammy groundcherry (PHYHE) and smooth groundcherry (PHYSU) in response to different treatments.

Treatments/ Species (no. of populations)	Metribuzin kg/ha	Sulfentrazone kg/ha	Halosulfuron kg/ha	Sulfosulfuron kg/ha	Pyridate kg/ha
SOLPT (12)	0.31 to >1.12	0.036 to 0.22	0.019 to > 0.138	0.032 to >0.138	0.44 to <0.225
SOLSA (8)	0.10 to 0.23	<0.028 to 0.10	0.021 to >0.138	<0.0086 to 0.037	<0.225
SOLCA (4)	<0.070	0.012 to 0.35	<0.0086 to 0.036	<0.0086 to 0.031	<0.225 to 0.51
PHYHE (1)	0.42	>0.44	ND	0.028	0.67
PHYSU (1)	<0.070	0.104	0.038	0.091	1.39

ND – refers to non availability of data

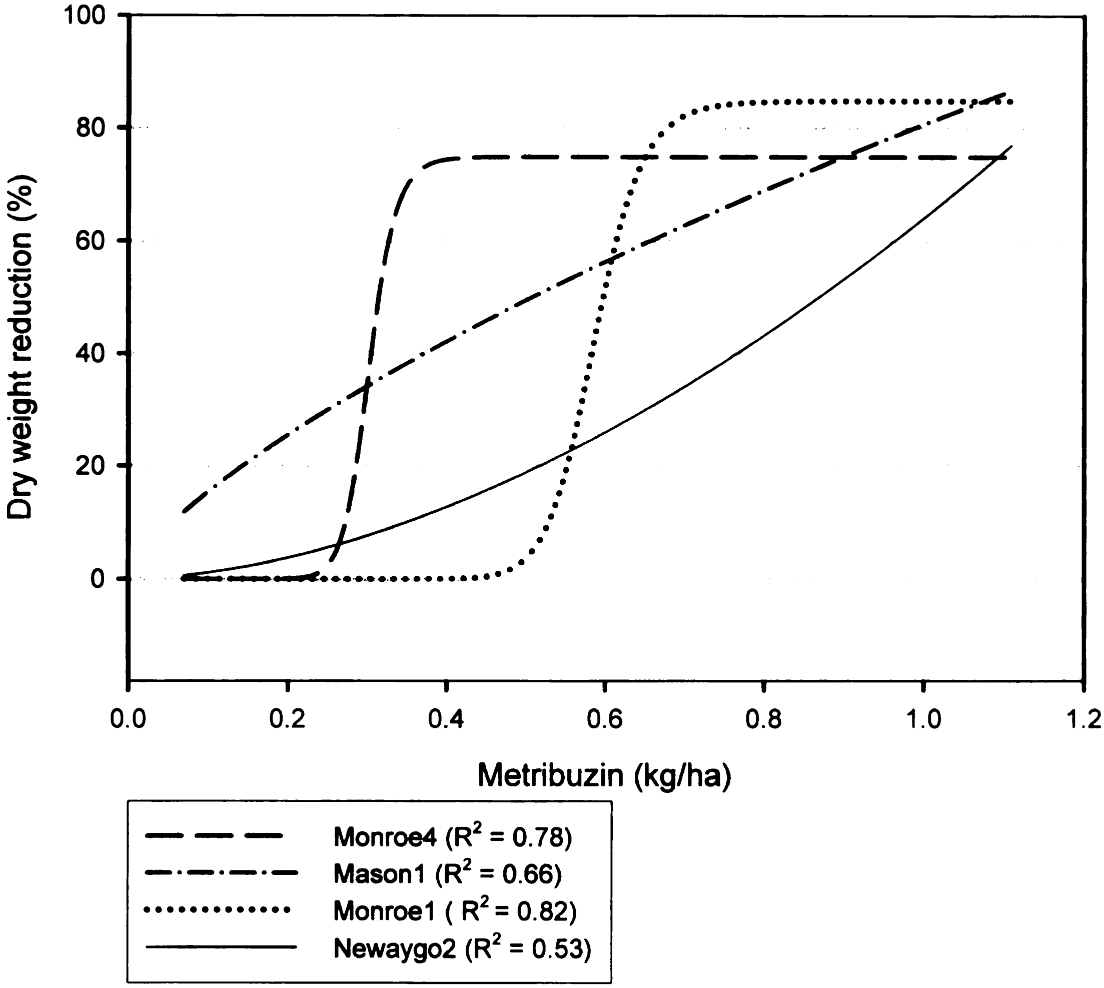

Figure 1a. Log logistic dose response curves of eastern black nightshade populations - Monroe4, Mason1, Monroe1, and Newago2 in response to metribuzin.

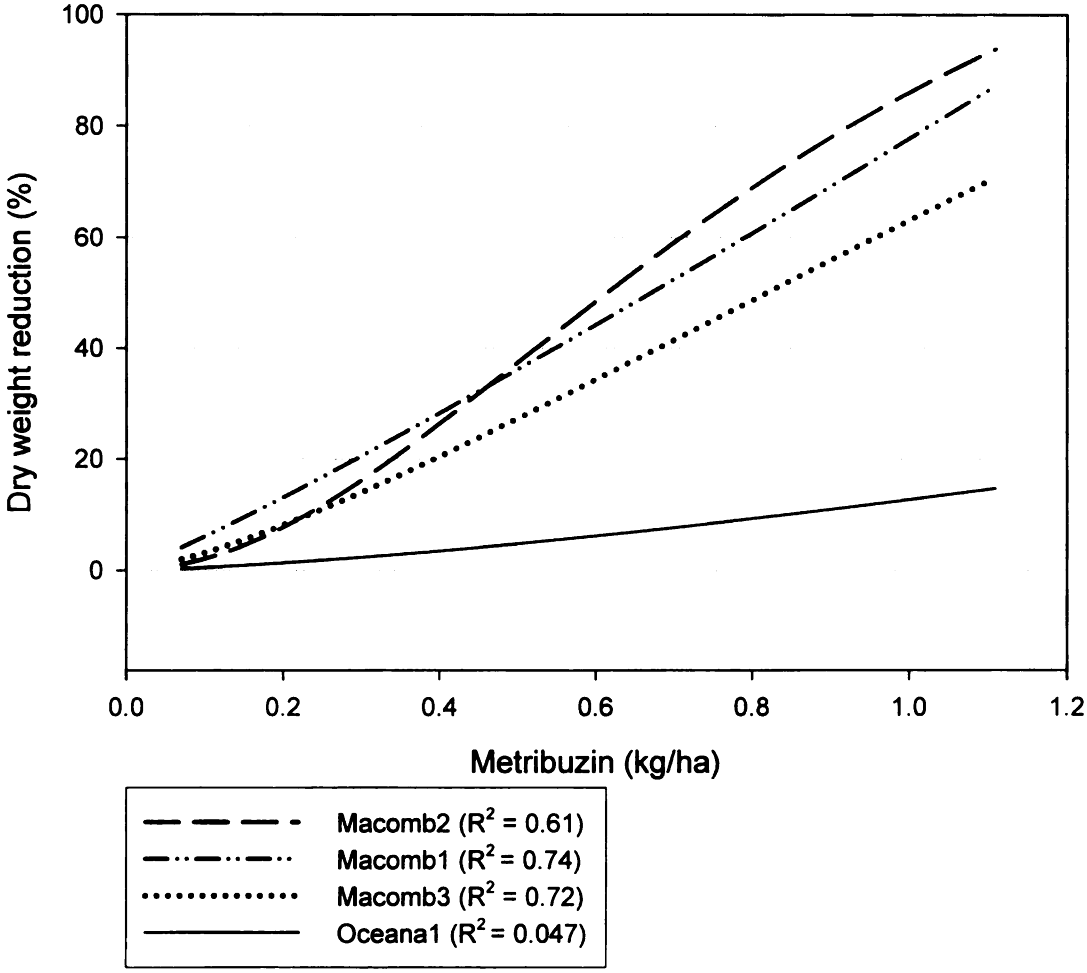

Figure 1b. Log logistic dose response curves of eastern black nightshade populations - Macomb1, Macomb2, Oceana1, and Macomb3 in response to metribuzin.

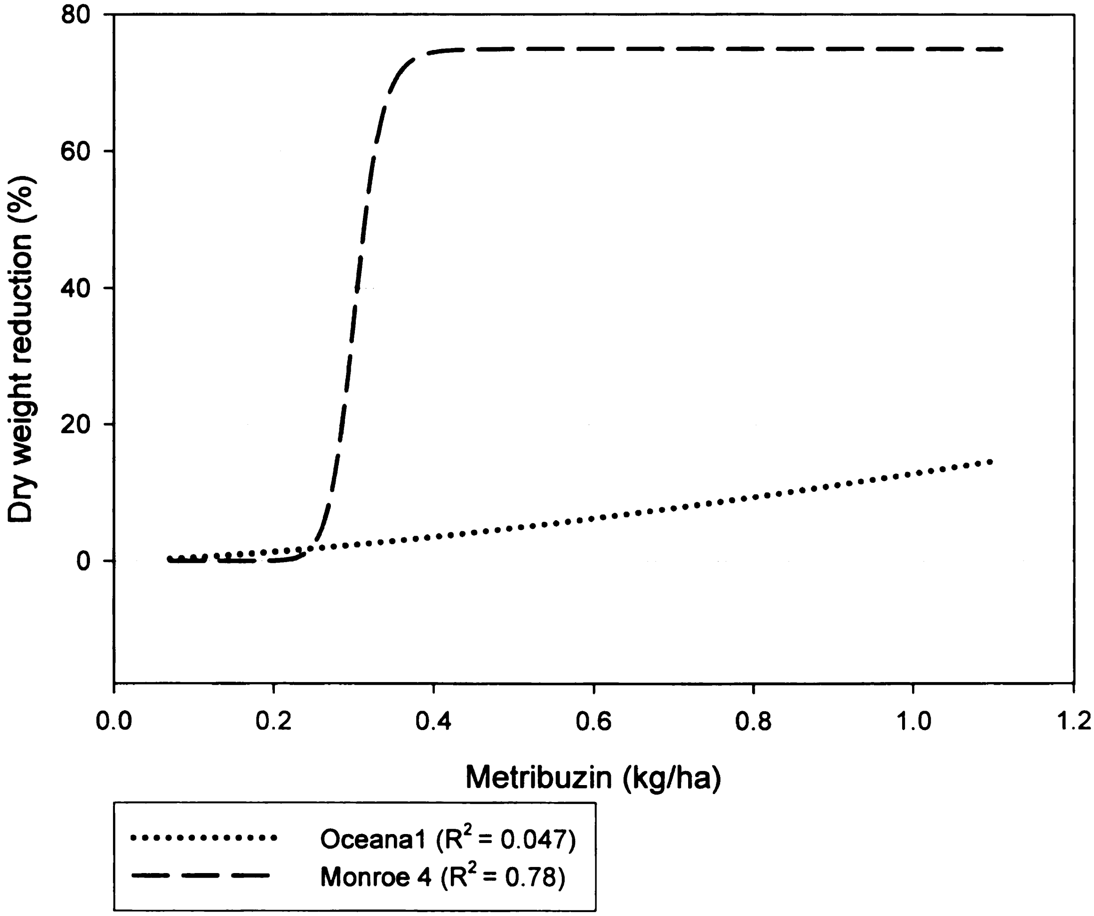

Figure 1c. Log logistic dose response curves of the most susceptible - Monroe4 and tolerant - Oceana1 eastern black nightshade populations in response to metribuzin.

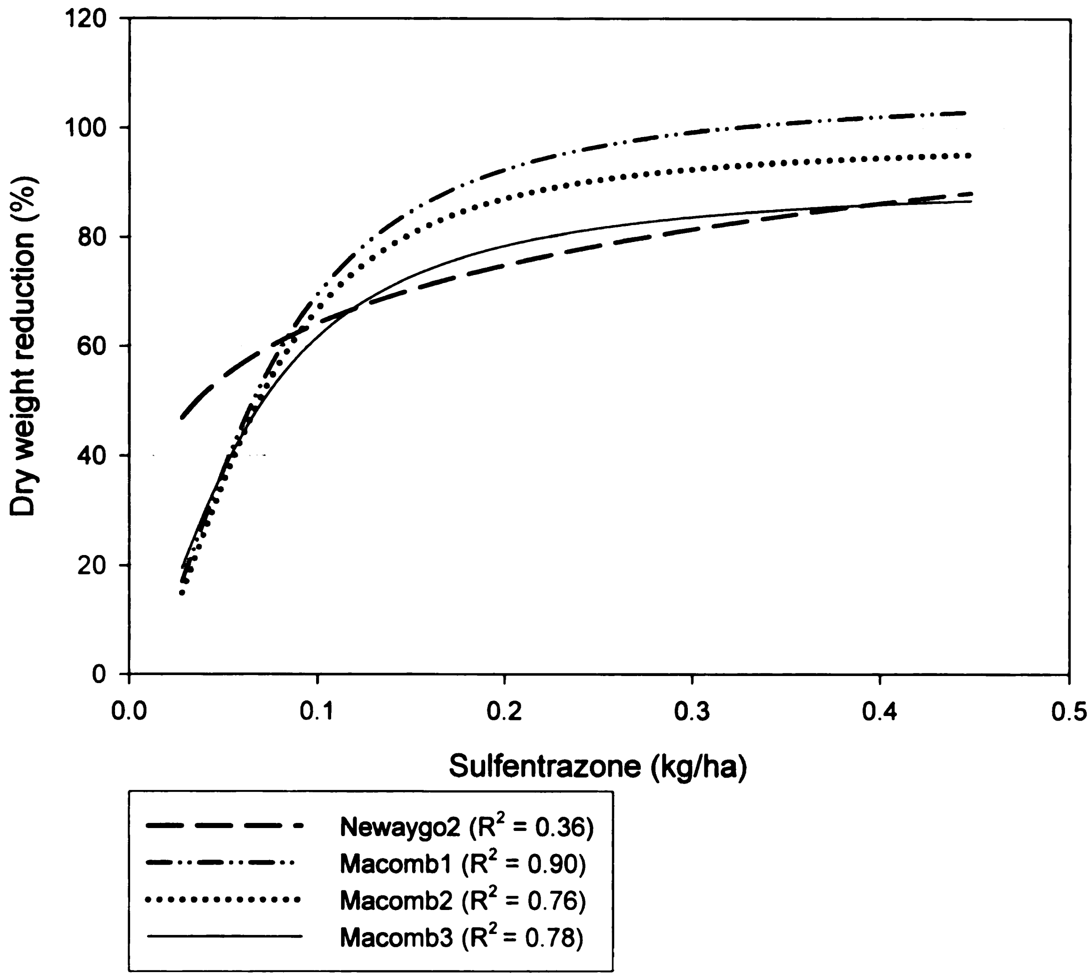

Figure 2a. Log logistic dose response curves of eastern black nightshade populations - Newago2, Macomb3, Macomb1, and Macomb2 in response to sulfentrazone.

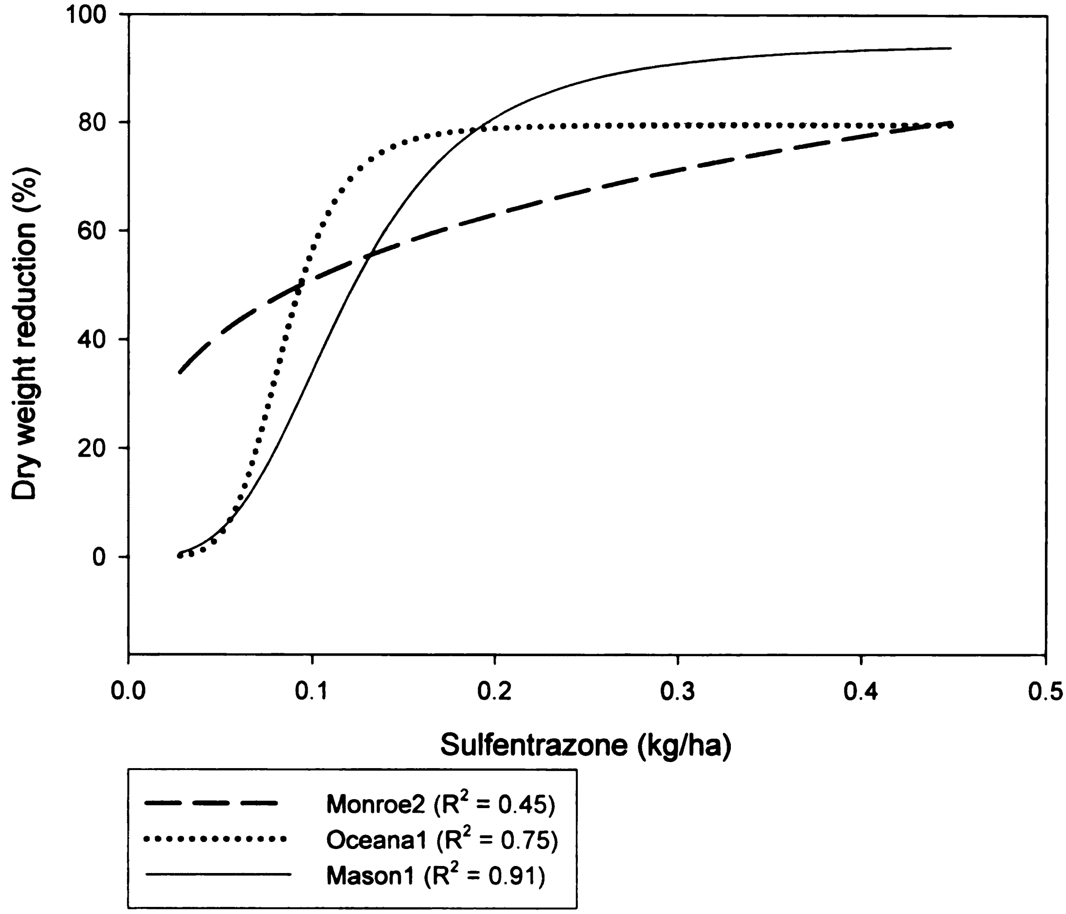

Figure 2b. Log logistic dose response curves of eastern black nightshade populations - Oceana1, Monroe2 and Mason1 in response to sulfentrazone.

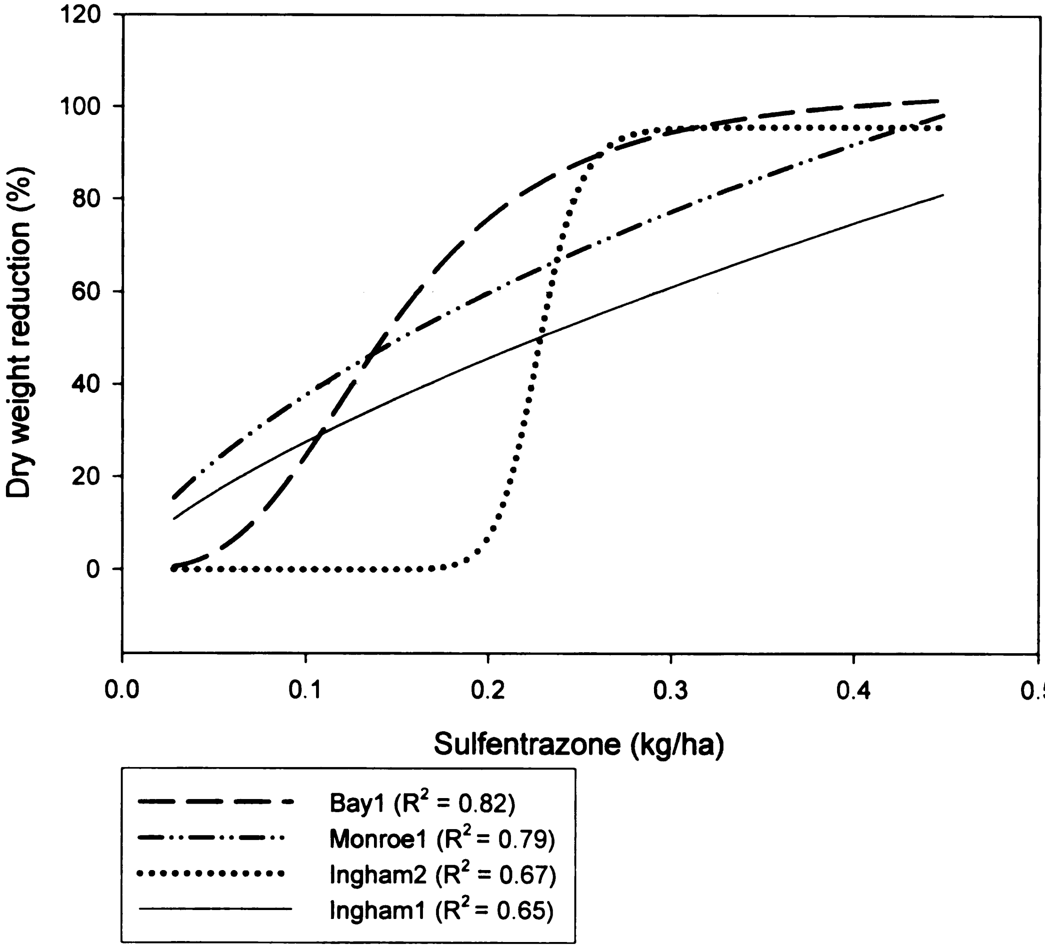

Figure 2c. Log logistic dose response curves of eastern black nightshade populations - Bay1, Monroe1, Ingham2, and Ingham1 in response to sulfentrazone.

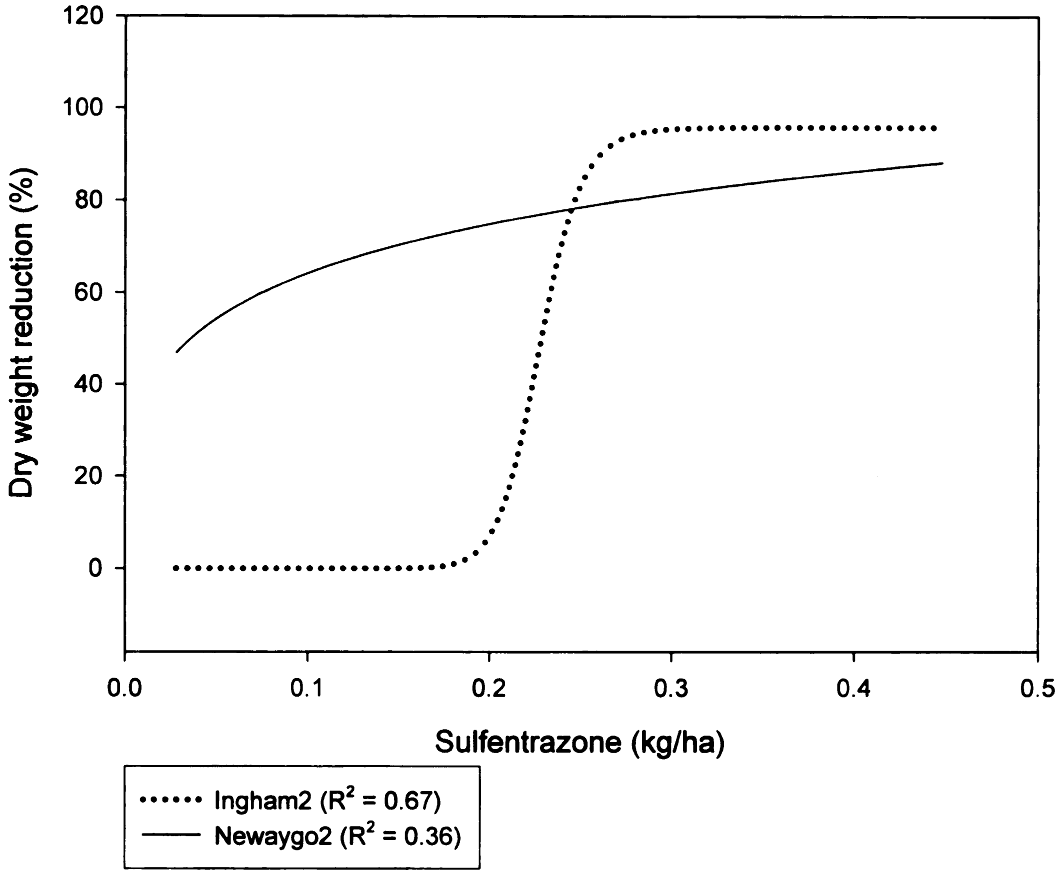

Figure 2d. Log logistic dose response curves of the most susceptible Newago2 and tolerant Ingham2 eastern black nightshade populations in response to sulfentrazone.

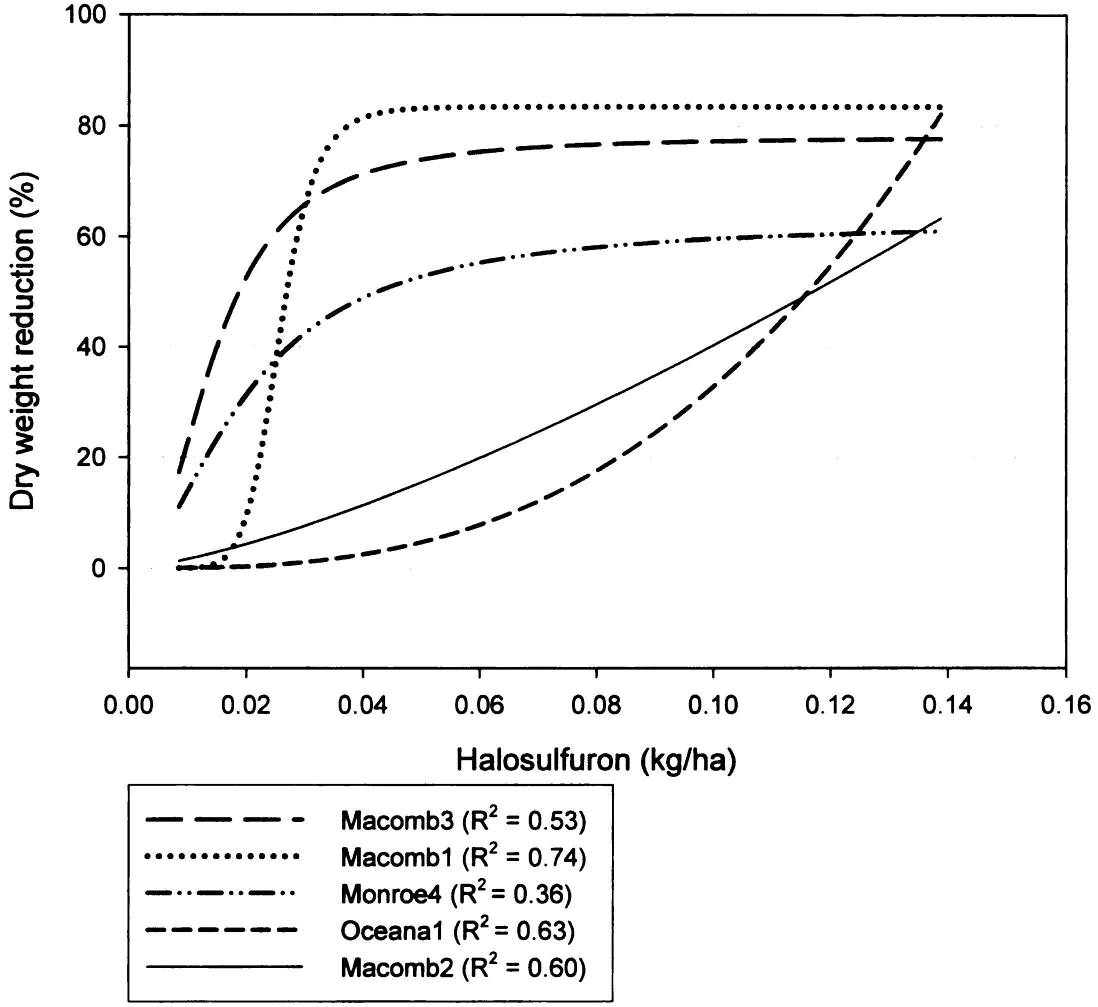

Figure 3a. Log logistic dose response curves of eastern black nightshade populations - Macomb3, Macomb1, Macomb2, Oceana1, and Monroe2 in response to halosulfuron.

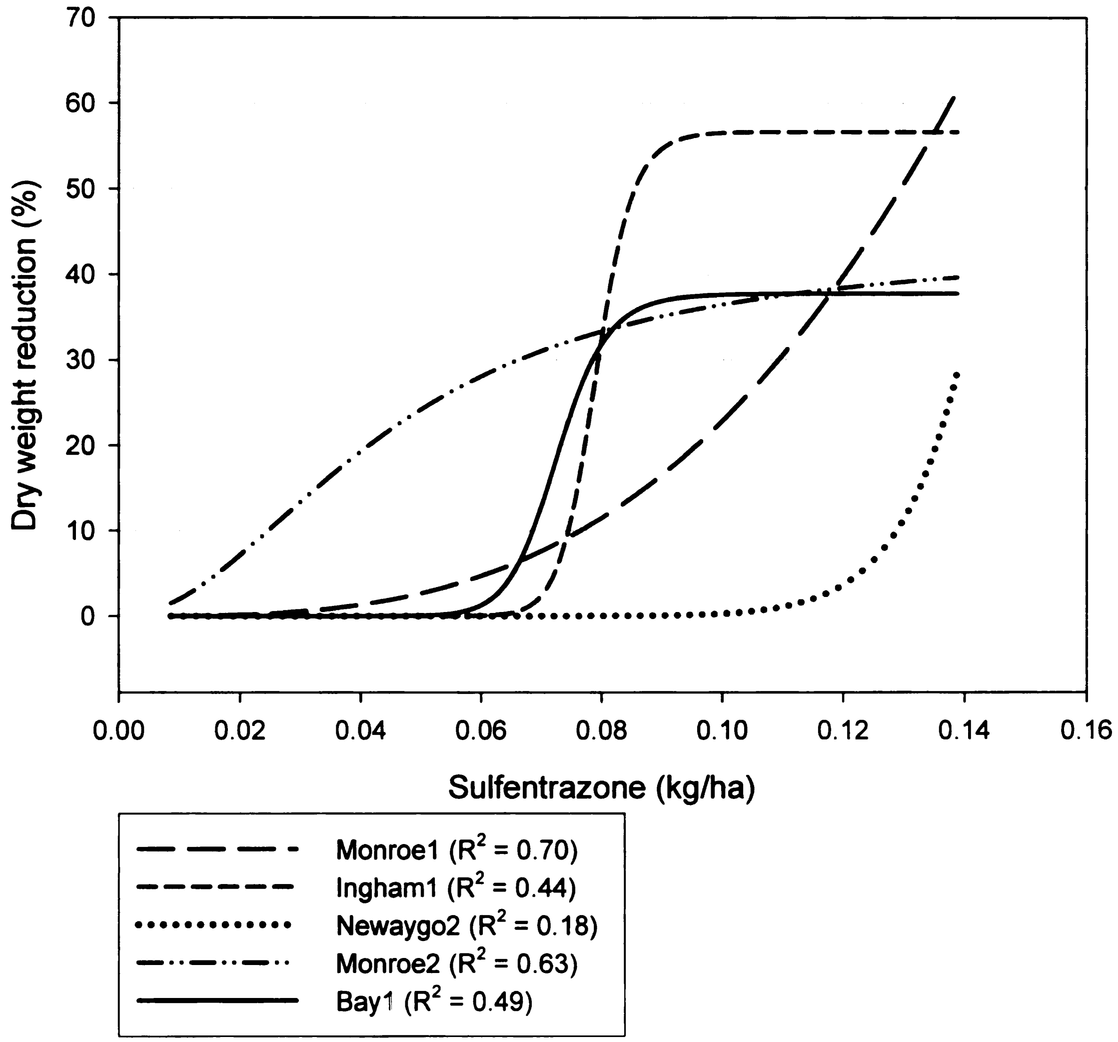

Figure 3b. Log logistic dose response curves of eastern black nightshade populations – Monroe1, Ingham1, Newago2, Monroe2, and Bay1 in response to halosulfuron.

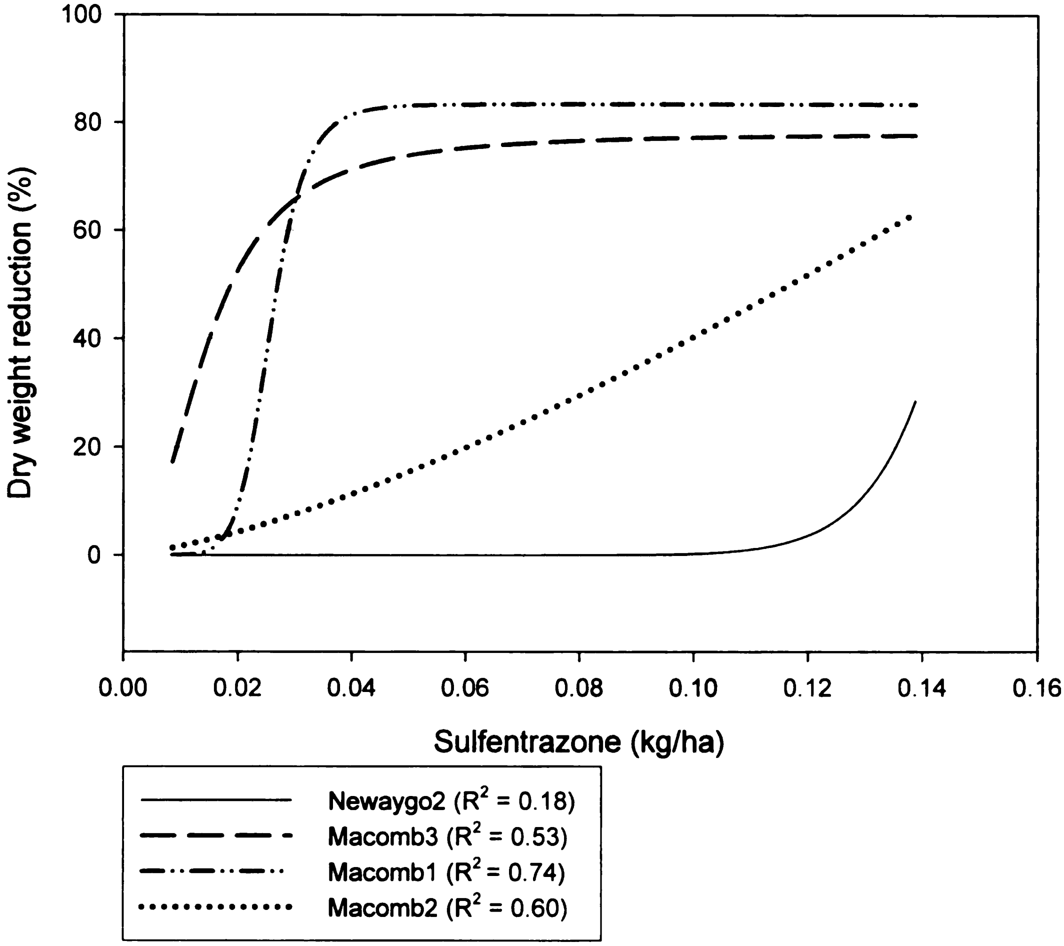

Figure 3c. Log logistic dose response curves of the most susceptible Macomb3, Macomb1 and tolerant Newago2, Macomb2 eastern black nightshade populations in response to halosulfuron.

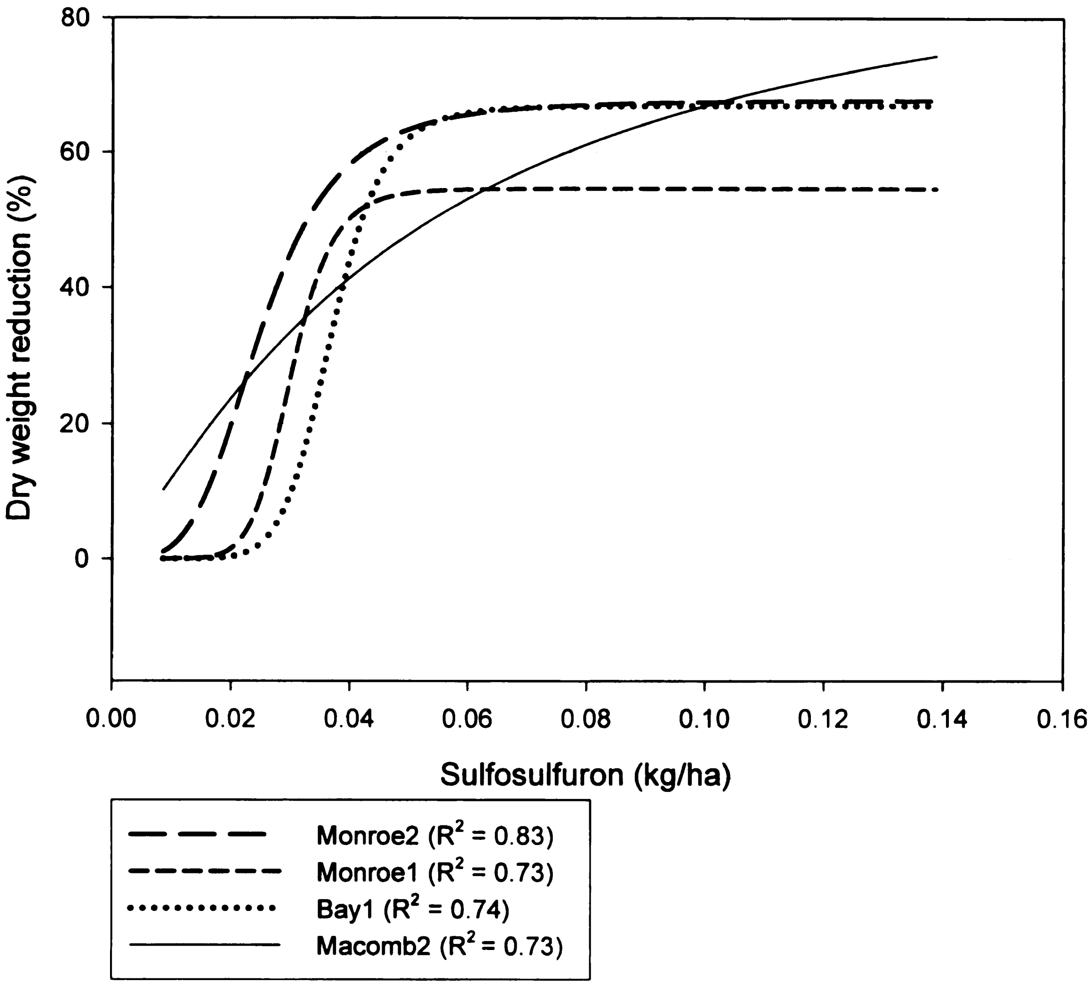

Figure 4a. Log logistic dose response curves of eastern black nightshade populations - Monroe2, Monroe1, Bay1 and Macomb2 in response to sulfosulfuron.

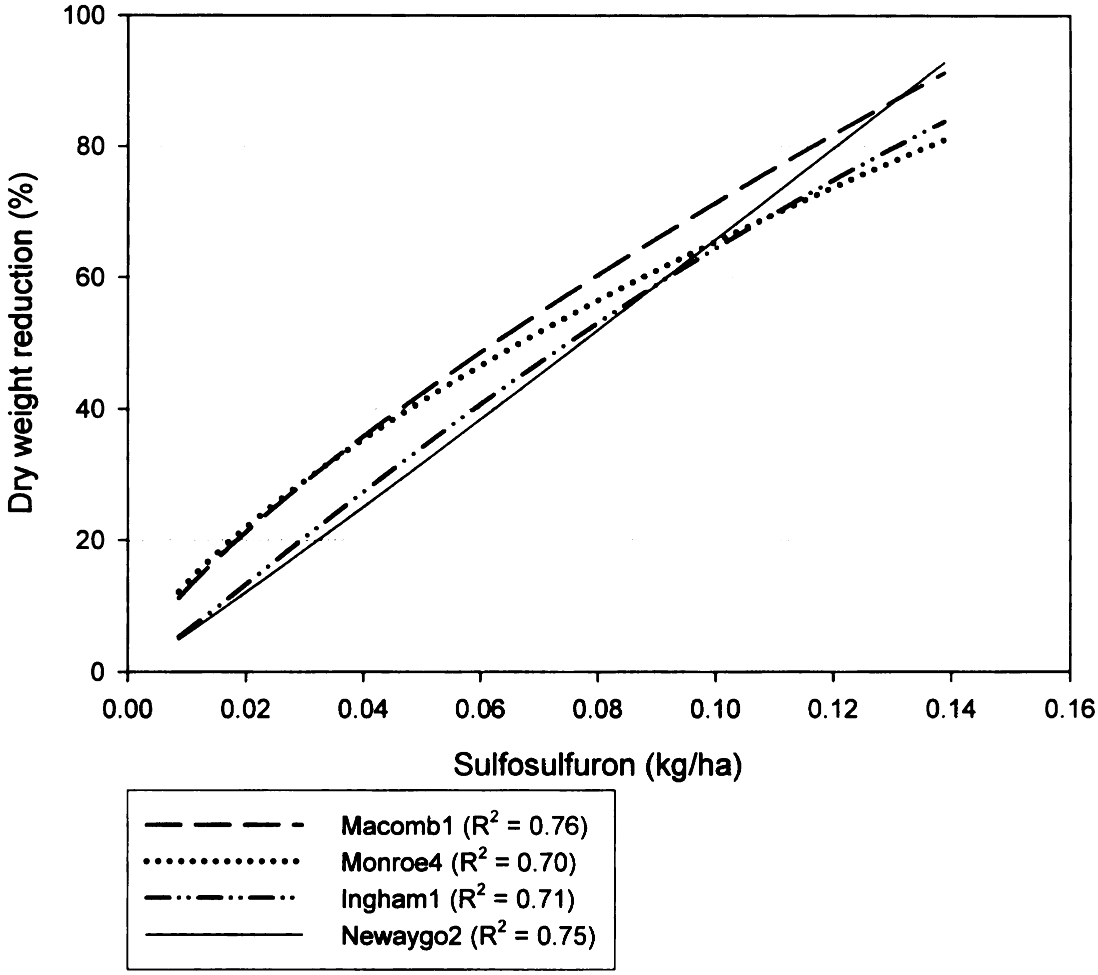

Figure 4b. Log logistic dose response curves of eastern black nightshade populations – Macomb1, Monroe4, Ingham1 and Newago2 in response to sulfosulfuron.

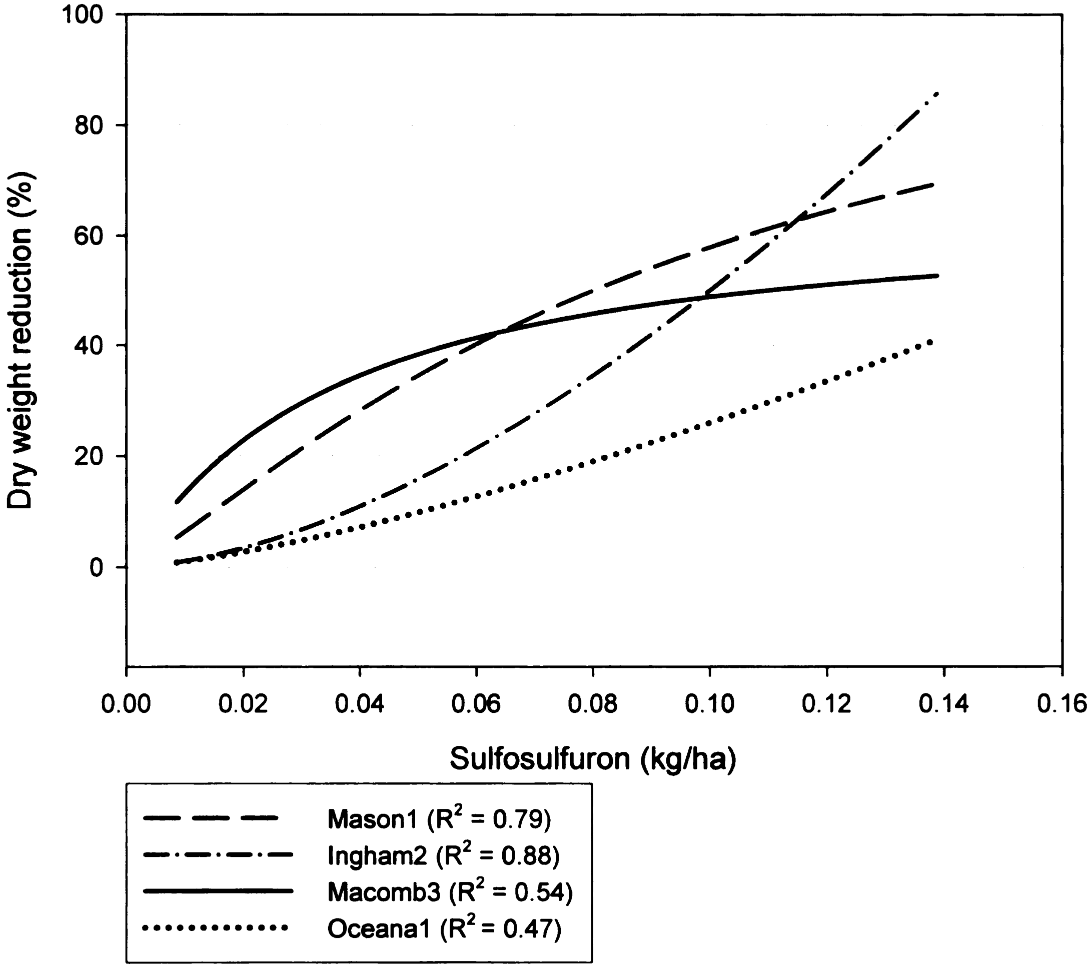

Figure 4c. Log logistic dose response curves of eastern black nightshade populations - Mason1, Ingham2, Macomb3, and Oceana1 in response to sulfosulfuron.

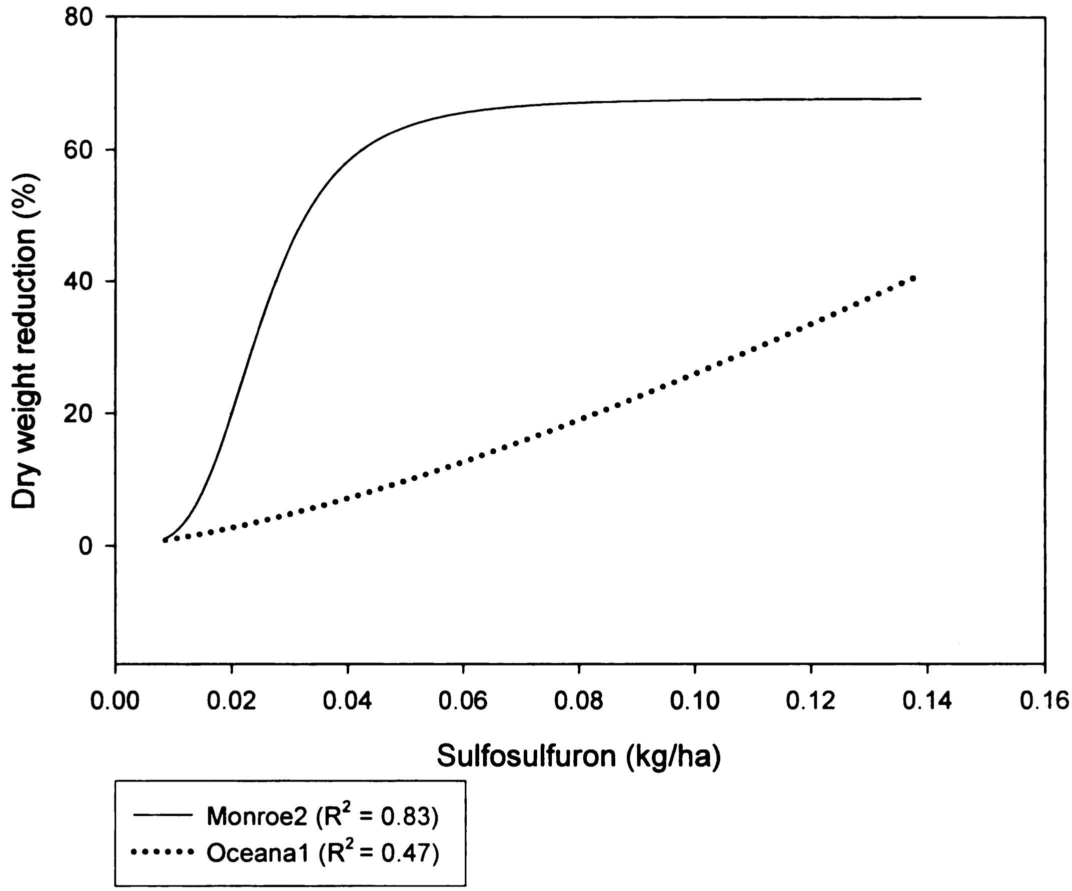

Figure 4d. Log logistic dose response curves of the most susceptible Monroe2 and tolerant Oceana1 eastern black nightshade populations in response to sulfosulfuron.

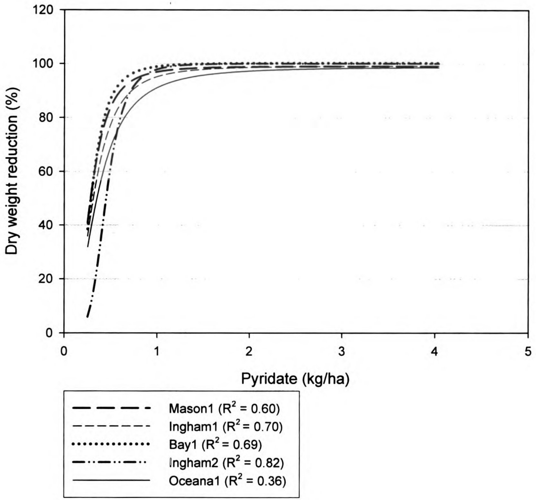

Figure 5a. Log logistic dose response curves of eastern black nightshade populations - Mason1, Ingham2, Ingham1, Bay1 and Oceana1 in response to pyridate.

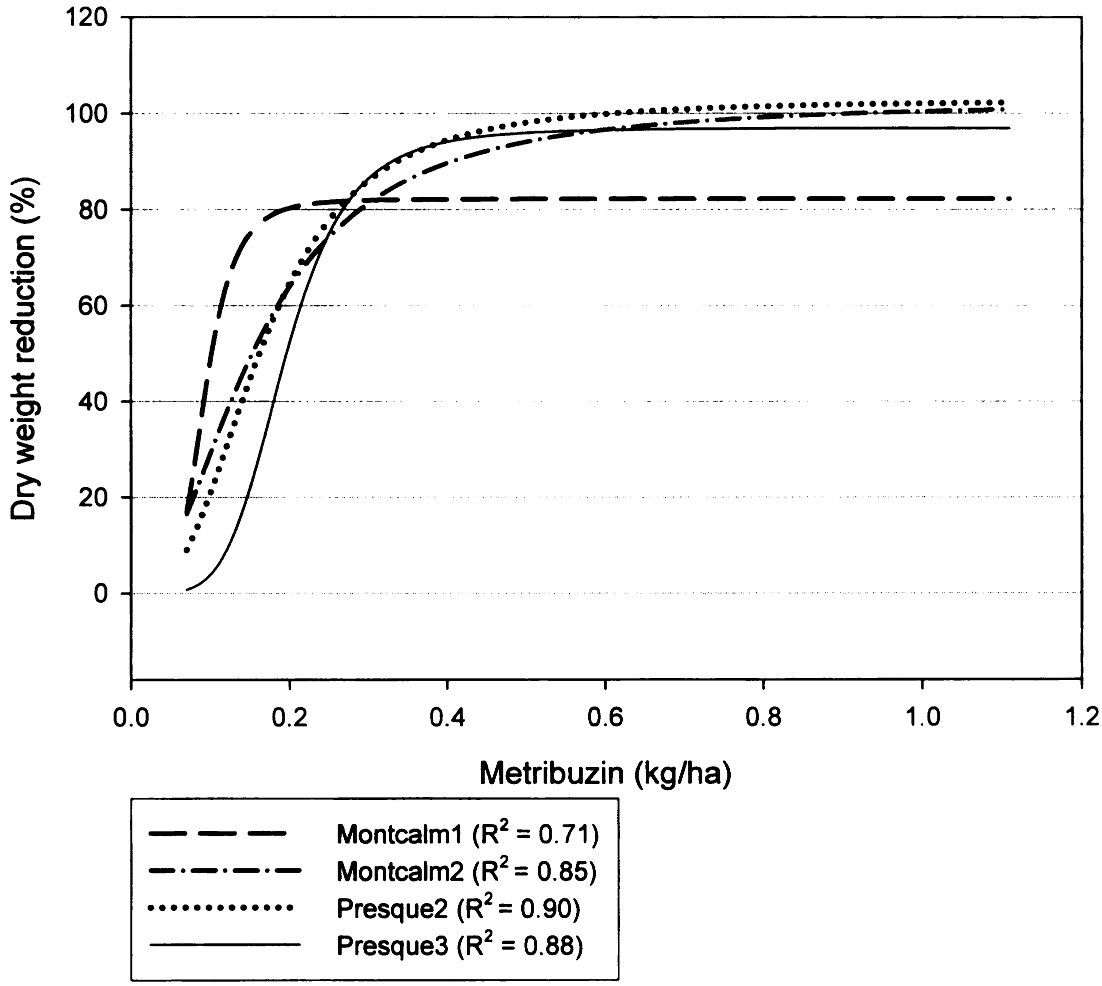

Figure 5b. Log logistic dose response curves of hairy nightshade populations - Montcalm1, Montcalm2, Presque2, and Presque3 in response to metribuzin.

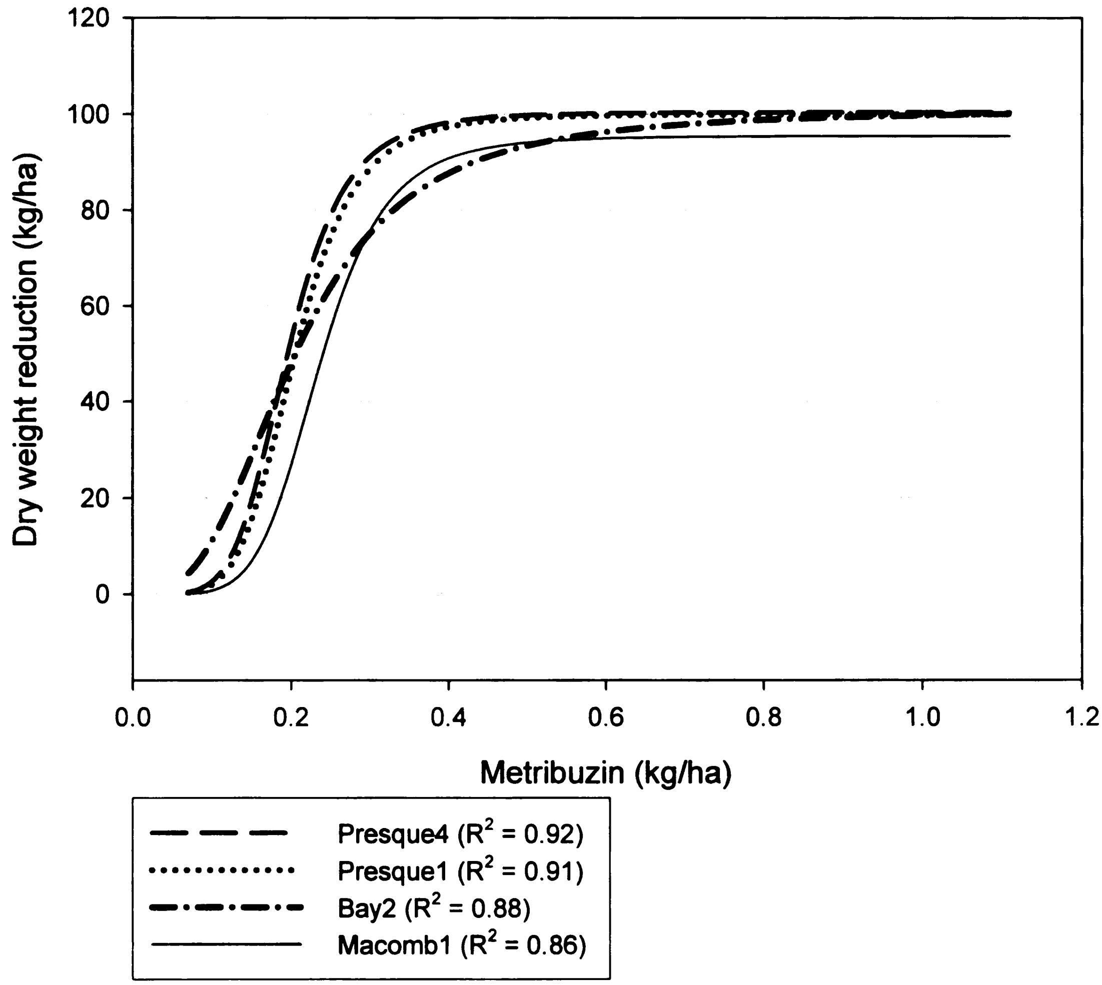

Figure5c. Log logistic dose response curves of hairy nightshade populations - Presque4, Presque1, Macomb1, and Bay2 in response to metribuzin.

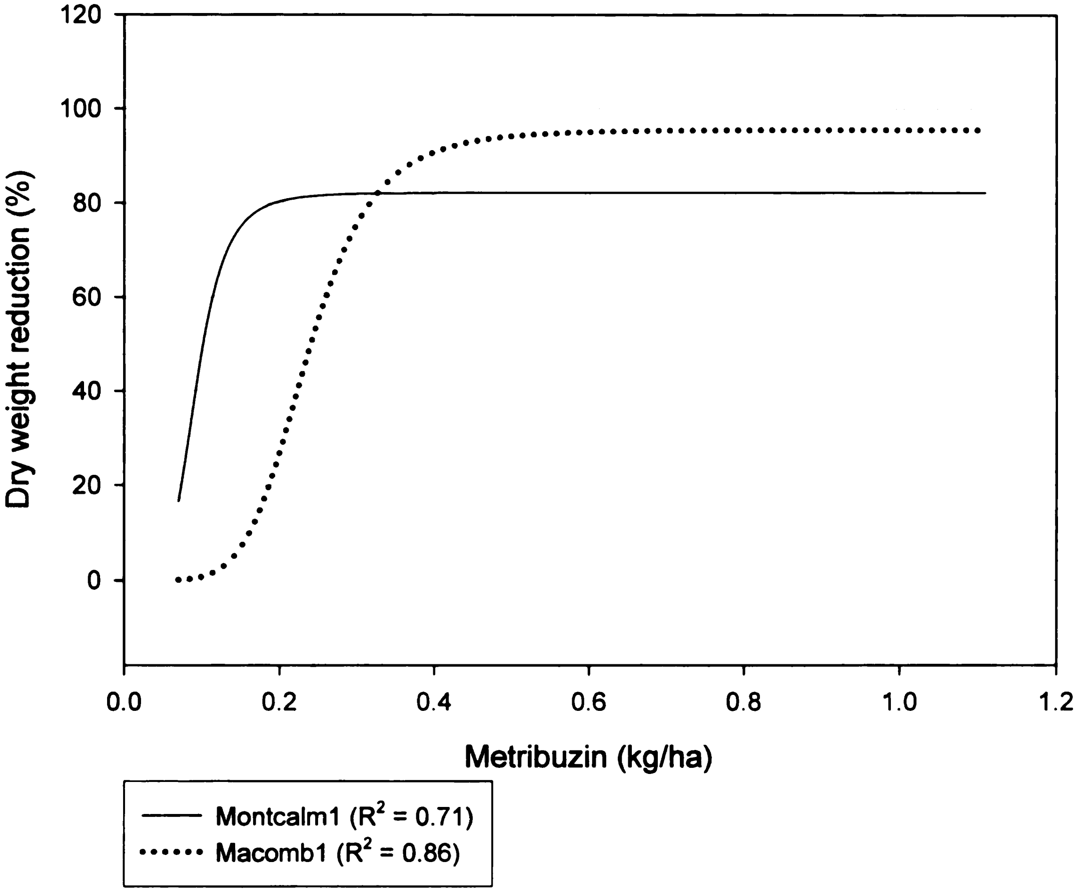

Figure 5d. Log logistic dose response curves of the most susceptible Montcalm1and tolerant Macomb1 hairy nightshade populations in response to metribuzin.

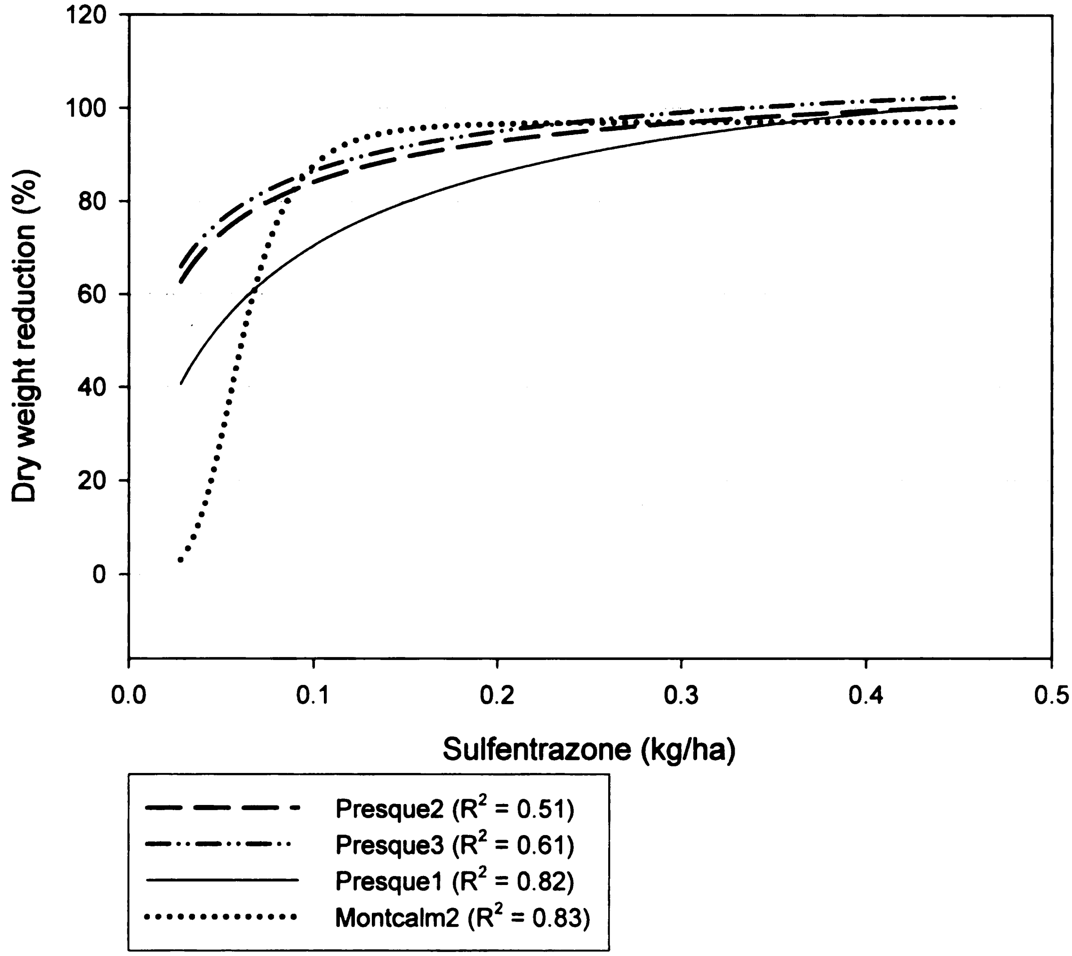

Figure 6a. Log logistic dose response curves of hairy nightshade populations - Presque2, Presque3, Presque1 and Montcalm2 in response to sulfentrazone.

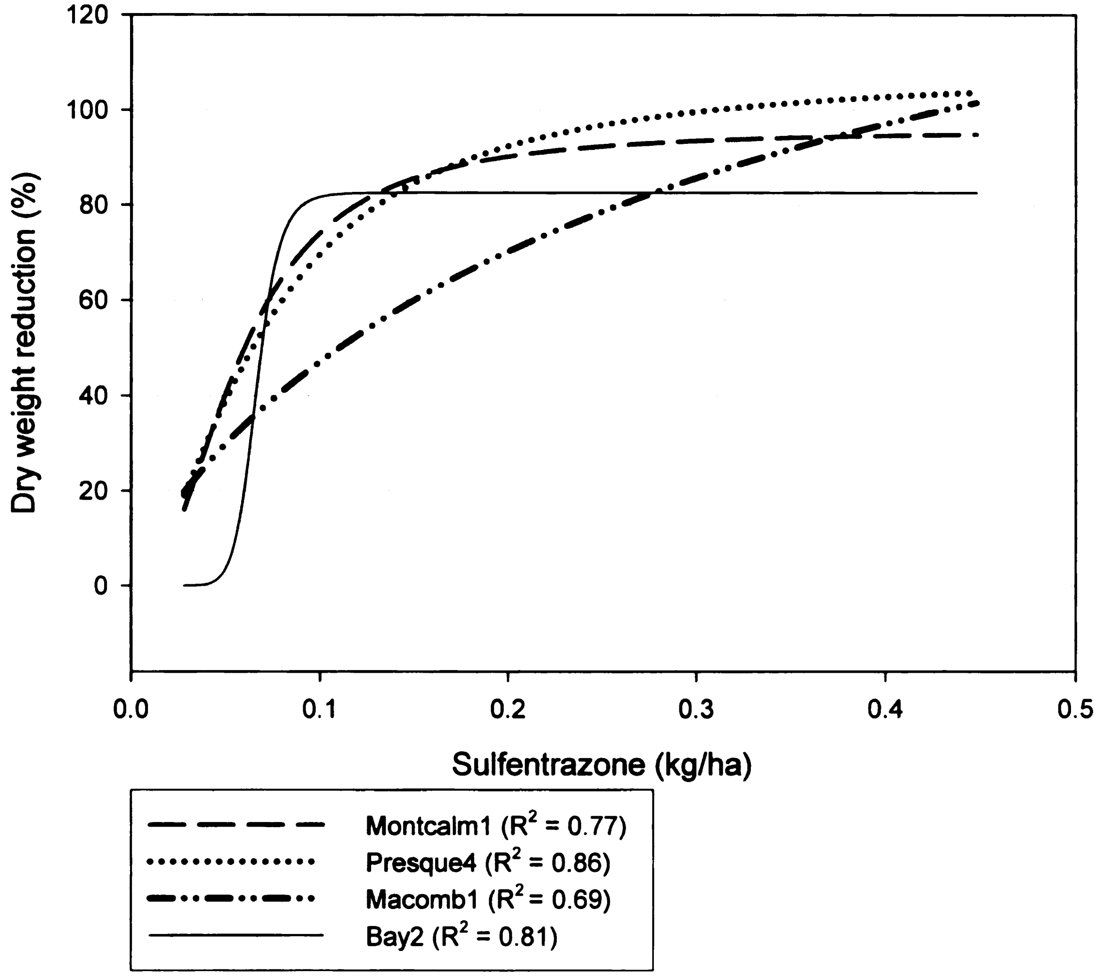

Figure 6b. Log logistic dose response curves of hairy nightshade populations - Presque4, Montcalm1, Macomb1, and Bay2 in response to sulfentrazone.

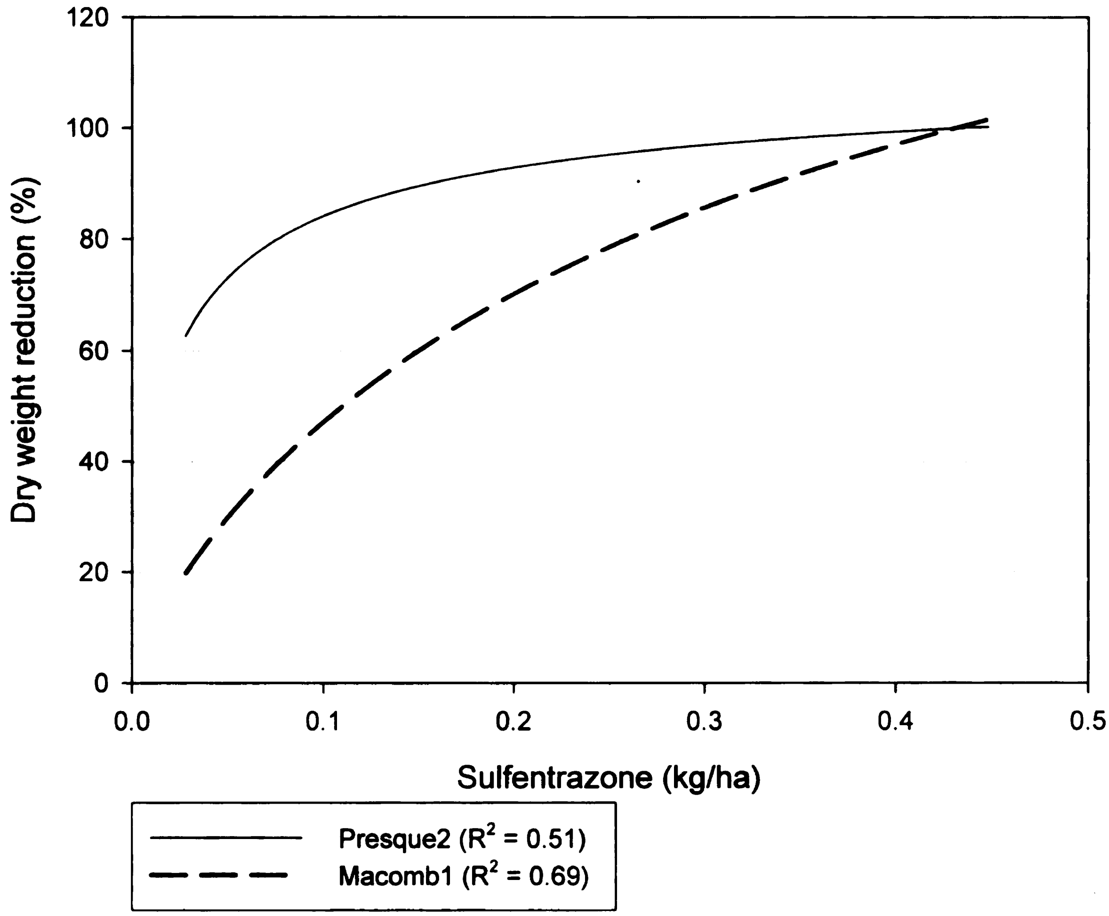

Figure 6c. Log logistic dose response curves of the most susceptible Presque2 and tolerant Macomb1 hairy nightshade populations in response to sulfentrazone.

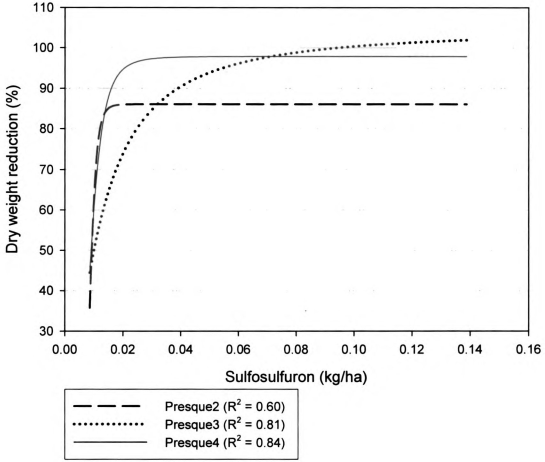

Figure 7a. Log logistic dose response curves of hairy nightshade populations - Presque2, Presque3, and Presque4 in response to sulfosulfuron.

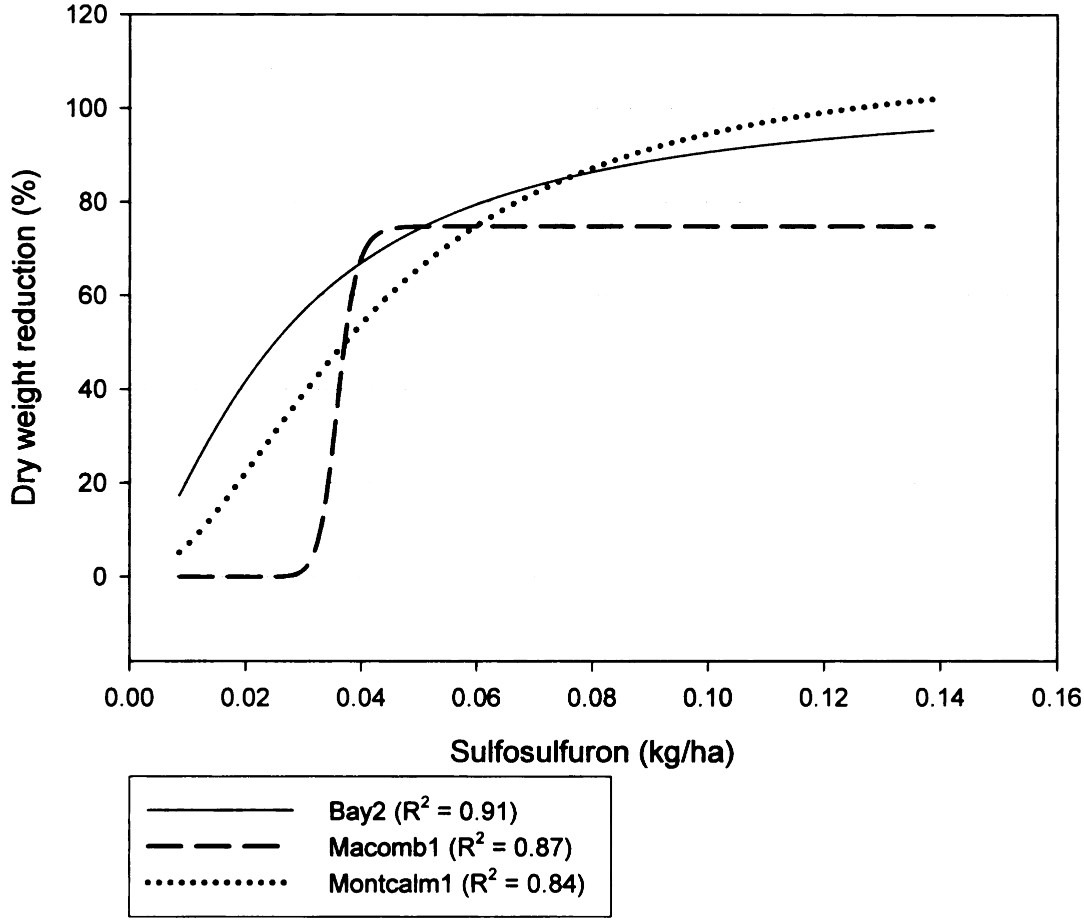

Figure 7b. Log logistic dose response curves of hairy nightshade populations - Macomb1, Montcalm1, and Bay2 in response to sulfosulfuron.

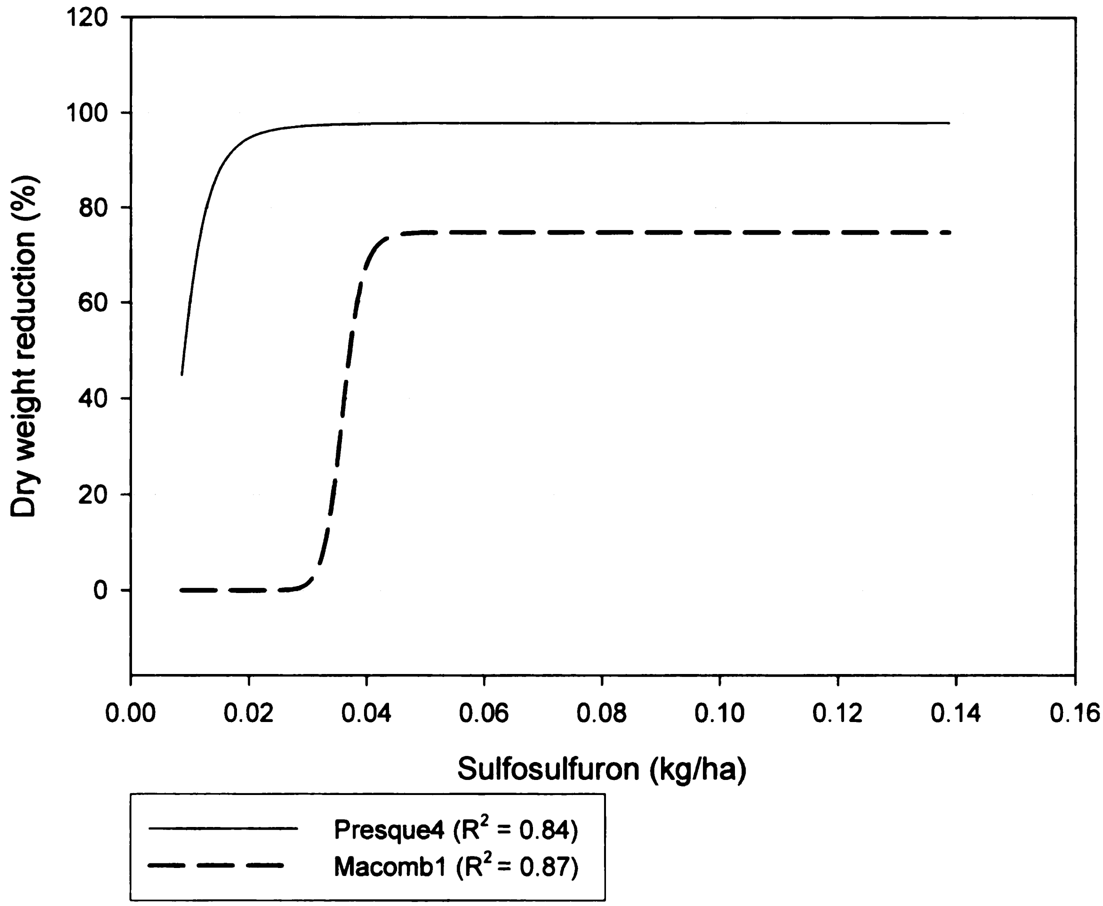

Figure 7c. Log logistic dose response curves of the most susceptible Presque4 and tolerant Macomb1 hairy nightshade populations in response to sulfosulfuron.

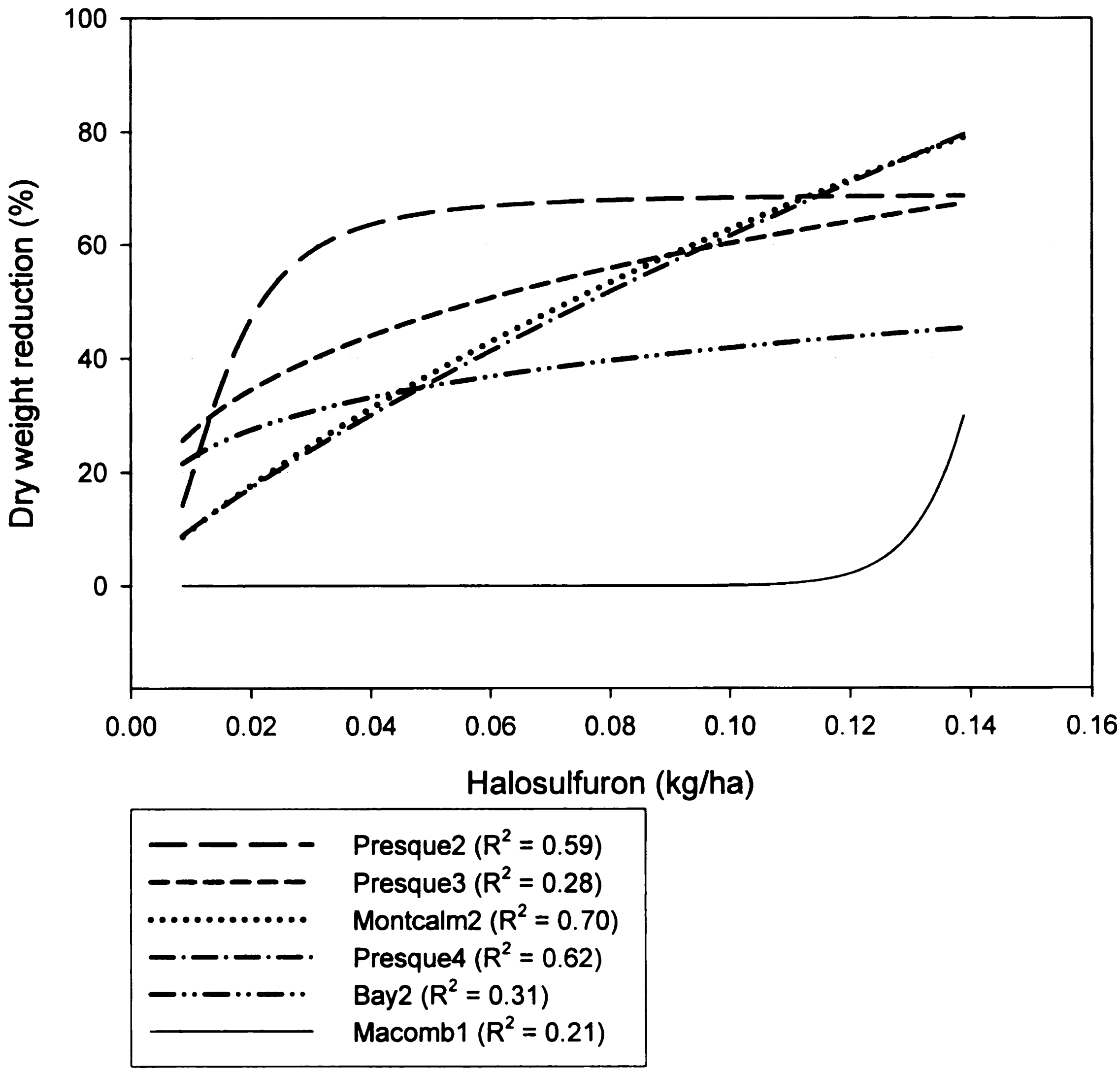

Figure 8a. Log logistic dose response curves of hairy nightshade populations - Presque2, Presque3, Montcalm2, Presque4, Bay2, and Macomb1 in response to halosulfuron.

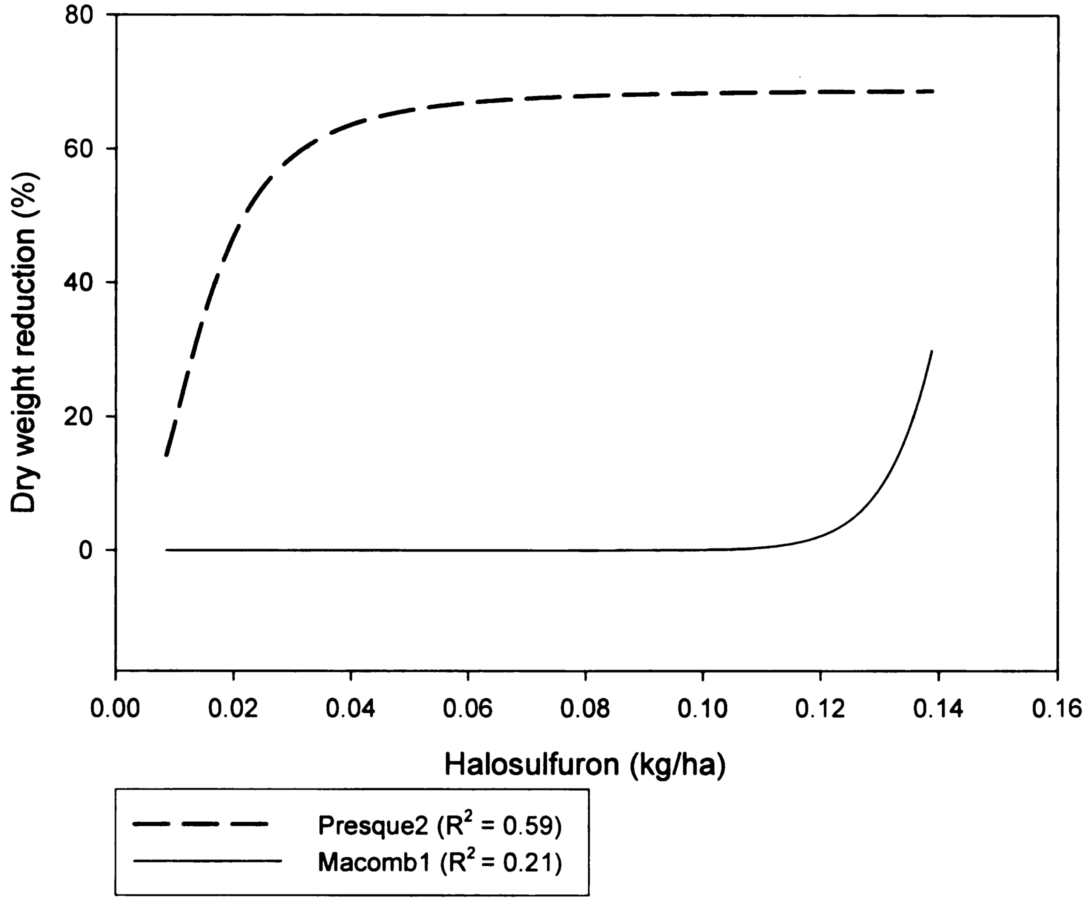

Figure 8b. Log logistic dose response curves of the most susceptible Presque2 and tolerant Macomb1 hairy nightshade populations in response to halosulfuron.

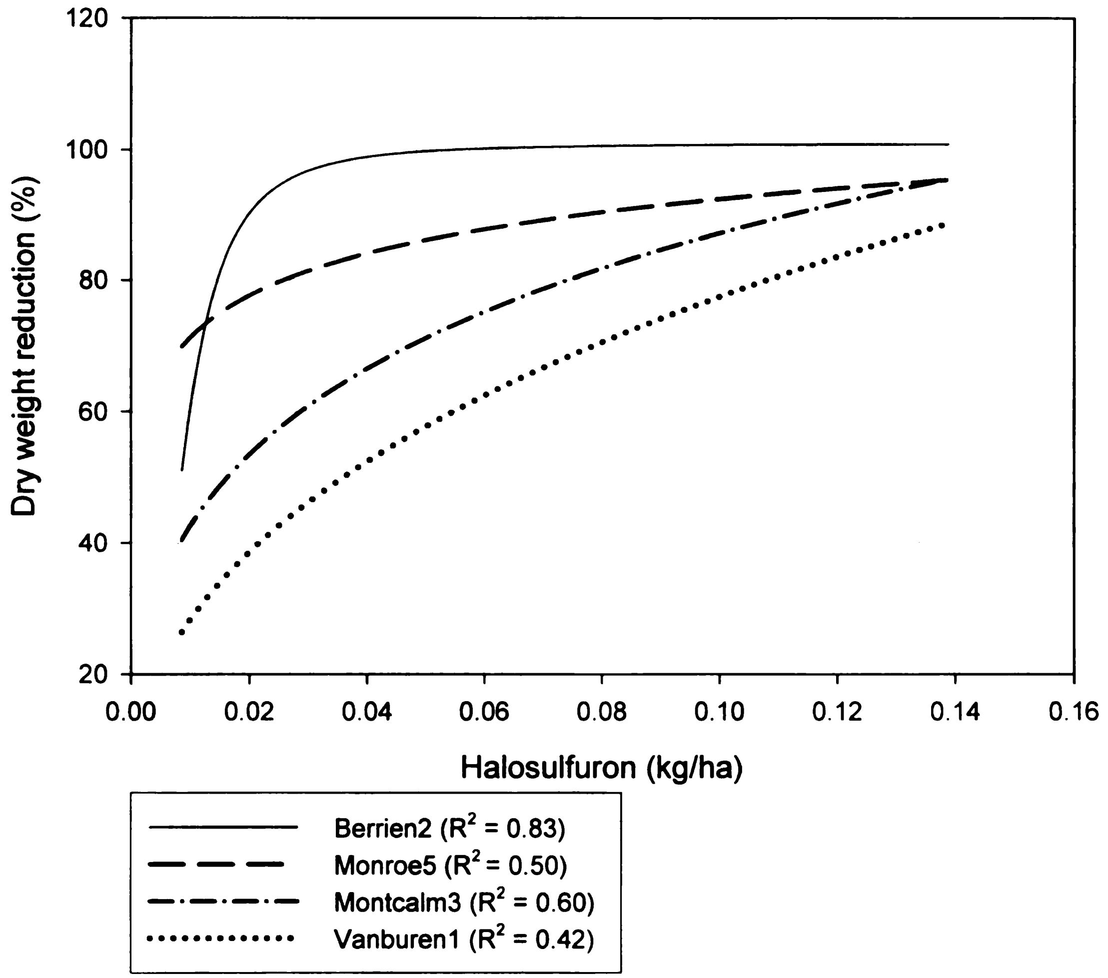

Figure 9. Log logistic dose response curves of horsenettle populations - Berrien2, Vanburen1, Montcalm3, and Monroe5 in response to halosulfuron.

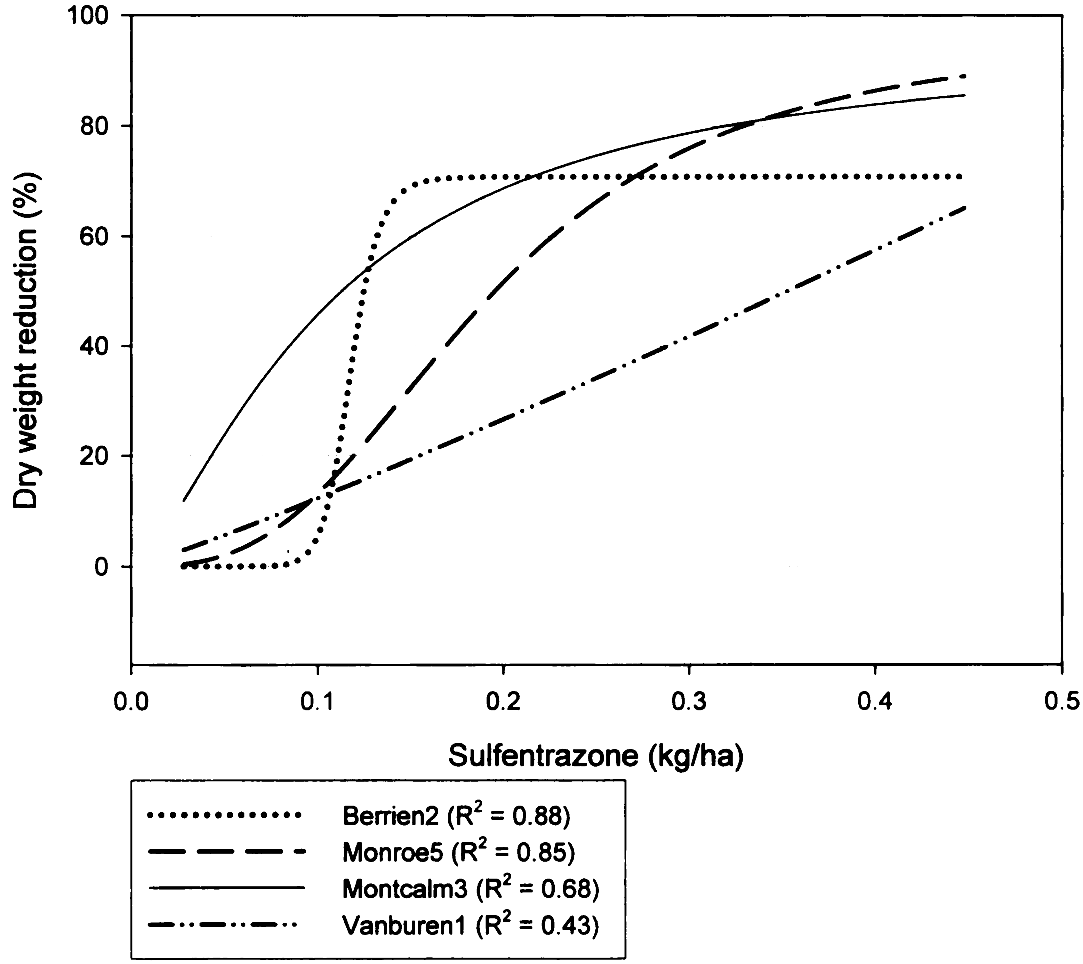

Figure 10. Log logistic dose response curves of horsenettle populations - Berrien2, Vanburen1, Montcalm3, and Monroe5 in response to sulfentrazone.

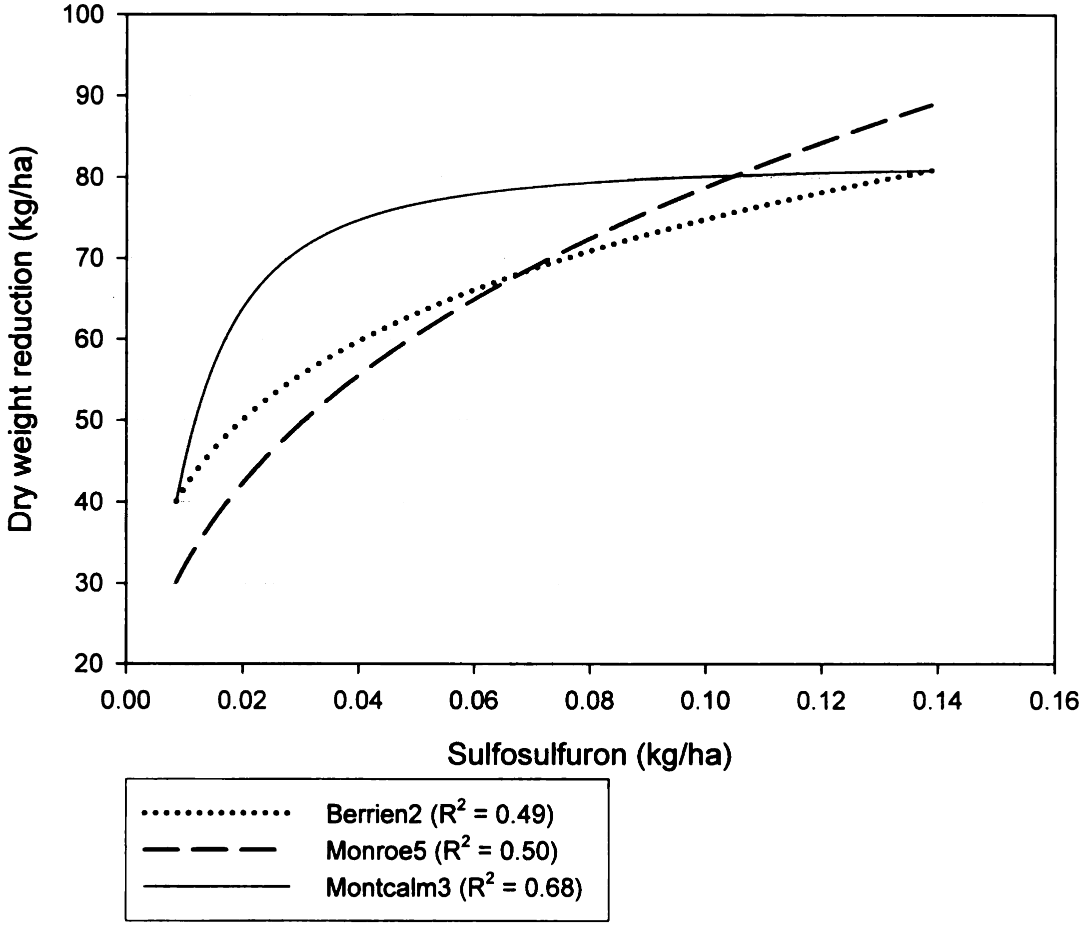

Figure 11. Log logistic dose response curves of horsenettle populations - Berrien2, Montcalm3, and Monroe5 in response to sulfosulfuron.

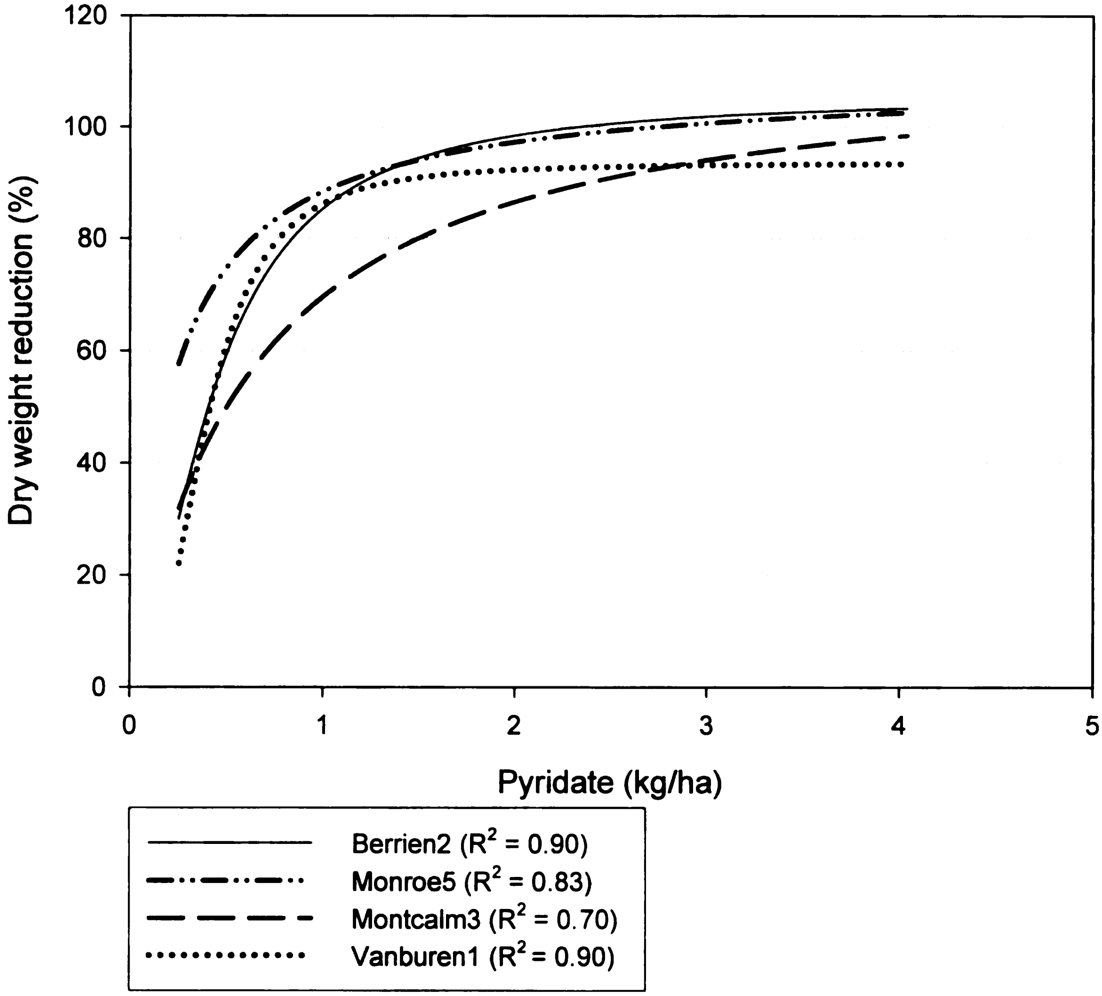

Figure 12. Log logistic dose response curves of horsenettle populations - Berrien2, Vanburen1, Montcalm3, and Monroe5 in response to pyridate.

CHAPTER 4

EFFECT OF TEMPERATURE ON GERMINATION OF EASTERN BLACK NIGHTSHADE, HAIRY NIGHTSHADE, HORSENETTLE, SMOOTH GROUNDCHERRY AND CLAMMY GROUNDCHERRY

Abstract. Populations of eastern black nightshade (Ingham1, Oceana1), horsenettle (Oceana4, Vanburen1), hairy nightshade (Bay1, Presque2), smooth groundcherry (Ingham3) and clammy groundcherry (Newago1) were subjected to four different day/night temperature regimes (28/20 °C, 24/16 °C, 22/14 °C, 15/10 °C) in the growth chamber for 15 days with 14 hr day and 10 hr night at constant light intensity to analyze the effect of temperature on germination of nightshade and groundcherry species. Temperature regime had a significant effect on germination of eastern black nightshade, horsenettle, smooth groundcherry, and clammy groundcherry. Under these conditions hairy nightshade populations did not germinate under any temperature regime. Eastern black nightshade populations germinated at least 70% at 28/20 °C. Horsenettle populations germinated at least 30% at 28/20 °C. Smooth groundcherry and clammy groundcherry had germination of 29% and 8% respectively at 28/20 °C. Within eastern black nightshade populations, Oceana1 germinated at a wider range of temperatures than the Ingham1 population.

Key words: Eastern black nightshade (*Solanum ptycanthum*), hairy nightshade (*Solanum sarrachoides*), horsenettle (*Solanum carolinense*), smooth groundcherry (*Physalis subglabrata*), clammy groundcherry (*Physalis heterophylla*), temperature.

INTRODUCTION

Nightshades are annual and short lived perennials that are common weeds in many parts of the world. In the U.S. there are 11 recognized species (Schilling, 1981) with 4 species in the *Solanum nigrum* complex recognized as troublesome weeds in Solanaceous crops such as tomato, potato and pepper (Heiser, 1979). These species are eastern black nightshade (*Solanum ptycanthum*), black nightshade (*Solanum nigrum*), American black nightshade (*Solanum americanum*), and hairy nightshade (*Solanum sarrachoides*) (Ogg et al., 1981). In the U.S., eastern black nightshade is found primarily east of the Rocky Mountains (Bassett et al., 1984), hairy nightshade is distributed throughout the U.S., and black nightshade and American black nightshade are found primarily in the Western (Ogg et al., 1981) and southern U.S. In addition to these annual nightshades, perennial nightshades such as horsenettle (*Solanum carolinense*) occur throughout the eastern U.S. Groundcherries such as clammy groundcherry (*Physalis heterophylla*) and smooth groundcherry (*Physalis subglabrata*) also are found throughout the eastern U.S.

In the north eastern U.S., Solanaceous vegetable crop production (tomato, pepper, eggplant, potato) is an important enterprise for many farmers. However yield loss due to weeds has always been a challenge to farmers and weed scientists. Bridges (1992) estimated about a 6.4 million dollar yield loss per year in fresh market tomato due to weeds in Michigan. Eastern black nightshade, hairy nightshade, and horsenettle are major competitive weeds in tomato production. Groundcherries such as smooth groundcherry and clammy groundcherry, usually are not major competitive weeds compared to other nightshade species.

The shift in the distribution and abundance of nightshade species (in particular eastern black nightshade) in the north eastern U.S. poses a continuing challenge to those concerned with weed control, as well as to those seeking to understand the causes of these shifts. Evolutionary changes have played a key part in the changing distribution pattern of nightshade species (Hermanutz and Weaver, 1990). Germination requirements of nightshade species is an important factor in species dominance and adaptation to dynamic environments.

Knowledge of germination patterns of different nightshade and groundcherry species is important in planning effective weed control programs. There is a typical period (or periods) of high emergence that is characteristic for each weed species (Brenchley and Warington, 1930; Chepil, 1946; Roberts, 1964; Roberts and Feast, 1970; Stoller and Wax., 1973). The time of weed seedling emergence can, in part, explain which species will be the most serious weeds within a given crop management system. Stoller and Wax (1973) concluded that weeds that complete most of their emergence early are likely to be killed during soil preparation before planting corn or soybean and are not seriously troublesome weeds after corn planting.

There are many germination studies determining the period of emergence of eastern black nightshade in U.S. Ogg and Dawson (1984) reported that eastern black nightshade seedlings began emerging in Washington in late March, with most emerging in April. Quakenbush and Andersen (1984) reported that eastern black nightshade germination began in mid April and early May in Minnesota. Studies by Ogg and Dawson (1984) reported that hairy nightshade germinated in Washington in late March to early April of each year and continued to emerge throughout the growing season. In

Warwick (U.K.), hairy nightshade germination ranged from April to June and induced dormancy occurred during August (Roberts and Boddrell, 1983). In general, soil temperatures optimum for germination of eastern black nightshade, hairy nightshade and smooth groundcherry are between 25-30°C (Vandeventer et al., 1982; Roberts and Boddrell., 1983; Thomson and Witt, 1987). But there was no information reported on the optimum temperature for germination of clammy groundcherry and horsenettle.

Because of the prevalence and importance of nightshade and groundcherry species in Michigan and the need for biological information to establish effective management systems, studies were conducted to obtain information on the influence of temperature on germination of eastern black nightshade, hairy nightshade, horsenettle, smooth groundcherry and clammy groundcherry.

MATERIALS AND METHODS:

Growth chamber experiments were conducted twice during April 2003 to determine the influence of temperature on the germination of nightshade and groundcherry species. Two populations from each nightshade species and one population from each groundcherry species were tested in this study. The nightshade populations were selected on the basis of unique morphological features observed during collection of nightshade berries in Michigan from different counties. The list of the population, location and associated crop are presented in Table 2.

Processing of seeds:

The nightshade and groundcherry berries were taken to the laboratory at Michigan State University and were crushed and soaked in water overnight to allow the fruit juices to ferment. The seeds were then placed in cheese cloth and squeezed to remove as much juice as possible. Then the seeds in the cheese cloth were washed repeatedly and air dried for a week at normal room temperature (24 ^{o}C). The seeds of all the nightshade and groundcherry populations were stored for two months at -20^{o}C and then stored in an incubator at 28^{o} C to overcome dormancy.

Viability test:

A viability test was conducted a week before the first germination study. Twenty five seeds of each population were subjected to a tetrazolium (0.1%) test to determine the viability of the seeds. The cotyledons of the seeds were cut into two halves (without injuring the embryo) to expose the seeds to tetrazolium solution. The seeds were soaked in 0.1% tetrazolium chloride solution in a Petri dish for about 3 hours. Seeds with embryos that turned pink in color were considered to be viable and seeds with embryos that did not change color were considered to be non-viable. The viability test results are presented in Table 2.

Design of the experiment:

The experiment was designed as a randomized complete block with 4 replications per treatment. Each replicate contained 50 seeds in one Petri dish. The base of the Petri dish was covered with Whatmann No.50 filter paper to hold the moisture in the Petri dish and to provide a base to anchor the seeds. Approximately 5ml of distilled water was added to the Petridish every day as needed to moisten the seeds. The seeds were covered by a thin, soft and porous white tissue paper to protect the seeds from the splashing effect of water.

Treatments:

Four different day/night temperature regimes, 28/20° C, 24/16 ° C, 22/14 ° C and 15/10 ° C were set up in different growth chambers[1] with a 14 h day and 10 h night. The temperature and duration of day/night was selected in accordance with Michigan climatic conditions during the summer. Light intensity of 35 $uE/m^2/sec$ and quality of 0.7 Red/Far red ratios were maintained in all the growth chambers. The humidity in the growth chamber was maintained at 80%.

Germination count:

The germination experiments were maintained for 15 days. The germination counts were taken every 3 days. Seeds that had both a radicle and plumule were considered germinated. The germinated seeds were removed from the Petri dishes after counting and were discarded.

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[1]Conviron E15, Controlled environments Ltd., Winnipeg, Manitoba, Canada.

Statistical anlaysis:

The data were subjected to analysis of variance (ANOVA) and germination means of the nightshade and groundcherry species at the specific temperature regime were separated by using Fisher's protected LSD at $\alpha = 0.05$ by using SAS program (SAS, 1990).

RESULTS AND DISCUSSION:

Germination response of eastern black nightshade populations:

Significant variation in germination percent was observed among eastern black nightshade populations across temperature regimes except at 28/20 °C (Table 1). Ingham1 and Oceana1 populations had mean germination percent of 80 and 74 at 28/20 °C. However a steep decline in germination percent to 23, 7, and 0 % was observed in Ingham1 population at 24/16 °C, 22/14 °C, 15/10 °C respectively.

On the other hand, Oceana1 population had a mean germination percent of 74, 60, 24 at 24/20 °C, 22/14 °C, and 15/10 °C respectively. Clearly, Oceana1 population has a potential of germination at wider range of temperature than Ingham1 population and can have a significant effect on weediness during the growing season. Having the potential to germinate early in the summer season at a temperature of 15/10 °C, Oceana1 eastern black nightshade has the potential to increase vegetative growth due to lack of competition from the crop and other weeds, during the early growing season. And hence Oceana1 eastern black nightshade can reproduce early in the growing season and can increase the seed bank in the soil within a short period.

There was considerable difference in period of emergence among eastern black nightshade populations. Early germination was observed in the Oceana1 population at 28/20 °C, 24/16 °C, 22/14 °C at day 3 and the maximum germination percent during the germination count period was observed at day 6 across all temperature regimes (Figure 1). Due to rapid germination potential, the Oceana1 population can dominate other weeds and compete strongly with the main crop for nutrients, light, space and water during the growing season.

On the other hand, germination of the Ingham1 population was observed 6 days after seeding (DAS) in the Petri dish across all temperature regimes except at 15/10 °C. Ingham1 population had maximum germination percent at 9 DAS in the Petri dish (Figure 2). Zero percent germination was observed in the Ingham1 population during the entire counting period at 15/10 °C. The Oceana1 population germinates earlier than the Ingham1 population.

Hermanutz and Weaver, (1990) observed similar result in northern populations (Harrow, Wright, Pelee, and Rondeau) of Canada possessing broader range of germination at various temperature regimes. They suggested that the colonization potential of northwardly migrating eastern black nightshade population might be due to genetic variability in germination parameters between northern and southern eastern black nightshade populations. Hence genetic variability in germination parameters between Ingham1 and Oceana1 population may be one of the reasons for differences in pattern across temperature regimes. From the results, the Oceana1 population has the colonization potential in new habitats of Michigan due to early germinating characteristic at wider range of temperature.

Germination response of horsenettle populations:

Horsenettle populations had no variation in germination across temperatures. Oceana4 and Vanburen1 populations had mean germination percentage of 37 and 33 at 28/20 °C respectively (Table 1). Very low germination is noted at other temperature regimes. Previous reports on the influence of temperature on germination of horsenettle seeds suggest that decreasing the day temperature and increasing the night temperature to about 20/30 °C and 20/35 °C for 16/8 hours increased the germination of horsenettle to 84% and 87% respectively (Buhler and Hoffman, 1999).

Both the horsenettle populations were slow to germinate and there was no significant variation in time of germination among the populations. Oceana4 and Vanburen1 populations had maximum germination percent at 15 DAS at 28/20 °C (Figure 4, 5). Based on the late and poor germination characteristic, horsenettle may be less competitive and may not be as serious a weed as the other annual Solanaceous weeds if horsenettle reproduces only through seeds.

Germination response of hairy nightshade populations:

None of the hairy nightshade populations germinated at any temperature (Table1). Induced dormancy might be the reason for zero percent germination. The following description about induced dormancy was based on Booth et al.(2003).

Induced dormancy or secondary dormancy is developed by the dispersed seed in response to the environment. Induced dormancy is usually imposed when environmental conditions are unfavorable for prolonged periods of time. Induced dormancy is also called a cyclical dormancy or seasonal dormancy, where seeds may cycle in and out of dormancy, changing from dormant to conditionally dormant (where the seeds germinate under a smaller range of conditions) to non-dormant; this cycle repeats and can result in seasonal dormancy cycles. Seasonal dormancy is induced by temperature.

Many reports suggest that induced dormancy is one of the germination characteristic of hairy nightshade. Roberts and Boddrell, (1983) reported that seasonal dormancy of hairy nightshade lasted until late April or early May. Germination virtually ceases at the end of August and develops back to induced dormancy at Warwick (U.K.). Studies by Ogg and Dawson (1984) observed the seasonal dormancy characteristic of hairy nightshade in Washington until late March or early April. The seasonal emergence pattern of hairy nightshade, can maintain a persistent seed bank in the soil. During the first year, 30-45% of hairy nightshade seed in the seed bank can germinate and the others continued to appear for at least next 4 years (Roberts and Boddrell, 1983).

Germination response of smooth groundcherry and clammy groundcherry:

Low germination percent was observed across temperature regimes for both groundcherry species (Table 1). However, smooth groundcherry had a significantly higher germination percent than clammy groundcherry at 28/20 °C (Table 1). A gradual decrease in germination across temperature regimes was observed in smooth grouncherry. Both species are slow to germinate. Smooth groundcherry had maximum germination at 15 DAS across all temperature regimes except at 15/10 °C (Figure 3). Maximum germination of 5% was observed after 12 DAS at 28/20 °C (Figure 3). Poor and slow germination of groundcherry species may cause less weediness than annual nightshade species like eastern black nightshade and hairy nightshade if groundcherry species reproduces only through seeds. In addition cultural practices followed in vegetable crop production like tillage, herbicide application affects the germinated groundcherry species produced from seeds.

The invasion success of a colonizing weed depends on the ability of its seed to germinate in new habitats (Groves, 1986). Temperature regime constitutes one of the most potent selective forces in limiting the spread of weeds in new habitats (Thompson, 1970). Based on these results, eastern black nightshade germinates earlier and at a higher germination percentage than other nightshade and groundcherry species across temperature regimes. Variability in germination characteristic of eastern black nightshade populations has tremendous impact on future range of expansion and it is more likely to be the dominant weed in the agriculture system. The seasonal emergence pattern of hairy nightshade can lead to persistent problem in the field for many years and it may become a more common weed in agriculture. A crop rotation system and proper application timing of pre emergence herbicides can be the better management system to control nightshades.

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Table1. Comparison of germination mean percent across temperature to analyze the trend in variability among eastern black nightshade (SOLPT) populations, horsenettle (SOLCA) populations, hairy nightshade (SOLSA) population, smooth groundcherry (PHYSU) and clammy groundcherry (PHYHE) species.

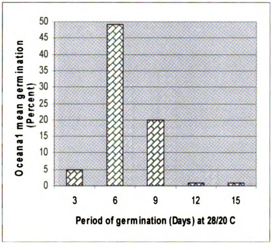
Species	Population	Germination mean (percent)			
		28/20 (°C)	24/16 (°C)	22/14 (°C)	15/10 (°C)
SOLPT	Ingham1	80a	23b	7b	0b
SOLPT	Oceana1	74a	74a	60a	24a
SOLCA	Oceana4	37b	2d	0b	0b
SOLCA	Vanburen1	33b	1d	4b	0b
SOLSA	Bay1	0c	0d	0b	0b
SOLSA	Presque2	0c	0d	0b	0b
PHYHE	Newago1	8c	1d	0b	0b
PHYSU	Ingham3	29b	10c	3b	0b
Standard deviation		29.22	24.68	20.11	7.96
LSD		10.16	7.21	6.85	5.77

Means followed by the same letter in the same column are not statistically significant at $\alpha = 0.5$

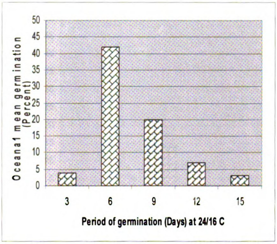
Table2. List of eastern black nightshade, hairy nightshade, horsenettle, clammy groundcherry and smooth groundcherry populations collected from various regions in Michigan; including location, associated crop and percent seed viability.

Species	Populations	Regions collected from Michigan	Current crop	Viability
Eastern black nightshade	Ingham1	T3N, R1W, Sec:12, Holt twp	Tomato	92%
	Oceana1	T15N, R17W, Sec:32, Hart twp	Asparagus	88%
Hairy nightshade	Bay1	T15N, R3E, Sec:22, Garfield twp	Potato	92%
	Presque Isle 2	T34N, R6E, Sec:30, S.Pulawski twp	Dry bean	88%
Horsenettle	Vanburen1	T3S, R16W, Sec:1, Hartford twp	Tomato	84%
	Oceana4	T16N, R17W, Sec:2, Weare twp	A*	92%
Clammy groundcherry	Newaygo1	T12N, R14W, Sec:36, Sheridan twp	Tomato	88%
Smooth groundcherry	Ingham3	T2N, R2W, Sec:14, Aurelius twp	Onion	84%

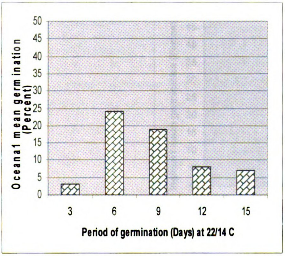
A*- Population is collected from uncultivated site.



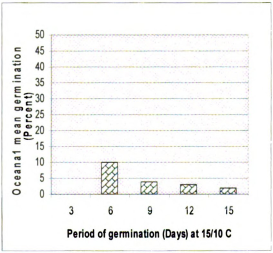
(A)



(B)

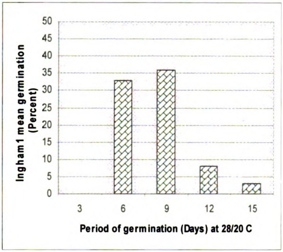


(C)

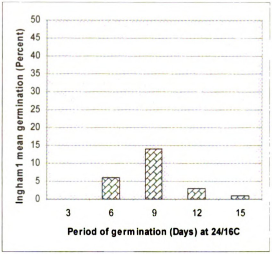


(D)

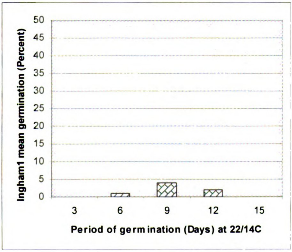
Figure 1.Temperature effect on the period of germination of Oceana1 eastern black nightshade population at A) 28/20° C, B) 25/16° C, C) 22/14° C and D) 15/10° C



(A)



(B)



(C)

Figure 2. Temperature effect on the period of germination of Ingham1 eastern black nightshade population at A) 28/20 °C, B) 25/16 °C and C) 22/14 °C

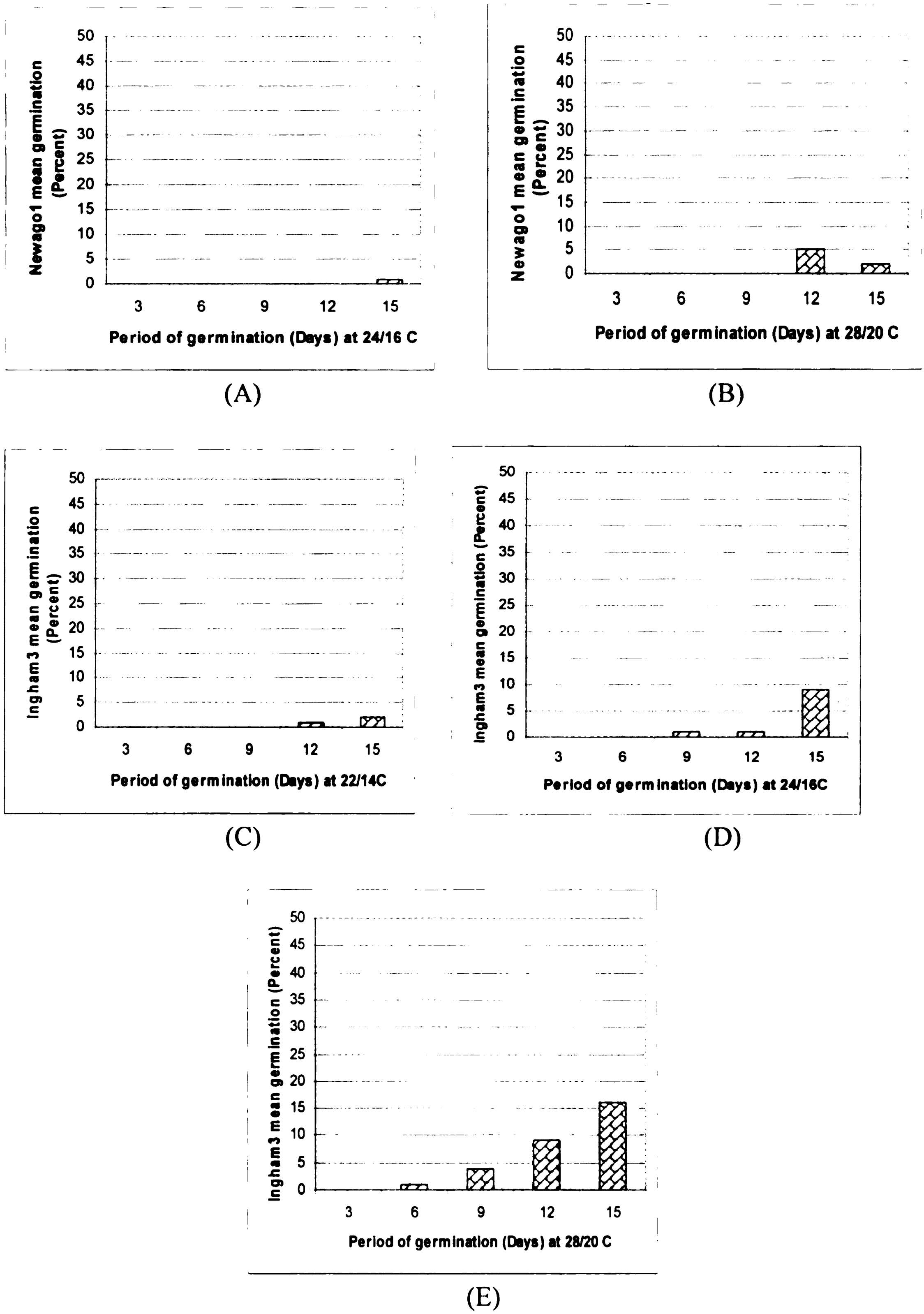


Figure 3. Temperature effect on the period of germination of clammy groundcherry population Newago1 at A) 24/16 °C, B) 28/20 °C and smooth groundcherry population Ingham3 at C) 22/14 °C, D) 24/16 °C, E) 28/20 °C.

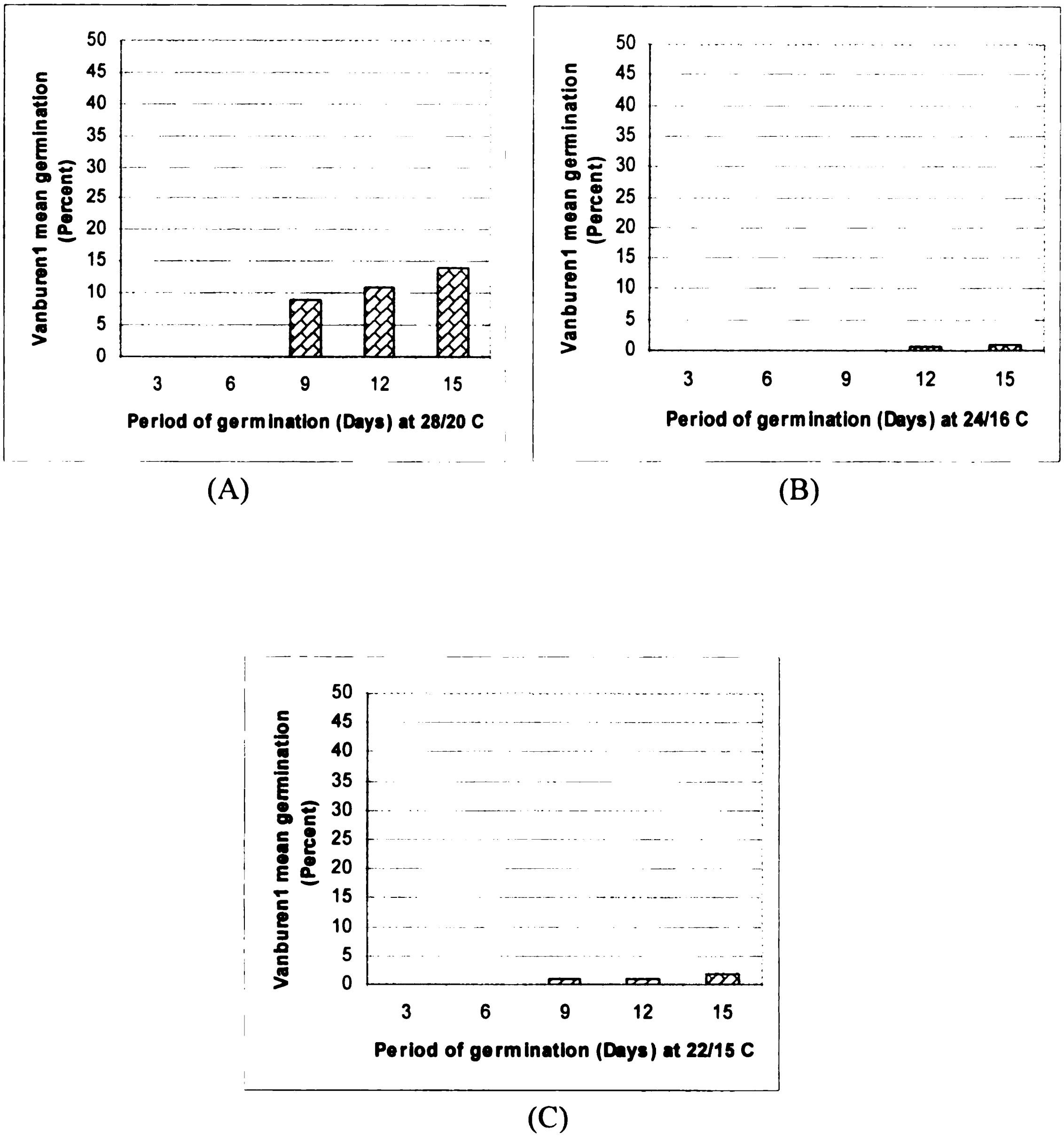


Figure 4. Temperature effect on the period of germination of Vanburen1 horsenettle population at A) 28/20 °C, B) 25/16 °C, and C) 22/14 °C

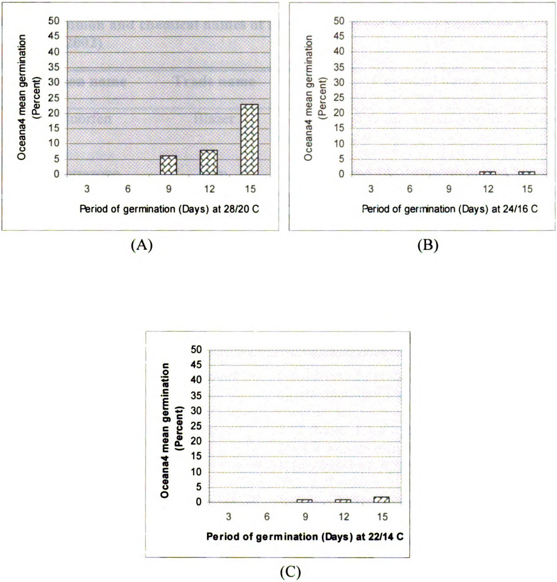


Figure 5. Temperature effect on the period of germination of Oceana4 horsenettle population at A) 28/20 °C, B) 25/16 °C, and C) 22/14 °C

APPENDICES

List of common and chemical names of herbicides (Weed Science Society of America, 2002)

Common name	Trade name	Chemical name
Acifluorfen	Blazer	5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid
Carfentrazone	Aim	X,2-dichloro-5-[4-(difluromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]-4-fluorobenzenepropanic acid
DCPA	Dacthal	Dimethyl 2,3,5,6-tetrachloro-1,4-benzenedicarboxylate), and chloramben (3-amino-2,5-dichlorobenzoic acid
Dimethenamid- P	Outlook	2-chloro-*N*(2,4-dimethyl-3-thienyl)-N-(2-methoxy-1-methylethyl)acetamide
Diquat	Reglone	6,7-dihydrodipyrido[1,2-a:2',1'-c]pyrazinediium ion
Flumioxazin	Valor	2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propnyl)-2H-1,4-benzoxazin-6yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione
Halosulfuron	Sandea	3-chloro-5[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-1-methyl-1*H*-pyrazole-4-carboxylic acid
Imazethapyr	Pursuit	2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid
Imazamox	Raptor	2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid
Methyl bromide	Methyl bromide, Pic Brom 25	bromomethane
Metribuzin	Sencor	4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one

Common name		Chemical name
Metolachlor-S	Dual II magnum	2-chloro-N-(2-ethyl-6-methylphenyl)-5,7-dimethoxy[1,2,4]triazolo[1,5-a]pyrimidine-2-sulfonamide
Napropramide	Devrinol	*N,N*-diethyl-2-(1-naphthalenyloxy) propanamide
Oxyflourfen	Goal	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene
Paraquat	Gramoxone	1,1'-dimethyl-4,4'-bipyridinium ion
Primisulfuron-methyl	Beacon	2-[[[[[4,6,-bis(difluoromethoxy)-1,3,5-triazine-2-yl]amino] carbonyl]amino]sulfonyl]benzoic acid
Pyridate	Tough	*O*-(6-(chloro-3-phenyl-4-pyridazinyl) *S*-octyl carbonothioate
Rimsulfuron	Matrix	*N*-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-3-(ethylsulfonyl)-2-pyridinesulfonamide
Sulfentrazone	Spartan	*N*-[2,4-dichloro-5-[4-(dichloro-5-[4-(difluromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide
Sulfosulfuron	Maverick	*N*-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-2-(ethylsulfonyl)imidazo[1,2-a]pyridine-3-sulfonamide