FIELD, GREENHOUSE, AND LABORATORY EVALUATION OF THE EFFICACY AND SELECTIVITY OF THE HERBICIDE THIFENSULFURON FOR WEED CONTROL IN SOYBEANS (*Glycine max*).

by

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(Abstract)

Thifensulfuron is a new herbicide of the sulfonylurea class under development by E. I. Dupont de Nemours Company Inc. for postemergence broadleaf weed control in soybeans [*Glycine max* (L.) Merr]. Field studies evaluated the influence of adjuvants and chlorimuron upon the efficacy of thifensulfuron. Thifensulfuron applied alone provided smooth pigweed (*Amaranthus hybridus* L. #AMACH) control at application rates 12% of those of the similar herbicide chlorimuron. Nonionic surfactant or crop oil concentrate increased soybean sensitivity to thifensulfuron, but an adjuvant was required to obtain consistent seedling common lambsquarters (*Chenopodium album* L. #CHEAL) control. Chlorimuron and thifensulfuron combinations did not control ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq. #IPOHE].

Greenhouse studies evaluated soybean cultivar sensitivity to thifensulfuron. Seven popular Virginia soybean varieties and one national variety (Williams 82) were screened for tolerance to thifensulfuron. Differences in varietal sensitivity was verified. Soybean varieties Vance, Essex, Hutcheson, and York proved to be more

sensitive to 9.1 g ha^{-1} thifensulfuron than FFR 561, Williams 82, or Deltapine 105. No relationship between sensitivity to thifensulfuron and Essex parentage could be drawn.

The selectivity of the sulfonylurea class of herbicides is reportedly based on differential metabolism of the herbicide between sensitive and tolerant weed and crop species. Laboratory studies were conducted utilizing thifensulfuron-sensitive and tolerant weed species, velvetleaf (*Abutilon theophrasti* Medic. #ABUTH) and spurred anoda [*Anoda cristata* (L.) Schlecht #ANVCR], respectively, as well as the relatively tolerant Williams 82 and sensitive Vance soybean. Absorption and distribution studies indicated that all species absorbed and translocated similar amounts of ^{14}C 1, 3, and 5 days after appllication of the methyl ester of [^{14}C-thiophene]thifensulfuron. Metabolism studies indicated that both tolerant spurred anoda and sensitive velvetleaf metabolized thifensulfuron at similar rates 3 days after treatment. Metabolism appears to be the major mechanism for the selectivity of thifensulfuron to soybeans. The mechanism for spurred anoda tolerance to thifensulfuron has yet to be determined.

This research indicates that broadcast foliar applications of 4.5 g ha^{-1} thifensulfuron with 0.125% v/v nonionic surfactant or 1% v/v crop oil concentrate can provide selective postemergence smooth pigweed and common lambsquarters control for soybean production in Virginia. Caution should, however, be taken in prescribing greater than 4.5 g ha^{-1} thifensulfuron due to the variability in cultivar sensitivity to thifensulfuron.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

LITERATURE REVIEW

Soybean [*Glycine max* (L.) Merr.], the third highest valued crop in Virginia, contributed 116 million dollars in revenue to the state from 220 thousand hectares of soybeans in 1987 (65). However, in 1987, soybean yield was reduced by approximately 6.6 million dollars by weed competition, even though herbicides were used (10). Weed competition is the major problem facing soybean production in Virginia. Weeds not only reduce soybean yield, they can also decrease quality (0.32 million dollars), increase the cost of land preparation and cultivation (0.3 million dollars), and increase the cost of harvest (0.3 million dollars) (estimates for VA soybean production) (10). Annually, farmers spend in excess of 9.9 million dollars for soybean herbicides (10). In 1987, weed interference cost Virginia farmers an estimated 17.4 million dollars in reduced yield and increased production costs (10).

Three methods of increasing weed control while limiting herbicidal inputs for soybean production include the prescription use of preemergence and/or postemergence herbicides based on field history and identification of emerged weeds, directed or banded herbicide applications in or between the crop row, and single or sequential herbicide applications at reduced rates. The development of selective postemergence herbicides have the potential for reducing the quantity of herbicide(s) required for weed control (68). Application of postemergence herbicides can be

prescribed when weed densities reach economic thresholds, combined with row cultivation as a directed spray, and applied at reduced rates in sequential treatments as needed. Dr. Harold Coble at North Carolina State University has been developing a computer program that will assist farmers in making postemergence herbicide selections based on weed species and weed/crop competition thresholds (12).

The success of a postemergence herbicide is dependent upon its penetration of the plant cuticle and subsequent movement to an active site (63). Addition of traditional adjuvants such as nonionic surfactants or crop oil concentrates to herbicide spray solutions increases foliar absorption and phytotoxicity of numerous herbicides (20, 21, 38). Phytotoxicity of herbicides to different plant species can vary under changing environmental conditions (46, 47). Adjuvants have been successful in reducing the influence of environmental factors on foliar penetration and phytotoxicity of herbicides (38). Kent and Wills (38) were able to overcome influences of changing relative humidity and temperature on ^{14}C-chlorimuron (2-[[[[4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid) absorption in sicklepod (*Cassia obtusifolia* L.#CASOB) and pitted morningglory (*Ipomoea lacunosa* L. # IPOLA) by adding surfactants to the spray solution. Addition of an organosilicone surfactant to formulated glyphosate [(N-(phosphonomethyl)glycine)] allowed rapid infiltration of the herbicide through perennial ryegrass (*Lolium perenne* L.) stomata and reduced the critical rainfall

period (20).

Effective postemergence weed control requires timely application of herbicides to susceptible weed species (19, 50, 52, 54, 57). Researchers have observed more effective weed control with postemergence herbicides when applied to weeds at early growth stages (3, 5, 19, 31, 32). Weed control at later stages of growth often requires higher rates and sequential applications (42, 50). Optimal timing of postemergence herbicide application is not always possible. Adverse weather conditions, cost of available herbicides, and inability of existing herbicides to control emerged weed species are major limitations to postemergence herbicide use. A postemergence weed control program can also be limited by herbicide tank-mixture compatibility (11, 13, 15, 27, 30, 48). Tank-mixtures of sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} and bentazon {3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide} have reduced sethoxydim grass weed contol and bentazon broadleaf weed control (27, 30). Tank-mixture antagonism can often be overcome by increasing rates of one or both herbicides in the mixture, or by adding a compatibility agent to the mixture (27, 30). Individual postemergence herbicides are also limited in their ability to completely control broadleaf weeds. Recovery of entireleaf [*Ipomoea hederacea* var. *integriuscula* Gray # IPOHG], ivyleaf [*Ipomoea hederacea* (L) Jacq. # IPOHE], and tall morningglory [*Ipomoea purpurea* (L) Roth # PHBPU] following application of acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid}, lactofen {(±)-2-ethoxy-1-methyl-2-

oxoethyl-5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-dintirobenzoate},orfomesafen{5-[2-chloro-4-(trifluoromethyl)phenoxy]-N-(methylsulfonyl)-2-nitrobenzamide} was reported (5, 36). Morningglory recovery to herbicide application increased soybean lodging, reduced soybean seed yield, and decreased mechanical harvesting efficiency (5, 36).

The most troublesome weeds to Virginia soybean production in order of occurrence are: morningglory species (*Ipomoea spp.* L.), common cocklebur (*Xanthium strumarium* L. #XANST), common lambsquarters (*Chenopodium album* L. #CHEAL), johnsongrass [*Sorghum halepense* (L.) Pers.#SORHA], jimsonweed (*Datura stramonium* L.#DATST), pigweed species (*Amaranthus spp.* L.), yellow nutsedge (*Cyperus esculentus* L.#CYPES), horsenettle (*Solanum carolinense* L.#SOLCA), common ragweed (*Ambrosia artemisiifolia* L.#AMBRA), and fall panicum (*Panicum dichotomiflorum* Michx.#PANDI) (17). Common lambsquarters, smooth pigweed, and ivyleaf morningglory persist in agricultural production fields (17, 29, 37). Persistence of these troublesome weed species can be accounted for by the presence of large seed reserves (17, 29, 37) seed dormancy (37, 43), genetic diversity, resistance of some genotypes to available herbicides (4), and poor or inconsistent control with currently available postemergence herbicides.

Thifensulfuron {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl] amino]sulfonyl]-2-thiophenecarboxylic acid}, a new postemergence herbicide of the sulfonylurea class, is very promising for controlling wild garlic (*Allium vineale* L.)

and common lambsquarters in cereal crops (6, 7, 14, 15). Thifesulfuron has also found to provide selective weed control in both corn (*Zea mays* L.) and soybeans (1, 22, 25). Research has indicated that thifensulfuron is also active on velvetleaf (*Abutilon theophrasti* Medic. #ABUTH) and smooth pigweed (*Amaranthus hybridus* L. #AMACH) at rates of 4.5 to 16 g ha^{-1} (21). Phytotoxicity of thifensulfuron can be enhanced by the addition of adjuvants. In recent studies, the addition of 28% urea ammonium nitrate (UAN) to thifensulfuron plus surfactant, enhanced the control of velvetleaf and reduced fresh weights of kochia [*Kochia scoparia* (L.) #KSHSC] compared to thifensulfuron alone or combined with surfactant (21, 25). Addition of 0.25% nonionic surfactant or 28% UAN at 5% v/v to thifensulfuron increased absorption into the second true leaf of velvetleaf by eight-fold 84 h after treatment (21). Studies also indicate that soybean and corn injury increase with increasing rates of thifensulfuron (14, 21).

Current Postemergence Broadleaf Herbicides For Soybean Production

Considerable progress has been made in the development of herbicides for postemergence broadleaf weed control in soybeans. Diphenylethers, bentazon, 2,4-DB, sulfonylureas, and imidazolinone herbicides provide selective postemergence broadleaf weed control in soybeans (3, 15, 16, 19, 21, 31, 36). Broad spectrum postemergence weed control in soybeans currently requires the timely application of combinations of available herbicides. Bentazon plus acifluorfen, a diphenylether,

applied to seedling common lambsquarters, common ragweed, and morningglory species commonly provide 88, 87, and 91% control respectively (61). Tank mixtures, however, do not always prove compatible. Tank mixtures of the sodium salt of bentazon with sethoxydim, a postemergence grass herbicide, decreased the activity of sethoxydim on grass species (11, 13, 15, 27, 30). The combination of the sodium salt of bentazon with sethoxydim in a high carrier volume and hard water tends to favor cation exchange and the formation of Na-sethoxydim, which is not absorbed as readily as sethoxydim (63).

The commonly used diphenylethers are acifluorfen, lactofen and fomesafen (68). Diphenylethers disrupt cell membranes and cause a symptomatic necrosis or leaf burn (22). Diphenylethers are primarily utilized for controlling glabrous and suppressing pubescent morningglory species. These herbicides also have varying degrees of residual broadleaf activity and limited seedling grass activity. Bentazon, is active on common cocklebur, common ragweed, and yellow nutsedge (42, 50). Bentazon and acifluorfen are available as a commercial package-mixture commonly used for common cocklebur and morningglory species control and suppression of smooth pigweed and common lambsquarters (36, 42, 47, 50).

The phenoxy 2,4-DB [4-(2,4-dichlorophenoxy)butanoic acid], is a postemergence broadleaf herbicide registered for use in soybeans (60). Soybean cultivars vary in their sensitivity to 2,4-DB (68). Addition of low rates (35 to 70 kg ha^{-1}) of 2,4-DB to acifluorfen and bentazon has been a common practice in some

soybean regions (68). This tank-mixture enhances control of morningglory species and is often used as a mid- to late-season treatment for larger morningglory(68).

The imidazolinones, imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2yl]-3-quinolinecarboxylic acid} and imazethapyr {(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}, and the sulfonylureas, chlorimuron and thifensulfuron, are unique in that both classes of herbicides inhibit acetolactate synthase (ALS; EC 4,13,18) (6, 57). ALS is a key enzyme critical to the biosynthesis of branched-chain amino acids in plants (7). These herbicides have a high unit of activity. Smooth pigweed and common cocklebur control can be obtain with 9.1 g ha^{-1} chlorimuron or 56 g ha^{-1} imazaquin (3, 38, 60). Morningglory control, however, has not been consistent with either herbicide class, and foliar applications tend to be more effective when 2,4-DB is added to the spray solution (5, 13, 31, 38, 57, 68).

Other herbicides used for broadleaf weed control in soybeans are: linuron {N'-(3,4-dichlorophenyl)-N-methoxy-N-methylurea}, a urea; metribuzin {4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one}, an asymetrical triazine; and glyphosate (60). These herbicides become selective by placement. Linuron and metribuzin can be applied as post-directed sprays with limited selectivity in soybeans. Glyphosate, a non-selective herbicide, can be applied with a rope-wick and selectivity is obtained via wiping of weeds which are taller than the crop (54, 60). These herbicides are generally used as treatments for escaped or hard to control weeds.

Basis for Selectivity of Foliar-Applied Herbicides

Two of the most important factors in the selectivity of foliar-applied herbicides are differential uptake and metabolism. Differential uptake of a foliar-applied herbicide can be influenced by a number of factors (3, 15, 18, 21, 26, 35, 38, 46, 53). Wanamarta and Penner (63) categorized these factors into three major groups: 1) the chemical and physical properties of the herbicide and the spray solution, 2) the morphological and anatomical properties of the plant foliage, and 3) the environmental conditions during which the plants are treated.

Differential Uptake

The success of a foliar-applied herbicide is dependent upon the penetration of the plant cuticle and subsequent movement through the cell wall and plasmalemma followed by translocation of the intact molecule to an active site (35). For maximum activity of foliar-applied imidazolinone and sulfonylurea herbicides, most of the herbicide must be absorbed by the plant and translocated out of the treated leaf to the growing points (6, 57). The cuticle is a non-living, non-cellular, lipoidal membrane consisting of layers of waxes, pectin, cutin, and cellulosic materials (52). The cuticle covers plant leaves and stems and functions to minimize water loss and acts as a barrier to the penetration of exogenous materials (52). The structure of the cuticle has been proposed to resemble a sponge in which the frame work is made of cutin and the holes are filled with wax (23, 52, 63). Pectins and cellulose

are found concentrated on the cell wall side of the cuticle. This cuticular construction forms a gradient from low polarity at the outer surface to high polarity next to the cell walls (49, 64).

Pathways of herbicide penetration through the plant cuticle are hypothesized to be different for polar and nonpolar compounds (63). Cuticle penetration by polar compounds has been the subject of much speculation (52). The aqueous (polar) pathway of cuticle penetration is based on the hydration of the cuticle. Under conditions of high humidity or adequate moisture supply, a plant's cuticle will be hydrated, providing separation of the lipophilic waxes. Spreading of the lipophilic waxes facilitates the absorption of polar compounds (63).

Cuticle penetration of nonpolar compounds has been proposed to occur via sorption into the outer wax layer, passage through the cutin matrix, and desorption into the apoplast (52). Desorption appears to be the rate limiting step for uptake of several nonpolar herbicides (28, 53).

The cuticle possesses a net negative charge on the surface and exhibits cation exchange properties that may influence the diffusion of herbicides (63). Cation permeability in isolated cuticles was found to be greater than anion permeability as a consequence of the net cuticle charge (67). The charge properties of the cuticle were found to be due to the dissociation of acid residues within the cuticle.

Environmental conditions encountered during plant growth can alter the structure of the cuticle. High temperatures, water stress, and high winds cause the

plant to produce a thicker cuticle (49, 52). These conditions make it more difficult for hydrophilic herbicides, like the imidazolinones and sulfonylureas, to penetrate the cuticle.

Penetration of herbicides can also be influenced by the hydration state of the cuticle (52). The cuticle expands and contracts, like a sponge, with changes in relative humidity (52). A fully hydrated cuticle will absorb a herbicide more easily than a cuticle that is not hydrated, such as in water-stressed plants under low relative humidity (49, 57). Growth chamber studies on the absorption of imazamethabenz, (±) - 2- [4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-4(and 5)-methylbenzoic acid (3:2), into wild oat (*Avena fatua* L.) leaves indicated that leaves absorbed three times more imazamethabenz under high (98%) humidity than under lower (50%) humidity (57). Under high humidity conditions, two factors can regulate the foliar absorption of herbicides. First, cuticle hydration is much higher under high humidity than low humidity; and second, the rate of herbicide drying on the leaf surface is slower (52). As a result, the herbicide will have a longer time to penetrate the cuticle. In general, penetration stops once the herbicide dries on the cuticle surface (52).

The herbicide formulation can also play a role in the foliar absorption. All of the imidazolinones and sulfonylureas require a surfactant for maximum absorption. Surfactants aid the leaf absorption of sulfonylurea and imidazolinone herbicides by 1) lowering the surface tension of the spray droplets on the leaf, which improves leaf

coverage and removes the air film between the spray droplet and the leaf, 2) reducing the interfacial tension between the relatively polar and non-polar regions of the leaf cuticle; 3) aiding stomatal penetration; 4) increasing the permeability of the cuticle; 5) interacting with the herbicide to allow more ready penetration of the cuticle; and 6) acting as a humectant by increasing the drying time of the spray solution on the leaf (46)

Another adjuvant which has recently been found to increase the foliar activity of the imidazolinones and sulfonylureas is liquid fertilizer, such as 28% urea ammonium nitrate and 10-34-0, which increases the foliar uptake of both herbicide classes (21, 57). While the mechanism of action of these liquid fertilizers is still unclear, they have been shown to promote uptake of a broad range of herbicides, including glyphosate, bentazon, and acifluorfen (57). The effectiveness of the liquid fertilizers varies with weed species and requires the presence of a surfactant or crop oil concentrate (57, 61, 67).

Translocation

In order for a foliar-applied sulfonylurea herbicide to kill a plant, it must be transported out of the leaf to the growing points (6). Any factor which prevents or reduces the translocation of sulfonylurea herbicides, such as metabolism or compartmentalization, will reduce the herbicidal activity of these chemicals.

The ability of sulfonylurea herbicides to move out of a treated leaf to the

meristematic regions lends to their flexibility and usefulness. Translocation of any chemical out of a leaf and to the growing points requires that the chemical be loaded into the phloem system and moved along with sugars to the growing points (61, 62). Although almost all chemicals can penetrate the phloem of plants, very few translocate out of the leaf (61, 62). Successful xenobiotic phloem transport is limited due to the proximity of the phloem to the xylem which moves its contents in the opposite direction of the phloem (61, 62). Leakage of compounds out of the phloem are swept back by the xylem or transpiration stream of the leaf (35).

In order for a herbicide to translocate within the phloem it must cross the phloem wall as an undissociated molecule and become "trapped" in the phloem as dissociated molecule. This property allows herbicides to accumulate in the cell and remain in the phloem for efficient translocation to the plants growing points (6, 40)

Metabolism

Differential metabolism of herbicides plays an important role in the deactivation and activation of herbicides in plants (6, 9, 10, 16). The conversion of 2,4-DB to 2,4-D [(2,4-dichlorophenoxy) acetic acid] by broadleaf weeds activates the herbicide, while the reduced conversiion in soybeans provides selectivity. Uptake and translocation studies indicate that the same amount of ^{14}C-chlorimuron is

absorbed and translocated in tolerant and sensitive species (9). Differential metabolism of chlorimuron between sensitive weed and tolerant crop species was proven to be the primary mechanism of selectivity (7, 9). The half-life of chlorimuron-ethyl was 2 to 4 h in tolerant soybeans and more than 30 h in sensitive cocklebur and pigweed (8)

Detoxification mechanisms for sulfonylurea herbicides in tolerant plant species include ester hydrolysis, conjugation with glucose and/or glutathione (homoglutathione), and hydroxylation (6, 7, 58). Brown and Neighbors (8) determined that soybeans detoxify chlorimuron-ethyl via homoglutathione conjugation (75%) and de-esterification (25%). Homoglutathione plays an important role in the detoxification of numerous herbicides in soybeans. Homoglutathione, however, appears to play a minor role in soybean detoxification of thifensulfuron. Unlike chlorimuron, 95% of the absorbed thifensulfuron was detoxified via de-esterification 48 h after treatment (9). Recently, increased crop injury has been reported by interactions between sulfonylurea herbicides (DPX-V9360, CGA-136872, and thifensulfuron) and organophosphate insecticides (1,62). Increased injury from combination of organophosphates insecticides and thifensulfuron may be related to the proposed mechanisms of detoxification (9, 45). Both the organophosphate insecticides and thifensulfuron require de-esterification for detoxification (9, 45). The presence of both OP and thifensulfuron in the plant may competitively inhibit esterases important in the detoxification process and increase the phytotoxic

response. Increased absorption of the herbicide is also possible, however, probably not as important, since the response was similar when herbicide and insecticide were applied several days apart (1).

Review of Thifensulfuron

Chemistry

Thifensulfuron is a sulfonylurea herbicide which is formulated as a water-dispersable granule (WDG) and is available as a 25% active ingredient. It is available in a prepackage mixture with tribenuron 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoic acid, another sulfonylurea herbicide, for use in cereal grains and alone for use in soybeans. The chemical structure of thifensulfuron is presented in figure 1.1.

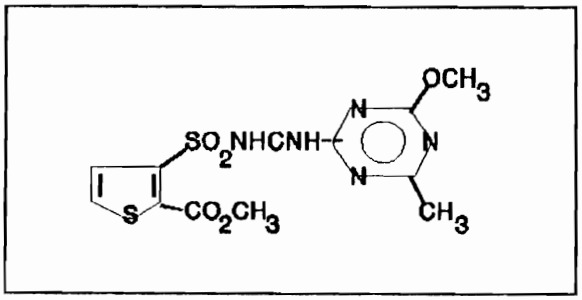

Figure 1.1. Chemical structure of the methyl ester of thifensulfuron.

Thifensulfuron is a product of E.I. Dupont de Nemours Co., Inc. The cereal grains prepackage mixture has the trade name Harmony-Extra™[1]. The soybean formulation of thifensulfuron has the trade name Pinnacle™ and was registered for use in 1990.

The recommended use rate of thifensulfuron in soybeans is 4.5 g ha^{-1} applied in a minimum spray volume of 95 L ha^{-1} by air and ground equipment (60). The addition of 0.125% v/v of an 80% active ingredient non-ionic surfactant is required (60). The addition of liquid nitrogen fertilizer at a rate of 5% v/v is recommended for control of velvetleaf (60).

Thifensulfuron and chlorimuron tank mixtures, 4.5 g ha^{-1} and 4.5 g ha^{-1} respectively, have been registered for use in soybeans for control of cocklebur, jimsonweed, and the suppression of annual morningglory species and common ragweed (60).

Mode of Action and basis of selectivity

The sulfonylurea herbicides act by inhibiting the biosynthesis of the branched chain amino acids valine, leucine, and isoleucine (41). LaRossa and Schloss (41) using sulfometuron methyl-resistant and sulfometuron methyl-susceptible *Salmonella typhimurium* identified the site of action of the sulfonylureas to be the enzyme acetolactate synthase (ALS; EC 4.13.18). ALS is a key enzyme in the biosynthesis of branched chain amino acids in bacteria, fungi and higher plants (6). ALS

[1]Harmony-Extra and Pinnacle are trade marks of E.I.Dupont de Nemours & Co., Inc.

catalyzes the condensation of two molecules of pyruvate to form alpha-acetolactate and carbon dioxide, which leads to the synthesis of valine and isoleucine (Figure 1.2). ALS also catalyzes the condensation of one molecule of pyruvate with alpha-ketobutyrate to form alpha- aceto-alpha-hydroxybutyrate, which leads to the formation of isoleucine (21). The reactions catalyzed by this enzyme involve no net oxidation or reduction, yet require the presence of thiamine pyrophosphate, Mg^{2+}, and FAD.

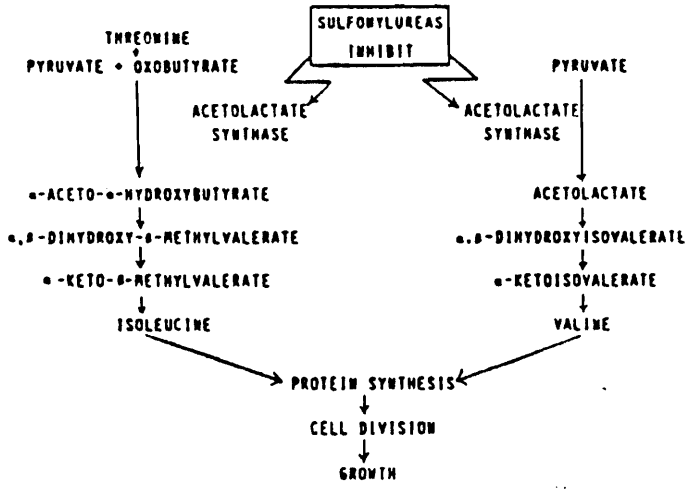

Figure 1.2. Proposed metabolic pathway for the synthesis of the branched chain amino acids valine and isoleucine (24)

The sulfonylurea molecule is composed of three distinct parts (Figure 1.3). The molecule is comprised of a nitrogenous heterocycle linked to a sulfonylurea bridge, which is in turn linked to an aryl group. Modification to any of the three groups can alter the activity of the molecule.

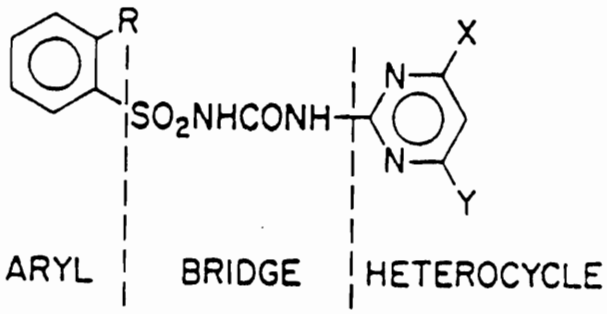

Figure 1.3. Basic model of the sulfonylurea molecule (6).

According to Levitt (7) the most active form of the molecule is exhibited when the heterocyclic portion of the molecule is a symmetrical pyrimidine or symmetrical triazine containing a lower alkyl or alkoxy substituent, the aryl portion of the molecule has a substituent ortho to the sulfonylurea bridge, and the bridge is unmodified (7). Sulfonylureas containing aryl groups other than the phenyl are also biologically active. This is the case with thifensulfuron. Thifensulfuron contains a thiophene group with a carboxylate substituent ortho to the unmodified sulfonylurea bridge linked to a symmetrical triazine (Figures 1.1 and 1.2). Furan, pyridine, and naphthalene groups are also possible aryl groups (7). It is important to note that the addition of a hydroxyl or carboxyl substituent to the aryl group ortho to the

sulfonylurea bridge does not potentiate herbicidal activity and may, instead, inactivate the molecule (7).

Other heterocycles may also influence the herbicidal activity, such as triazoles, asymmetrical triazines, fused-ring pyrimidines, and pyridines (7). Modifications to the sulfonylurea bridge may also influence the herbicidal activity, which is dependent upon the type of aryl and heterocycle present. Currently, the following bridge modifications occur: $SO_2NHC(S)NH$, $OSO_2NHCONH$, $SO_2NHCON(CH_3)$ and $CH_2SO_2NHCONH$ (7). Chlorimuron consists of a pyrimidine heterocycle linked to an unmodified sulfonylurea bridge which has a phenyl aryl group with a benzoate substituent ortho to the bridge (Figures 1.1 and 1.2).

Activity

The potency of the sulfonylurea herbicides is unprecedented. The use rates of the sulfonylureas in soybeans are between 4.5 and 9 g ha^{-1}, while those of conventional herbicides, such as acifluorfen and bentazon, are between 0.5 and 2.0 kg ha^{-1}. Visual symptoms of root and shoot inhibition can occur within the seven or ten days after application. Sulfonylurea-induced injury is characterized by general chlorosis of leaves, reduction in internode length, reddening of veins and nodes, and early leaf abscission.

Thifensulfuron and chlorimuron have low oral (LD 50 of 2300 mg kg^{-1}) and dermal acute toxicity (LD 50 of 2000 mg kg^{-1}). They are effective at very low rates

postemergence (1 to 16 g ha^{-1}) and they are relatively soil mobile (60). Chlorimuron has a soil half-life of 31 to 43 days, while thifensulfuron has a half-life of less than 14 days (7). Degradation of these compounds in the soil is primarily accomplished by chemical hydrolysis followed by microbial decomposition. Because these herbicides are weak acids, their soil degradation and mobility is dependent upon soil pH, moisture, and temperature (6). In alkaline soils, these compounds will not readily dissociate into the soil solution and therefore are not readily available to the plant or soil microorganisms (6, 23, 39). In acid soils, the sulfonylureas are readily dissociated into the soil solution, where they can be hydrolyzed, taken up by plants, or inactivated by soil microorganisms (6, 23, 39). The interaction of cool soil temperature and low soil moisture compounded with alkaline soil pH will reduce the availability and degradation of the sulfonylurea herbicides (6, 23, 39).

In spite of the low dosage and moderate degradation of chlorimuron in soils, recropping restrictions exist due to the high sensitivity of rotational crop species (6). Proposed soybean use rates of thifensulfuron (2 to 9 g ha^{-1}) should not cause injury to rotational crop species.

Resistance

In 1987 and 1988, kochia, russian thistle and prickly lettuce biotypes were identified as being resistant to the sulfonylurea chlorsulfuron (43,58). Resistance across sulfonylurea herbicides was characterized and cross-resistance with imidazolinones was found (44, 59). Resistant biotypes were first identified in fields

which had received applications of 88 to 123 g ha^{-1} per year for 3 to 5 years (59). Dupont currently has restricted applications of residual sulfonylureas to once every-other-year in an effort to reduce the selection pressure for resistant biotypes. The resistance mechanism has been attributed to an altered form of the ALS enzyme which has decreased sensitivity to inhibition by sulfonylurea and imidazolinone herbicides (59). Research indicates that resistance can occur following a single dominant nuclear mutation resulting in the substitution of a single amino acid in the ALS enzyme (34, 55, 56, 66). Sebastian and Chaleff (56) bathed soybean var. Williams seed in a mutagenic agent and were able to isolate seeds with 1000 fold tolerance to chlorsulfuron. Isolate W20 is currently being tested for tolerance to sulfonylurea herbicides. Development of soybean resistance to chlorsulfuron will allow rotation into areas where previous applications of chlorsulfuron were made in cereal grains. Resistant weed management programs currently recommend discontinuing use of long residual sulfonylurea and imidazolinone herbicides for at least 1 to 2 years. Application of short-residual ALS inhibiting herbicides where possible, and tank mixtures of herbicides with dissimilar modes of action to reduce selection pressure are recommended.

The objectives of this research were to 1) evaluate postemergence application of low rates of thifensulfuron alone and in combinations with nonionic surfactant and crop oil concentrate for broadleaf weed control and soybean tolerance; 2) evaluate tank mixtures of thifensulfuron with chlorimuron for postemergence broadleaf weed

control and soybean tolerance; 3) evaluate soybean varietal response to foliar applied thifensulfuron; and 4) investigate the uptake, translocation, and metabolism of thifensulfuron among velvetleaf, spurred anoda, and soybean. Weed species of interest included common lambsquarters, smooth pigweed, spurred anoda, velvetleaf, and ivyleaf morningglory.

LITERATURE CITED

1. Ahrens, William H. 1990. Enhancement of Soybean injury and weed control by thifensulfuron-insecticide mixtures. Weed Tech. 4:524-528.

2. Aldrich, R.J. 1984. Weed-Crop Ecology, Principles in Weed Management. Breton Publishers, N. Scituate, MA.

3. Ballard, T.O. 1988. Postemergence weed control with imazethapyr in soybeans as influenced by application timing. Proc. North Centr. Weed Control Conf. 43:38.

4. Bandeen, J.D., G.R. Stephenson, and E.R. Cowett. 1982. Discovery and distribution of herbicide-resistant weeds in North America pp.9-30. In Herbicide Resistance in Plants. H.M. LeBaron and J. Gressel, eds. John Wiley & Sons, Toronto.

5. Barker, M.A., L. Thompson, Jr., and F. Michael Godley. 1984. Control of annual morningglory in soybeans. Weed Sci. 32:813-818.

6. Beyer, E. M. Jr., M.J. Duffy, J.V. Hay, and D. Schlueter. 1988. Sulfonylureas pp. 117-189. In Herbicides: chemistry, degradation and mode of action. P.C. Kearny and D.D. Kaufman, eds. Marcel Dekker, Inc. New York.

7. Blair, A. M., and T.D. Martin. 1988. A review of the activity, fate and mode of action of sulfonylurea herbicides. Pestic. Sci. 22:195-219.

8. Brown, H.M. and S.M. Neighbors. 1987. Soybean metabolism of chlorimuron ethyl: Physiological basis for soybean selectivity. Pest. Biochem. Physiol.

29:112-120.

9. Brown, H.M., V.A. Wittenbach, D. R. Forney, and S.D. Strachan. 1990. Basis for soybean tolerance to thifensulfuren methyl. Pestic. Biochem. Physiol. 37:303-313.

10. Bryson, C.T., 1989. Economic losses due to weeds in southern states. Proc. South. Weed Sci. Soc. 42:385-392.

11. Chen, Y.Z. and D.Penner. 1985. Combination effects of acifluorfen with crop oil concentrates and postemergence grass herbicides. Weed Sci. 33:91-95.

12. Coble, H. 1990. Herbicide selection program for IBM PC and compatible computers. Proc. South. Weed Sci. Soc. In press.

13. Croon, K.A. and M.G. Merkle. 1988. Effects of bentazon, imazaquin or chlorimuron on haloxyfop or fluazifop-P efficacy. Weed Tech. 2:36-40.

14. DeFelice, M.S., W.B. Brown, R.J. Aldrich, B.D. Sims, D.T. Judy, and D.R. Guethle. 1989. Weed control in soybeans with reduced rates of postemergence herbicides. Weed Sci. 37:365-374.

15. Dexter, A.G. and J.D. Nalewaja. 1986. Interactions among postemergence herbicides. Proc. North Centr. Weed Contr. Conf. 41:48.

16. Eberlein, C.V., K.M. Rosow, J.L. Geadelmann, and S.J. Openshaw. 1989. Differntial tolerance of corn genotypes to DPX-M6316. Weed Sci. 37:651-657.

17. Elmore, C.D., 1989. Weed survey - southern states. Proc. South. Weed Sci. Soc. 42:408-420.

18. Fedtke, C. 1982. Biochemistry and Physiology of Herbicide Action. Springer Verlag, Berlin. pp. 182.

19. Feldick, T. and G. Kapusta. 1986. Influence of weed size on the efficacy of reduced rates of postemergence applied acifluorfen, bentazon, imazaquin and DPX-F6025 in soybeans. Proc. North Centr. Weed Contr. Conf. 41:47.

20. Field, R.J. and N.G. Bishop. 1988. Promotion of stomatal infiltration of glyphosate by an organosilicone surfactant reduces the critical rainfall period. Pestic. Sci. 24:55-62.

21. Fielding, R.J. and E.W. Stoller. 1990. Effects of additives on the efficacy, uptake, and translocation of the methyl ester of thifensulfuron. Weed Sci. 38:172-178.

22. Fletcher, W. W. and R. C. Kirkwood. 1982. Herbicides and Plant Growth Regulators. Granada Publishing Limited, London.

23. Friedman, P.J.. 1977. Biochemistry: The little brown Medical Review Series. Little Brown and Company, Boston. p. 161-178.

24. Goodwin, T.W. and E.I. Mercer. 1985. Introduction to Plant Biochemistry. Pergamon Press, New York. pp. 339-355.

25. Green, J.M., D. Berengut, M.G. King, and P.A. Brown. 1989. Influence of nonionic surfactant properties on DPX-M6316 performance in corn and soybeans. Abst. Weed Sci. Soc. Amer. 29:23.

26. Green, J.M. 1988. Effect of inorganic salts on the efficacy of chlorimuron and

DPX-M6316 on soybeans. Abst. Weed Sci. Soc. Amer. 28:16.

27. Green, J.M. and S.P. Bailey. 1988. Herbicide interactions with herbicides and other agricultural chemicals. In Methods of applying herbicides. ed. C.G. McWhorter and M.R. Gebhardt. Weed Sci. Soc. Amer. monograph 4:37-61.

28. Hamilton, R.J. A.W. McCCann, P.A. Sewell, and G.T. Merrall. 1982. Foliar uptake of the wild oat herbicide flamprop-methyl by wheat. pp. 303-313 *In* D.F. Cutler, K.L. Alvin, and C.E. Price, eds. The Plant Cuticle, Linn. Soc. Symp. Ser. 10. Academic Press, London.

29. Harrison, S.K. 1990. Interference and seed production by common lambsquarters in soybeans. Weed Sci. 38:113-118.

30. Hartzler, R.G. and C.L. Foy. 1983. Compatibility of BAS 9052 OH with acifluorfen and bentazon. Weed Sci. 31:597-599.

31. Harvey, R.G., S.J. Halstead, J.W. Albright, and T. Anthon. 1986. Postemergence: soybean herbicide study. North Centr. Weed Contr. Conf. Res. Rep. 43:220-221.

32. Harvey, J. Jr. 1986. Timing postemergence herbicides for soybean weed control. Proc. North Centr. Weed Contr. Conf. 43:220-221.

33. Haugh G. W. and C. Somerville. 1986. Sulfonylurea resistant mutants of *Arabidopsis thaliana*. Mol. Gen. Genet. 204:430-434.

34. Haughn G.W., J.Smith, B. Mazur, and C. Somerville. 1988. Transformation with a mutant arabidopsis acetolactate synthase gene renders tobacco resistant

to sulfonylurea herbicides. Mol. Gen. Genet. 211:266-271.

35. Hess, F. D. 1985. Herbicide absorption and translocation and their relationship to plant tolerances and susceptibility. In Weed Physiology, S.O. Duke (ed) CRC Press, Boca Raton, FL. Vol. II, 191-214.

36. Higgins, J.M., T. Whitwell, E.C. Murdock, and J.E. Toler. 1988. Recovery of pitted morningglory and ivyleaf morningglory following applications of acifluorfen, fomesafen, and lactofen. Weed Sci. 36:345-353.

37. Holm, L.G., D.L. Plucknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds, Distribution and Biology. Univ. Press of Hawaii, Honolulu. pp 84-91.

38. Kent, L.M. and G.D. Wills. 1988. Factors affecting absorption and translocation of ^{14}C-chlorimuron in pitted morningglory and sicklepod. Proc. South. Weed Sci. Soc. 42:84.

39. Kurzer, F. 1961. In Organic sulfur compounds. N. Kharasch ed. Pergamon Press, New York. pp. 491-511.

40. Kirkwood, R. C. 1978. Some criteria determining penetration and translocation of foliage applied herbicides. In Herbicides and Fungicides, Factors Affecting Their Activity. N. R. McFarlane ed. The Chem. Soc. pp 67-80.

41. LaRossa, R.A. and J.V. Schloss. 1984. The sulfonylurea herbicide sulfometuron methyl is an extremely potent and selective inhibitor of

acetolactate synthase in *Salmonella typhimurium*. J. Biological Chem. 259(14):8753-8757.

42. Lee, S.D. and R.L. Oliver. 1982. Efficacy of acifluorfen on broadleaf weeds. Time and method of application. Weed Sci. 30:520-526.

43. Lewis, J. 1973. Longevity of crop and weed seeds: survival after 20 years in soil. Weed Res. 13:179-191.

44. Mallory, C.A., D.C. Thill, and M.J. Dial. 1989. Sulfonylurea resistant prickly lettuce, *Lactuca serriola* L. Abst. Weed Sci. Soc. Am. 29:77.

45. Matsumura, F. 1985. Toxicology of Insecticides. Plenum Press. New York. p. 598.

46. Mcwhorter, C.G. 1985. The physiological effects of adjuvants on plants. In Weed Physiology, S.O. Duke (ed) CRC Press, Boca Raton, FL. Vol. II, 141-158.

47. Meeusen, R.M., S.M. Lokey, and R.Y. Yih. 1983. Effects of environmental factors on the herbicidal activity of acifluorfen. Aspects of Appl. Biol. 4:253-263.

48. Mueller, T.C., W.W. Witt, and M. Barrett. 1989. Antagonism of johnsongrass control with fenoxaprop, haloxyfop, and sethoxydim by 2,4-D. Weed Tech. 3(1):86-89.

49. Muzik, T. J. 1974. Influence of environmental factors on toxicity to plants. p. 564 *In* L.J. Audus, ed. Herbicides-Physiology, Biochemistry, and Ecology.

2nd ed. Academic Press, London.

50. Owen, M.D.K. 1988. Effects of herbicide additives, application rate and timing on acifluorfen and bentazon efficacy. Abst. Weed Sci. Soc. Amer. 28:16.

51. Owen, W.J. 1987. Herbicide detoxification and selectivity. Proc. British Crop Prot. Conf. Weeds. 1:309-318.

52. Price, C. E. 1982. A review of the factors influencing the penetration of pesticides through plant leaves. Pages 237-252 *In* D.F. Cutler, K.L. Alvin, and C.E. Price, eds. The Plant Cuticle, Linn. Soc. Symp. Ser. 10. Academic Press, London.

53. Richard, E.P., Jr and W. S. Slife. 1979. In vivo and in vitro characterization of the foliar entry of glyphosate in hemp dogbane (*Apocynum cannabinum* L.) Weed Sci. 27:426-433.

54. Ross, M. A. and C. A. Lembi. 1985. Applied Weed Science. Burgess Publishing Company, Minneapolis, MN.

55. Sathasivian, K., G.W. Haughn, and N. Murai. 1988. Isolation and sequencing of acetolactate synthase gene from imazapyr-resistant *Arabidopsis thaliana* L. Heynh cv. Columbia. Plant Physiol. 86:136 Suppl. 4.

56. Sebastian S.A., and R. S. Chaleff. 1987. Soybean mutants with increased tolerance for sulfonylurea herbicides. Crop Sci. 27:948-952.

57. Shaner, D. L. 1989. Factors Affecting Soil and Foliar Bioavailability of Imidazolinones. American Cyanamid Company. pp 24.

58. Sweetser, P.B., G.S. Schow, and J.M. Hutchinson. 1982. Metabolism of chlorsulfuron by plants: Biological basis for selectivity of a new herbicide for cereals. Pest. Biochem. Physiol. 17:18-23

59. Thill, D.C., C.A. Mallory, L.L. Saari, J.C. Cotterman, and M.M. Primiani. 1989. Sulfonylurea resistance: mechanism of resistance and cross resistance. Abst. Weed Sci. Soc. Am. 29:132.

60. Weed Science Society of America. 1989. Herbicide Handbook. 6th edition. pp. 54-55, 117-119. Weed Sci. Soc. Am. Champaign, IL 61820.

61. Wilcut, J. W., D.N. Horton and L.D. Fortner. 1990. Postemergence combinations with imidazolinone and sulfonylurea herbicides in soybeans. Proc. Northeast. Weed Sci. Soc. 44:40.

62. Wilson, H.P. 1989. Interaction of DPX-V9360 and soil applied organophosphate insecticides in corn. unpublished data

63. Wanamarta, G. and D. Penner. 1989. Foliar absorption of herbicides. In Reviews of Weed Science. C.L. Foy (ed). 4:215-231.

64. Van Overbeek, J. 1956. Absorption and translocation of plant regulators. Annu. Rev. Plant Physiol. 7:355-372.

65. Virginia Crop Reporting Service. 1988. Soybeans, County estimates. U.S. Dept. Ag. and VA Dept. Ag. and Consumer Services. P.O. Box 1659, Richmond, VA 23213.

66. Yadav N., R.E. McDevitt, S. Benard, and S.C. Falco. 1986. Single amino acid

substitutions in the enzyme acetolactate synthase confer resistance to the herbicide sulfometuron-methyl. Proc. Natl. Acad. Sci. USA 83:4418-442

67. Yamada, Y., S.H. Wittwer, and M.J. Bukovac. 1964. Penetration of ions through isolated cuticles. Plant Physiol. 39:28-32.

68. York, A.C., J. W. Wilcut, M. M. Keene, and F. W. Walls, Jr. 1991. Soybean response to postemergence herbicide mixtures containing 2,4-DB. Weed Tech. 5(1):43-47.

69. Zhao, C.C., J.R. Teasdale, and C.B. Coffman. 1989. Interaction of DPX-V9360 with broadleaf herbicides for weed control in corn. Proc. Northeast. Weed Sci. Soc. 43:16.

CHAPTER II

INFLUENCE OF ADJUVANTS ON THE EFFICACY OF THIFENSULFURON FOR POSTEMERGENCE BROADLEAF WEED CONTROL IN SOYBEAN (Glycine max)

Abstract. Nonionic surfactant and crop oil concentrate (COC) were utilized in spray mixtures with low rates of thifensulfuron to investigate common lambsquarters, smooth pigweed, and ivyleaf morningglory control in soybeans. Greater than 95% control of smooth pigweed was obtained with thifensulfuron at 1.1 to 4.5 g ha^{-1} alone and with adjuvants. Common lambsquarters control depended upon adjuvant, adjuvant rate, and rate of thifensulfuron. In 1989, common lambsquarters control from 4.5 g ha^{-1} thifensulfuron increased from 54%, when applied alone, to 96% and 94% with the addition of 0.125% nonionic surfactant and 1% COC, respectively. Soybean injury increased with the addition of adjuvants. Soybean injury also increased with increasing concentrations of thifensulfuron with and without adjuvants. Death of apical meristem in 1987 with rates of 9.1 g ha^{-1} precluded the use of this rate in 1988 and 1989. Soybean yield was not reduced by 4.5 g ha^{-1} thifensulfuron alone or in combination with 0.06 to 0.125% nonionic surfactant or 1% COC in 1988 and 1989. Nomenclature: Thifensulfuron, 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid; soybean, *Glycine max*

(L.) Merr. 'Essex', 'Asgrow 4906', 'Asgrow 5149'; smooth pigweed, *Amaranthus hybridus* L. #[1] AMACH; common lambsquarters, *Chenopodium album* L. # CHEAL; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. # IPOHE; nonionic surfactant[2]; crop oil concentrate[3];

Additional index words. DPX-M6316, thiameturon, nonionic surfactant, AMACH, CHEAL, IPOHE.

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[1]Letters following these symbols are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2, Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

[2]X-77, Chevron Chem. Co., San Francisco, CA 94119. Currently available from Valent USA Corporation, Walnut Creek, CA 94596-8025. Principal functioning agents are alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol.

[3]Crop oil concentrate, Booster Plus, BASF Corp. Chem. Div., 26 Davis Drive, Research Triangle Park, NC 27709.

INTRODUCTION

The methyl ester of thifensulfuron {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid}, a new postemergence herbicide of the sulfonylurea class, is very active on wild garlic (Allium vineale L.) (8, 9, 12) and common lambsquarters (8, 9) in cereal crops (3, 8, 9) and has selectivity in corn and soybeans (2, 4, 5, 6, 7, 17, 18). Research has indicated that thifensulfuron is also active on velvetleaf and smooth pigweed at rates of 4.5 to 16 g ha^{-1} (4, 7, 11, 14, 16). Phytotoxicity of thifensulfuron can be enhanced by the addition of adjuvants. In recent studies, the addition of 28% urea ammonium nitrate (UAN) to thifensulfuron plus surfactant enhanced the control of velvetleaf (*Abutilon theophrasti* Medic. #ABUTH) (4, 7) and reduced fresh weights of kochia [*Kochia scoparia* (L.)# KCHSC] (15) in comparison to thifensulfuron alone or combinations with surfactant. Addition of 0.25% nonionic surfactant or 28% UAN at 5% v/v to thifensulfuron increased absorption into the second true leaf of velvetleaf by eight-fold 84 hours after treatment (4). Studies also indicate that X to Y % soybean and X to Y % corn injury can occur from x to y rates of thifensulfuron (2, 4).

The objective of this research was to evaluate the influence of surfactant and crop oil concentrate on the phytotoxicity of low rates of thifensulfuron to seedling broadleaf weeds and soybeans. Weed species of interest were common lambsquarters, smooth pigweed, and ivyleaf morningglory.

MATERIALS AND METHODS

General field procedures. Research was conducted in 1987, 1988, and 1989 on a State sandy loam soil (Typic Hapladults) near Painter, VA. The soil consisted of 67% sand, 28% silt, 5% clay, and 1% organic matter. The soil pH ranged from 5.4 to 6.1. Herbicides were applied with a propane-pressurized backpack sprayer delivering 190 L ha^{-1} water at 220 kPa pressure using flat fan tips[4]. In 1987, studies were conducted using thifensulfuron at 9.1 g ha^{-1}, a rate equal to the commercial rate of chlorimuron, a similar sulfonlyurea herbicide. Thifensulfuron at 9.1 g ha^{-1} killed the apical meristem on 80% of the soybeans in these studies. In an effort to reduce soybean injury and maintain phytotoxicity to weed species, lower rates of thifensulfuron (0, 1.1, 2.3, 4.5 g ha^{-1}) were investigated in 1988 and 1989. Plot size was 3 by 6 m. Each plot consisted of four rows with the center two rows treated. Soybeans were planted in 0.76 m rows at 19 plants m^{-1}. Planting date, variety planted, application time, weed species, and weed density in these studies are presented in Table 2.1. Weed species were treated at the cotyledon to eight true leaf stage. Soybeans were in the second trifoliolate leaf stage (V3) at time of herbicide application. Plots were harvested with a combine; and seed yields, adjusted for moisture at 13%, were determined. In 1989, soybeans were not harvested until December because of excessive soil moisture in October and November followed by freezing rain and snow. Pod shattering occured prior to and during 1989 harvest

[4] Teejet 8003 tips. Spraying Systems Co., Wheaton IL 60287.

reducing the gross harvest weight.

Adjuvant experiments. Nonionic surfactant was mixed with the spray solution at 0, 0.03, 0.06 and 0.125% (v/v). Crop oil concentrate (COC) was mixed with the spray solution at 0 and 1% (v/v).

Weed population. Soybean plots were seeded with weeds prior to final seed bed preparation. A rotary seeder applied 68 kg ha^{-1} of a weed seed mixture 3:1:0.5:4:4 containing smooth pigweed, common lambsquarters, common cocklebur, ivyleaf morningglory, and pitted morningglory. Germination and distribution of common cocklebur was poor for all years and was not included in the evaluation of thifensulfuron. Natural populations of annual grasses were controlled with postemergence applications of sethoxydim, 2-[1-(ethoxyimino) butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one, at 215 g ha^{-1} in 190 L ha^{-1} water at 220 kPa within 7 to 14 days of grass emergence.

Environment. Seasonal rainfall and temperature are presented in Tables 2.2 and 2.3. Moisture was adequate at planting for all 3 years, allowing establishment of a uniform stand of soybeans and weeds. In 1987, drought occurred from July to September. In 1988, sufficient rain occurred throughout the season to sustain exceptional soybean and weed growth. Excessive rainfall throughout June, July, and August of 1989, made it difficult to make timely postemergence applications of sethoxydim. Postemergence grass weed control was complicated by multiple flushes of germinating grass seeds following application in 1989.

Evaluation. Soybean injury was visually evaluated 7 to 14, 14 to 21, and 30 to 35 days after herbicide treatment (DAT). A scale of 0 to 100 was used, with 0 indicating no injury and 100 indicating plant death. Symptoms of soybean injury included: interveinal leaf chlorosis, leaf crinkling, shortening of internode length, abscission of apical meristem, and reddening of midvein, petiole, and stem. Weed control was visually evaluated at the beginning (7 to 14 DAT), middle (14 to 21 DAT), and end (35 DAT) of the growing season. This evaluation was on a scale of 0 to 99, with 0 indicating no control, and 99 indicating complete weed death.

Experimental design. Experiments were conducted using a randomized complete block design with four replications. Data from all visual observations were transformed using arcsine transformation (1) before analysis, with original data presented in tables and figures. Data were subjected to analysis of variance, and means were separated using Duncan's multiple range test (at the 0.05 significance level) and/or contrast analysis where appropriate. Significant sample variance between years as determined by Hartley's maximum F-ratio procedure (10, 13) did not allow combination of data across years. In individual tables, means have been separated within levels of factors when a significant interaction ($P < 0.05$) occurred. Figures represent a factorial analysis of nonionic surfactant at four rates by thifensulfuron at three rates. Orthogonal contrast analysis was used to determine significant differences between COC and 0.125% nonionic surfactant (13). Data from the factorial study were subjected to Duncan's multiple range test to determine

significance between means within surfactant rate.

RESULTS AND DISCUSSION

Soybean injury. Injury increased with increasing rate of nonionic surfactant and herbicide (Tables 2.5 and 2.6). Fielding and Stoller (4) also reported increased soybean injury with increasing thifensulfuron from 2.2 to 5.8 g ha^{-1}. Soybean injury was most severe 7 DAT with 0 to 45% injury depending on rate, surfactant combination, and year. Thifensulfuron at 9.1 g ha^{-1} in combination with 0.125% nonionic surfactant or 1% COC caused death of the apical meristem in 80% of soybeans treated (data not shown) and reduced soybean growth by approximately 30% in 1987. Soybeans compensated for apical death by enhanced growth of lateral meristems. Recovery was slow, requiring greater than 30 days. Moisture stress and high temperatures following herbicide application probably contributed to the slow rate of recovery in 1987. In 1988 and 1989, thifensulfuron at 4.5 g ha^{-1} with either 0.125% nonionic surfactant and COC caused equal amounts of soybean injury (41 to 49%) with no apical death (Table 2.7). Soybean recovery from injury in 1988 and 1989 occurred within 14 DAT. Adequate to excessive soil moisture and high relative humidity following herbicide application likely contributed to the faster rate of recovery in 1988 and 1989.

Common lambsquarters control. Common lambsquarters emergence was sporadic. Germination was greatest in May, when cool day/night temperatures with high soil moisture prevailed. Research in 1987 and 1988 was conducted in mid- to late-June, when lambsquarters germination is normally declining in response to high temperature and low soil moisture. In 1989, field studies were initiated in mid- and late-May, when a more uniform and dense population of common lambsquarters was present than in previous years.

Variation in years, as tested by Hartley's maximum F-ratio at 0.05 level of significance, was attributed primarily to differences in annual rainfall and prevented combination of treatments over years. Thifensulfuron at 4.5 g ha^{-1} plus nonionic surfactant at 0.06 or 0.125% provided greater than 93% common lambsquarters control in 1988 and 1989 (Tables 2.8 and 2.9). In 1989, greater than 93% control of common lambsquarters was obtained when thifensulfuron at 4.5 g ha^{-1} was combined with either 0.125% nonionic surfactant or 1% COC (Tables 2.8, 2.9, and 2.10). However, in 1988, COC at 1% in combination with 4.5 g ha^{-1} of thifensulfuron provided only 83% control of common lambsquarters, while 0.125% nonionic surfactant provided 98% control (Table 2.10). Contrast of COC with the higher rate of nonionic surfactant within rates of thifensulfuron determined that COC provided equal or less common lambsquarters control than 0.125% nonionic surfactant in both years of this study (Table 2.10). Less than 60% common lambsquarters control was obtained with thifensulfuron at 1.1 and 2.3 g ha^{-1} in combinations with 0, 0.03, and

0.06% nonionic surfactant in 1988 and 1989 (Tables 2.8 and 2.9). Addition of 0.125% nonionic surfactant to 1.1 and 2.3 g ha^{-1} of thifensulfuron increased control to 83 and 93% respectively in 1989, while no increase was obtained in 1988. Control at 1.1 and 2.3 g ha^{-1} thifensulfuron without adjuvant was less than 5% in 1988 and greater than 20% in 1989. Differences among years were probably caused by low soil moisture and high temperatures in 1988. Plants under water stress tend to have lower photoassimilate accumulation and translocation. The translocation of absorbed thifensulfuron to active sites in 1988 may have been less than in 1989 due to water stress, contributing to the differences in observed phytotoxicity at the lower thifensulfuron rates.

Smooth pigweed control: Thifensulfuron alone at 1.1 to 9.1 g ha^{-1} provided 90 to 99% control of smooth pigweed in studies conducted from 1987 to 1989 (Tables 2.10, 2.11, 2.12, and 2.13). In 1988 and 1989, smooth pigweed control was not influenced by adjuvant ($P > 0.05$). While increasing rate to 4.5 g ha^{-1} provided consistent control of smooth pigweed with or without adjuvants. All thifensulfuron rates and adjuvant combinations provided 99% control of smooth pigweed in 1989 (Tables 2.13). Low soil moisture and high soil and air temperatures prior to herbicide application in 1988 probably contributed to the differences in response of smooth pigweed to thifensulfuron between 1988 and 1989. Smooth pigweed was under moderate moisture stress during application in 1988 and may not have absorbed or translocated as much of the herbicide to the active site as in 1989. Consistent control of smooth

pigweed can be obtained with an acceptable level of crop injury by applying thifensulfuron at 2.3 g ha^{-1} with the addition of 0.125% nonionic surfactant or 1% COC.

Ivyleaf morningglory control. Thifensulfuron, at 1.1 to 4.5 g ha^{-1}, initially suppressed the growth of ivyleaf morningglory. However, ivyleaf morningglory control did not exceed 51% with thifensulfuron at any rate or adjuvant combination (Table 2.10). Ivyleaf morningglory control increased with herbicide rates (Table 2.10), suggesting that acceptable levels of control may be obtainable. However, rates of thifensulfuron above 4.5 g ha^{-1} caused unacceptable levels of soybean injury (Table 2.4). Use of thifensulfuron as a morningglory herbicide in soybean production does not appear feasible. Poor control of ivyleaf morningglory increased soybean lodging and impeded soybean harvest in 1988 and 1989.

Soybean yield analysis. Average yields for 1988 were higher (3182 kg ha^{-1}) than 1987 (1310 kg ha^{-1}) or 1989 (1544 kg ha^{-1}). Low yields in 1987 may be attributable to drought stress as well as competition from morningglory species (Tables 2.2 and 2.10). In 1989, high soil moisture in October and November followed by freezing rain and snow delayed soybean harvest until December. Shattering of pods prior to and during harvest contributed to low overall yields in 1989. Yields did increase when thifensulfuron was applied compared to untreated plots in 1988 and 1989 (Tables 2.14). However, soybean yield did not differ among thifensulfuron or surfactant rate ($P > 0.05$) in 1989, while only nonionic surfactant rate differed in 1988.

Nonionic surfactant at 0.03% averaged across all rates of thifensulfuron in 1988 was lower than all other rates of surfactant, including zero surfactant, but did not differ from the untreated plot ($P > 0.05$) (Table 2.14). High ivyleaf morningglory pressure, reduced smooth pigweed control (78% at 1.1 g ha-1 thifensulfuron), and low soil moisture during pod set likely contributed to yield reduction in the 0.03% surfactant treatments in 1988 (Tables 2.1, 2.2, 2.12).

In these studies, thifensulfuron at 4.5 g ha^{-1} plus 0.125% nonionic surfactant provided consistent control of both smooth pigweed and common lambsquarters (>98%). Control, however, was slow to develop, requiring 14 to 21 days. Greater than 96% control of smooth pigweed was obtained with thifensulfuron at 2.3 to 4.5 g ha^{-1} without adjuvants. Common lambsquarters control (>95%) was dependent upon the addition of 0.125% nonionic surfactant to thifensulfuron at 4.5 g ha^{-1}. Ivyleaf morningglory was initially suppressed by all rates of thifensulfuron and adjuvant combinations, but plants recovered within 21 DAT. Thifensulfuron at 4.5 g ha^{-1} inhibited soybean growth and development for approximately 14 to 21 DAT. This rate did not reduce soybean yield. Additional research should identify the effect of tank mixing thifensulfuron with existing postemergence grass and broadleaf herbicides to obtain a broader spectrum of postemergence weed control in soybeans.

LITERATURE CITED

1. Bartlett, M.S. 1947. The use of transformations. Biometrics. 3:39-51.

2. Eberlein, C.V., K.M. Rosow, J.L. Geadelmann, and S.J. Openshaw. 1989. Differential tolerance of corn genotypes to DPX-M6316. Weed Sci.37:651-657.

3. Feist, D.A. and J.D. Nalewaja. 1986. Adjuvants with DPX-M6316 in wheat and soybeans. Proc. North Centr. Weed Control Conf. 41:58-59.

4. Fielding, R.J. and E.W. Stoller. 1990. Effects of additives on the efficacy, uptake, and translocation of the methyl ester of thifensulfuron. Weed Sci. 38:172-178.

5. Forney, D.R., K.S. Amuti, J.S. Claus, J.D. Long, J.M. Green, L.L. Saari, H.M. Brown, and S. Sebastian. 1988. DPX-M6316, A new postemergence soybean herbicide; activity, selectivity and soil residual considerations. Abst. Weed Sci. Soc. Am. 28:17.

6. Green, J.M., D. Berengut, M.G. King, and P.A. Brown. 1989. Influence of nonionic surfactant properties on DPX-M6316 performance in corn and soybeans. Abst. Weed Sci. Soc. Am. 29:23.

7. Green, J.M. 1988. Effect of inorganic salts on the efficacy of chlorimuron and DPX-M6316 on soybeans. Abst. Weed Sci. Soc. Am. 28:16.

8. Guethle, D.R., B.D. Sims, and M.S. DeFelice. 1989. Wild garlic control in wheat. Proc. South. Weed Sci. Soc. 42:64.

9. Hammes, G.G., J.L. Saladini, and D.T. Ferguson. 1989. Weed control in

winter wheat with DPX-R9674. Proc. South. Weed Sci. Soc. 42:36.

10. Hartley, H.O. 1950. The maximum F-ratio as a short-cut test for heterogeneity of variance. Biometrika, 37:308-312.

11. Harvey, R.G. 1986. Postemergence: soybean herbicide study. Proc. North Centr. Weed Control Conf. 43:220-221.

12. Kaufman, L.M. and R.L. Ritter. 1987. Efficacy and persistence of new small grain herbicides. Abst. Weed Sci. Soc. Am. 27:8.

13. Lentner, M. 1986. Experimental design and analysis. Valley Book Company, Blacksburg, VA 24060 p.565.

14. Moomaw, R.S. 1986. Evaluation of experimental postemergence soybean herbicides. Proc. North Centr. Weed Control Conf. 43:325.

15. Nalewaja, J.D. and K.A. Adamaczewski. 1988. Thiameturon phytotoxicity to Kochia. Weed Sci. 36:296-300.

16. Sims, B.D., M.S. DeFelice, D.R. Guethle, and W.B.Brown. 1989. Influence of liquid fertilizers on postemergence herbicide activity in soybeans. Proc. South. Weed Sci. Soc. 42:83.

17. Wilms, W.C., F.B. Maxcy, and R.A.McKelvey. 1988. DPX-M6316: A new soybean postemergent broadleaf herbicide. Proc. North Centr. Weed Control Conf. 43:38.

18. Zhao, C.C., J.R. Teasdale, and C.B. Coffman. 1989. Factors affecting the activity of DPX-M6316. Abst. Weed Sci. Soc. Am. 29:23-24.

Table 2.1. Treatment information for postemergence applications of thifensulfuron in conventional soybeans.

Planting date	Soybean variety	Application time	Species	Growth stage	Density
		DAP[a]			no. m^{-2}
5 June 1987	Asgrow 5149	13	soybean	V3[b]	19[c]
			AMACH	cot-4 leaf	397
			CHEAL	cot-7	21
16 June 1987	Essex	27	soybean	V3	19
			AMACH	0.61[d]	43
			IPOHE	1.2	54
7 June 1988	Asgrow 4906	17	soybean	V3	19
			AMACH	cot-2 leaf	488
			CHEAL	cot-7 leaf	104
			IPOHE	cot-3 leaf	52
19 May 1989	Essex	17	soybean	V3	19
			AMACH	cot-4 leaf	172
			CHEAL	cot-8 leaf	72
			IPOHE	cot-4 leaf	32

[a]DAP- days after planting.
[b]Fehr, W.R. *et al.* 1971. Stage of Development descriptions for soybeans. Crop Sci. 11:929-931.
[c]Soybean seeding rate in m^{-1}.
[d]Weed seedling height in meters.

Table 2.2. Growing season precipitation from 1987 through 1989 at Painter, VA.

Month	1987	1988	1989
		cm	
April	7	8	11
May	4	8	7
June	11	8	11
July	3	12	18
August	2	13	23
September	5	8	7
October	7	8	9
Total	39	65	86
Monthly average	6	9	12

Table 2.3. Maximum and minimum growing season temperatures by month from 1987 through 1989 at Painter, VA.

Month	1987		1988		1989	
	Max.	Min.	Max.	Min.	Max.	Min.
	C					
April	17	7	18	7	18	6
May	26	13	23	13	23	13
June	29	15	28	17	29	20
July	32	21	31	21	30	21
August	31	20	30	22	27	19
September	28	18	26	16	27	18
October	19	7	18	7	22	11

Table 2.4. Soybean injury as influenced by 9.1 g ha^{-1} thifensulfuron applied alone and or in combination with either nonionic surfactant (Ns) or crop oil concentrate (COC). Ratings were made 7, 14, 21, and 36 days after treatment (DAT) in 1987[a].

Adjuvant		Injury			
		DAT[b]			
Type	Concentration	7	14	21	36
	%	%			
——[b]	0	20	15	18	0
Ns	0.125	31	19	26	0
COC	1.00	30	20	29	0
LSD (0.05)		5	4	3	NS

[a]Means are averages of two studies with four replications each.
[b]Thifensulfuron applied without adjuvant.

Influence of Adjuvants . . .

Table 2.5. Soybean injury 7, 21, and 35 days after foliar treatment (DAT) with thifensulfuron alone and in combinations with either nonionic surfactant (Ns) or crop oil concentrate (COC) in 1988.

Thifensulfuron rate	Adjuvant		DAT		
	Type	Rate	7	21	35
g ha^{-1}		%		%	
1.1	none	—	0	0	0
2.3		—	0	0	0
4.5		—	9	0	0
1.1	Ns	0.03	0	0	0
1.1	"	0.06	1	0	0
1.1	"	0.125	5	0	0
1.1	COC	1.00	0	0	0
2.3	Ns	0.03	3	0	0
2.3	"	0.06	9	0	0
2.3	"	0.125	20	0	0
2.3	COC	1.00	23	0	0
4.5	Ns	0.03	19	0	0
4.5	"	0.06	33	0	0
4.5	"	0.125	45	0	0
4.5	COC	1.00	47	0	0
LSD (0.05)			10	NS	NS

Influence of Adjuvants . . .

Table 2.6. Soybean injury 7, 21, and 35 days after foliar treatment (DAT) with thifensulfuron alone and in combination with either nonionic surfactant (Ns) or crop oil concentrate (COC) in 1989.

Thifensulfuron rate	Adjuvant		DAT		
	Type	Rate	7	21	35
g ha^{-1}		%	%		
1.1	none	—	0	0	0
2.3		—	3	0	0
4.5		—	5	0	0
1.1	Ns	0.03	2	0	0
1.1	"	0.06	3	0	0
1.1	"	0.125	9	1	0
1.1	COC	1.00	4	0	0
2.3	Ns	0.03	10	0	0
2.3	"	0.06	10	0	0
2.3	"	0.125	36	2	0
2.3	COC	1.00	20	2	0
4.5	Ns	0.03	30	0	0
4.5	"	0.06	35	1	0
4.5	"	0.125	41	3	0
4.5	COC	1.00	49	4	0
LSD (0.05)			6	1	NS

Influence of Adjuvants . . .

Table 2.7. Soybean injury at three rates of thifensulfuron applied alone or in combination with 0.125% nonionic surfactant (Ns) or 1% crop oil concentrate (COC) in 1988 and 1989[ab]. Ratings were made 7, 14, and 21 days after treatment (DAT).

	Year							
	1988				1989			
Time rate	None	Ns	COC		None	Ns	COC	
g ha^{-1}	injury %							
7 DAT								
1.1	0Bb	5Ac	0Bc	-	0Cb	9Ab	4Bc	–
2.3	0Cb	20Bb	30Ab	=	3Ca	36Aa	20Bb	–
4.5	9Ba	45Aa	45Aa	=	5Ca	41Aa	49Aa	=
14 DAT								
1.1	0	0	0	=	0Ba	1Ac	0Bc	–
2.3	0	0	0	=	0Ba	2Ab	1Ab	=
4.5	0	0	0	=	0Ba	1Ba	4Aa	+
21 DAT								
1.1	0	0	0	=	0Ba	0Ab	0Ab	=
2.3	0	0	0	=	0Ba	0Bb	0Ab	=
4.5	0	0	0	=	1Ba	4Aa	4Aa	=

[a]Means are average of 4 replications. Individual means for herbicide rates and adjuvant rates within a year, evaluation time, and a column followed by the same lower case letter and means within row with the same upper case letter do not differ significantly ($P>0.05$) as determined by Least Significant Difference test.

[b]Mean separation was performed using single degree of freedom contrasts. Within row, = indicates that COC was not different from 0.125% surfactant at given herbicide rate; + indicates that COC was more active than surfactant; - indicates COC was less active than surfactant.

Influence of Adjuvants . . .

Table 2.8. Common lambsquarters control 7, 21, and 35 days after foliar treatment (DAT) with thifensulfuron alone and in combination with either nonionic surfactant or crop oil concentrate (COC) in 1988.

Thifensulfuron rate	Adjuvant Type	Adjuvant Rate	DAT 7	DAT 21	DAT 35
g ha^{-1}		%	%	%	%
1.1	none	—	12	0	57
2.3		—	23	0	80
4.5		—	87	33	95
1.1	Ns	0.03	20	0	—
1.1	"	0.06	16	4	64
1.1	"	0.125	47	0	89
1.1	COC	1.00	25	0	75
2.3	Ns	0.03	32	44	—
2.3	"	0.06	69	58	92
2.3	"	0.125	82	46	96
2.3	COC	1.00	50	3	65
4.5	Ns	0.03	94	83	98
4.5	"	0.06	99	98	98
4.5	"	0.125	99	98	99
4.5	COC	1.00	97	83	98
LSD (0.05)			24	6	25

Influence of Adjuvants . . .

Table 2.9. Common lambsquarters control 7, 21, and 35 days after foliar treatment (DAT) with thifensulfuron alone and in combination with either nonionic surfactant (Ns) or crop oil concentrate (COC) in 1989.

Thifensulfuron rate	Adjuvant		DAT		
	Type	Rate	7	21	35
g ha^{-1}		%		%	
1.1	none	—	23	26	23
2.3		—	22	38	26
4.5		—	40	66	53
1.1	Ns	0.03	28	62	53
1.1	"	0.06	31	68	51
1.1	"	0.125	37	83	83
1.1	COC	1.00	31	90	80
2.3	Ns	0.03	28	58	49
2.3	"	0.06	40	86	58
2.3	"	0.125	56	98	93
2.3	COC	1.00	46	88	88
4.5	Ns	0.03	56	98	93
4.5	"	0.06	55	98	93
4.5	"	0.125	61	98	96
4.5	COC	1.00	62	97	94
LSD (0.05)			9	8	7

Influence of Adjuvants . . .

Table 2.10. Common lambsquarters (CHEAL), smooth pigweed (AMACH), and ivyleaf morningglory (IPOHE) control with thifensulfuron alone and in combinations with 0.125% nonionic surfactant (Ns) or 1% crop oil concentrate (COC) 35 days after treatment.[ab]

	Weed Control							
	1988				1989			
Species rate	None	Ns	COC		None	Ns	COC	
g ha^{-1}	%							
CHEAL								
1.1	0Ab	0Ac	0Ab	=	23Cb	83Ab	79Ab	=
2.3	0Cb	46Ab	3Bb	-	26Eb	93Aa	88Bab	–
4.5	34Ca	98Aa	83Ba	-	54Ba	96Aa	94Aa	=
AMACH								
1.1	90Ab	90Ab	93Aa	=	99	99	99	=
2.3	96Aa	94Ab	95Aa	=	99	99	99	=
4.5	99Aa	99Aa	99Aa	=	99	99	99	=
IPOHE								
1.1	0	0	0	=	13Cb	31Ac	31Ac	=
2.3	0	0	0	=	15Cb	45Ab	40Ab	=
4.5	0	0	0	=	31Ca	51Aa	50Aa	=

[a]Means are average of 4 replications. Individual means for herbicide rates and adjuvant rates within a year, broadleaf weed species and a column followed by the same lower case letter and means within row with the same upper case letter do not differ significantly at the 0.05 level as determined by Least Significant Difference test.

[b]Mean separation was performed using single degree of freedom contrasts. Within row, = indicates that COC was not different from 0.125% surfactant at given herbicide rate; + indicates that COC was more active than surfactant; - indicates COC was less active than surfactant.

Influence of Adjuvants . . .

Table 2.11. Smooth pigweed and common lambsquarters control 35 days after treatment (DAT) and yield of soybeans following foliar applications of 9.1 g ha^{-1} thifensulfuron applied alone or in combinations with either nonionic surfactant (Ns) or crop oil concentrate (COC) in 1987[a].

Adjuvant		Control[b]		
Type	Concentration	AMACH	CHEAL	YIELD
	%	—— % ——		kg ha^{-1}
——[b]	0	99	96	1490
Ns	0.125	99	98	1295
COC	1.00	99	99	1417
untreated	0	0	0	1100
LSD (0.05)		0	11	NS

[a]Means are averages of 4 replications.
[b]Thifensulfuron applied without adjuvant.

Influence of Adjuvants . . .

Table 2.12. Smooth pigweed control 7, 21, and 35 days after foliar treatment (DAT) with thifensulfuron alone and in combination with either nonionic surfactant (Ns) or crop oil concentrate (COC) in 1988.

Thifensulfuron rate	Adjuvant		DAT		
	Type	Rate	7	21	35
g ha^{-1}		%		%	
1.1	none	—	98	90	90
2.3		—	99	96	96
4.5		—	99	99	99
1.1	Ns	0.03	93	86	78
1.1	"	0.06	99	91	96
1.1	"	0.125	96	90	92
1.1	COC	1.00	99	94	98
2.3	Ns	0.03	95	95	98
2.3	"	0.06	99	99	99
2.3	"	0.125	99	94	98
2.3	COC	1.00	87	78	75
4.5	Ns	0.03	99	99	99
4.5	"	0.06	99	98	99
4.5	"	0.125	99	99	99
4.5	COC	1.00	99	99	99
LSD (0.05)			10	13	19

Influence of Adjuvants . . .

Table 2.13. Smooth pigweed control 7, 21, and 35 days after foliar treatment (DAT) with thifensulfuron alone and in combination with either nonionic surfactant (Ns) or crop oil concentrate (COC) in 1989.

Thifensulfuron rate	Adjuvant		DAT		
	Type	Rate	7	21	35
g ha^{-1}		%		%	
1.1	none	—	88	99	99
2.3		—	93	99	99
4.5		—	95	99	99
1.1	Ns	0.03	93	99	99
1.1	"	0.06	91	99	99
1.1	"	0.125	96	99	99
1.1	COC	1.00	95	99	99
2.3	Ns	0.03	95	99	99
2.3	"	0.06	96	99	99
2.3	"	0.125	96	99	99
2.3	COC	1.00	96	99	99
4.5	Ns	0.03	96	99	99
4.5	"	0.06	97	99	99
4.5	"	0.125	96	99	99
4.5	COC	1.00	97	99	99
LSD (0.05)			2	NS	NS

Influence of Adjuvants . . .

Table 2.14. Soybean yield as influenced by three rates of thifensulfuron in combinations with either nonionic surfactant or crop oil concentrate (COC) in 1988 and 1989[a].

	Nonionic surfactant %				COC %			
rate	0	0.03	0.06	0.125	1.00	check	mean	LSD
g ha^{-1}	kg ha^{-1}							
1988[b]								
1.1	2749	2908	3201	2835	2957	—	2930	NS
2.3	3299	2541	3628	3213	3348	—	3206	NS
4.5	3885	2773	3201	3616	3580	—	3411	NS
check	—	—	—	—	—	—	2566	NS
mean	3311	2740	3343	3221	3295	2566		NS
LSD (0.05)							481	
1989								
1.1	1970	2331	1952	1633	2889*	—		956
2.3	1871	1959	1970	2716	2012	—		680
4.5	3507	2222	2296	2239	2276	—		NS
check	—	—	—	—	—	1528		
LSD (0.05)	1015	NS	NS	645	671			

[a]Means are average of 4 replications.
[b]Means within COC column with * indicates significantly different from 0.125% v/v nonionic surfactant at equivalent thifensulfuron rate as determined by orthogonal contrast analysis ($P \leq 0.05$).

Influence of Adjuvants . . .

CHAPTER III

THIFENSULFURON AND CHLORIMURON COMBINATIONS FOR POSTEMERGENCE BROADLEAF WEED CONTROL IN SOYBEAN (Glycine max)

Abstract. Thifensulfuron and chlorimuron were tank mixed in 4:1, 2:1, 1:1, 1:2 and 1:4 ratios and applied with 0.125% nonionic surfactant to seedling common lambsquarters, smooth pigweed, and ivyleaf morningglory to investigate control in soybeans. Experiments were conducted between 1987 and 1989 utilizing both herbicides at rates of 1.1 to 9.1 g ha^{-1} in 1987 and 1.1 to 4.5 g ha^{-1} in 1988 and 1989. Soybean injury occurred within 7 days after treatment (DAT) and persisted for no more than 35 days in each year of the study. In 1987, no more than 22% soybean injury occurred, while up to 54% injury was recorded 14 DAT in 1988 and 1989. Injury was manifested as growth reduction, reddening of midvein and nodes, retarded leaf expansion, abscission of apical or lateral meristems, and general chlorosis of newly formed leaves. In 1988, soybean height was reduced by 3 and 4% 60 DAT with thifensulfuron alone at 2.3 and 4.5 g ha^{-1}, respectively. Combinations with chlorimuron, however, did not reduce soybean growth. No growth reduction was recorded in 1987 or 1989. Thifensulfuron alone and in combination with chlorimuron provided 99% control of smooth pigweed at rates as low as 1.1 g ha^{-1} in 1987 and 1989. In 1988, greater than 2.3 g ha^{-1} of thifensulfuron was required to obtain 95% smooth pigweed control. Thifensulfuron provided smooth pigweed control at half the

rate of chlorimuron in each year of this study. In 1988, thifensulfuron at 2.3 g ha^{-1} provided 97% smooth pigweed control 35 DAT, while 4.5 g ha^{-1} of chlorimuron was required to obtain the same level of control. Common lambsquarters control with thifensulfuron increased over time. Plants died within 35 days of thifensulfuron treatments. Thifensulfuron activity on common lambsquarters increased with increasing rate, providing 68 to 99% control in 1988 and 1989. Chlorimuron was not active on common lambsquarters at rates tested. The addition of chlorimuron to thifensulfuron did not influence common lambsquarters control. Ivyleaf morningglory control increased with increasing rates of both herbicides, however levels of control >90% were not obtained. Soybean yields varied with year and treatment. Chlorimuron and chlorimuron + thifensulfuron treatments in general provided higher yields than thifensulfuron alone in all years of this study. Nomenclature: Thifensulfuron, 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid; Chlorimuron, 2-[[[[4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl] benzoic acid; Acifluorfen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid; Bentazon, 3-(1-methylethyl-)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one2,2-dioxide; Imazaquin, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid; 2,4-DB, 4-(2,4-dichlorophenoxy)butanoic acid; sethoxydim {2-[1-ethyoxyimino)butyl]-5-{2-(ethylthio)propyl]-3-hyroxy-2-cyclohexen-1-one}; soybean, *Glycine max* (L.) Merr.

'Essex, Asgrow 4906, Asgrow 5149'; smooth pigweed, *Amaranthus hybridus* L. #[1] AMACH; common lambsquarters, *Chenopodium album* L. # CHEAL; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. # IPOHE;

Additional index words. DPX-M6316, thiameturon, nonionic surfactant, adjuvant, AMACH, CHEAL, IPOHE.

INTRODUCTION

Common lambsquarters, smooth pigweed, and ivyleaf morningglory are predominant weeds in many cultivated fields in eastern Virginia (20). Preemergence herbicides such as acetanilides, dinitroanilines, and imidazolinones are available for smooth pigweed and common lambsquarters control in soybeans. Control, however, varies with herbicide. Weed seedling escapes often occur in response to inadequate moisture for herbicide activation or excessive rainfall, which can leach the herbicide out of its optimum zone of activity. Considerable progress has been made in the development of herbicides for postemergence broadleaf weed control in soybeans. Diphenylethers, bentazon, sulfonylureas, and imidazolinone herbicides provide postemergence control of several broadleaf weeds with selectivity to soybeans (1,5,10,12,14). Broad-spectrum postemergence weed control in soybeans currently

[1]Letters following these symbols are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2, Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

requires the timely application of combinations of available herbicides (17). Bentazon plus acifluorfen applied to seedling common lambsquarters, common ragweed, and morningglory species provided 88, 87, and 91% control, respectively, in Virginia (19). Tank mixtures, however, do not always prove compatible. Tank mixtures of bentazon with sethoxydim decreased the activity of sethoxydim on grass species and decreased soybean selectivity (6,9,11,15).

Thifensulfuron, a new postemergence sulfonylurea herbicide, provided greater than 96% control of both seedling common lambsquarters and smooth pigweed in soybeans at rates as low as 4.5 g ha^{-1} (19). Common lambsquarters control with thifensulfuron, however is dependent upon the addition of nonionic surfactant (7). Wilcut et al. (19) applied thifensulfuron in tank mixtures with acifluorfen plus 2,4-DB and decreased common lambsquarters control by 29% compared to thifensulfuron applied alone. Chlorimuron, another sulfonylurea postemergence soybean herbicide, provides control of common cocklebur, (*Xanthium strumarium* L. #XANST), redroot pigweed (*Amaranthus retroflexus* L. #AMARE), and partial control of annual morningglory species (*Ipomoea sp.*), however, it does not provide control of common lambsquarters (18). Combinations of chlorimuron with acifluorfen, bentazon, 2,4-DB, or imazaquin provide 70 to 98% common lambsquarter control (19). These data illustrate the potential utility of chlorimuron tank mixtures for broad-spectrum postemergence broadleaf weed control in soybeans.

Combination of Thifensulfuron ...

The objective of this research was to investigate seedling common lambsquarters, smooth pigweed, and ivyleaf morningglory control and soybean response to foliar-applied combinations of thifensulfuron with chlorimuron.

MATERIALS AND METHODS

General field procedures. Research was conducted in 1987, 1988, and 1989 on a State sandy loam soil (Typic Hapladults) near Painter, VA. The soil consisted of 67% sand, 28% silt, 5% clay and 1% organic matter. The soil pH ranged from 5.4 to 6.1. Herbicides were applied with a propane-pressurized backpack sprayer delivering 190 L ha^{-1} water at 220 kPa pressure using flat fan tips[2]. In 1987, studies were conducted using thifensulfuron and chlorimuron at 1.1 to 9.1 g ha^{-1}. Thifensulfuron at 9.1 g ha^{-1} alone and in combination with chlorimuron killed the apical meristem in approximately 80% of the soybeans treated in 1987 (data not shown). Lateral meristem growth of treated soybeans compensated for the dead apical meristem within 35 DAT. Apical meristem removal was considered undesirable because of its potential for delaying canopy closer and reducing yield. Therefore, 9.1 g ha^{-1} of thifensulfuron was not included in 1988 and 1989 experiments. Field experiments were conducted utilizing plots which consisted of

[2] Teejet 8003 tips. Spraying Systems Co., Wheaton, IL 60287.

four rows with the center two rows treated. Soybeans were planted in 7.6 m rows at 19 plants m^{-1}. The treated area was 0.7 m wide by 6 m long. Planting date, tillage, variety planted, application time, weed species, and weed density in these studies are presented in Table 3.1. Weed species were treated at the cotyledon to eight true leaf stage (height 1 to 10 cm). Soybeans were in the second trifoliolate leaf stage (V3) at time of herbicide application. Plots were harvested with a combine, and seed yields, adjusted for moisture at 13%, were determined.

Adjuvant. All treatments contained nonionic surfactant[3] at a rate of 0.125% (v/v) of spray solution.

Weed population. Soybean plots were seeded with weeds prior to final seed bed preparation. A rotary seeder applied 68 kg ha^{-1} of a weed seed mixture containing smooth pigweed, common lambsquarters, ivyleaf morningglory, and pitted morningglory. Natural populations of annual grasses were controlled with postemergence applications of sethoxydim, at 215 g ha^{-1} in 190 L ha^{-1} water at 220 kPa within 7 to 14 days of grass emergence.

Environment. Seasonal rainfall and temperature are presented in Tables 3.2 and 3.3, respectively. Adequate soil moisture at planting all 3 years allowed

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[3]X-77, Chevron Chem.Co., San Francisco, CA 94119. Currently available from Valent USA Corporation, Walnut Creek, CA 94596-8025. Principal functioning agents are alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol.

establishment of a uniform stand of soybeans and weeds. In 1987, drought occurred from July to September. In 1988, sufficient rain occurred throughout the season to sustain good soybean growth and weed populations. Excessive rainfall throughout June, July, and August 1989 made it difficult to make timely application of postemergence treatments and reduced the efficacy of postemergence grass herbicides.

Evaluation. Visual estimates of percent soybean injury were made 7, 21, and 35 DAT on a scale of 0 to 100%, with 0% indicating no injury and 100% indicating plant death. Visual estimates of weed control were rated at the beginning, middle, and end of the growing season on a scale of 0 to 100%, with 0% indicating no control and 100% indicating complete death of weed species. The sulfonylurea herbicides are relatively slow acting herbicides, often requiring 21 to 30 days to control weeds.

Experimental design. Experiments were conducted using a randomized complete block design with four replications. Data from all visual observations were transformed using arcsine transformation (13) before analysis, with original data presented in tables. Transformed data were analyzed statistically by analysis of variance, and means were separated using Least Significant Difference (LSD) multiple range test at the 0.05 significance level and/or contrast analysis where appropriate. Significant sample variance between years as determined by Hartley's

maximum F-ratio procedure did not allow combination of data across years (8, 13). In individual tables, means have been separated within levels of factors when a significant (α = 0.05) interaction occurred. Tables for 1988 and 1989 represent a two factor factorial analysis with herbicides (thifensulfuron and chlorimuron) by concentrations (0, 1.1, 2.3, and 4.5). Data from the factorial study were subjected to LSD multiple range test to determine significance between means within herbicide and concentration.

RESULTS AND DISCUSSION

Soybean response. Sulfonylurea-induced injury to soybean was expressed as growth reduction (height), reddening of midvein and nodes, retarded leaf expansion, abscission of apical or lateral meristems, and general chlorosis of newly formed leaves. In all 3 years, injury increased with increasing rates of thifensulfuron and chlorimuron 7 to 14 DAT (Tables 3.4, 3.5, and 3.6). Soybean injury occurred within 7 DAT and persisted for no more than 35 days in any year of the study (Tables 3.4, 3.5, and 3.6). Thifensulfuron at 9.1 g ha^{-1} caused death of the apical meristem in 80% of plants treated in 1987 (data not shown). Soybean plants compensated for apical death by increasing growth of lateral meristems. Apical death was not recognized until 40 DAT in 1987, therefore crop injury ratings for 1987 do not take into account apical death (Table 3.4, 3.5, and 3.6). Overall height 60 DAT did not

differ across treatments (Table 3.4 and 3.7). In spite of compensatory lateral meristem growth, apical death from 9.1 g ha^{-1} of thifensulfuron was considered unacceptable due to potential delay in plant maturity, canopy closer, and yield. This rate was excluded from experiments conducted in 1988 and 1989.

Soybean injury in 1987 was delayed approximately 14 days compared to 1988 and 1989 (Tables 3.4, 3.5, and 3.6). Low soil moisture following herbicide application limited soybean growth in 1987 and is reflected in overall soybean height 60 DAT and yield (Table 3.4). Poor cuticle hydration and slow overall growth rates may have contributed to the delay in injury symptoms by reducing initial uptake and translocation of the herbicides. In 1988, soybeans treated with 1.1 to 4.5 g ha^{-1} chlorimuron were 3 to 6 cm taller 60 DAT than those treated with equivalent rates of thifensulfuron (Table 3.7). Chlorimuron and thifensulfuron combinations slowed soybean growth all 3 years, yet harvest heights were not consistantly reduced (Tables 3.4 and 3.7). Varietal or environmental influences probably contributed to thifensulfuron-induced soybean height reduction in 1988. Asgrow 4906 was planted in experiments in 1988, while Essex was planted in 1987 and 1989 (Table 3.1). Delay in soybean growth can be detrimental to overall weed management. Weed and crops compete for sunlight. Soybean canopy closer aides weed control by shading out weeds below the canopy. Shading can reduce or eliminate competition from annual weeds which can germinate throughout the growing season. Delay in soybean canopy

closer may allow weeds to compete that otherwise would have been shaded out. In such cases, an additional cultivation or herbicide treatment may be necessary to control successive flushes of weeds. Differential tolerances of corn and soybean varieties to thifensulfuron have been reported (6) and tolerance of several Virginia soybean varieties is addressed in chapter 4. No difference, however, appear to exist between Essex and Asgrow 4906 on a visual percentage injury basis 7 and 35 DAT (Tables 3.4, 3.5 and 3.6). Soybean injury as high as 54% was recorded within 14 DAT with combinations of 4.5 g ha^{-1} thifensulfuron and 4.5 g ha^{-1} chlorimuron, in both 1988 and 1989; yet neither caused height reduction 60 DAT (Tables 3.5, 3.6, and 3.7). Metabolism of thifensulfuron (3) by Asgrow 4906 and Essex soybean may differ enough to explain the height differences in 1988. Soybeans recovered from initial herbicide injury within 35 DAT in all years of this study (Tables 3.4, 3.5, and 3.6).

Smooth pigweed. In each year of this study, thifensulfuron and chlorimuron, alone and in combination, inhibited smooth pigweed growth within 7 DAT (Tables 3.8, 3.9, and 3.10). Smooth pigweed death was more rapid than other species in this study, howev er, 21 to 30 days were required to determine whether plants would recover. Thifensulfuron alone and in combination with chlorimuron provided 95 to 99% smooth pigweed control across all rates and rate ratios in 1987 and 1989 (Tables 3.8 and 3.10). Chlorimuron alone at 1.1 g ha^{-1} provided 99% smooth pigweed control in

1987 and 1989, while less than 66% smooth pigweed control was obtained in 1988 (Tables 3.8 and 3.9). In 1988, 1.1 g ha^{-1} of thifensulfuron provided only 65% smooth pigweed control, while chlorimuron alone at 1.1 and 2.3 g ha^{-1} provided only 66 and 55% control, respectively. Combinations of thifensulfuron at 1.1 g ha^{-1} with chlorimuron at 1.1 and 2.3 g ha^{-1} in 1988 increased smooth pigweed control from less than 65% for each treatment alone to greater than 90% control 35 DAT (Table 3.9). Herbicide penetration in 1988 may have been less than in other years due to the occurrence of a heavy rain fall (5 cm) within 4 hours of application. In 1989, all rates of thifensulfuron provided greater than 97% smooth pigweed control alone and in combination with chlorimuron (Table 3.10). A minimum of 4.5 g ha^{-1} chlorimuron, applied alone, was required to provide greater than 95% smooth pigweed control in 1988 and 1989 (Tables 3.9 and 3.10). Consistent smooth pigweed control was obtained with 2.3 g ha^{-1} thifensulfuron, while 4.5 g ha^{-1} of chlorimuron was required to obtain the same results in all years of this study (Tables 3.8, 3.9, and 3.10). Combinations of 1.1 g ha^{-1} thifensulfuron with 1.1 to 4.5 g ha^{-1} chlorimuron have the potential of providing consistent smooth pigweed control. Reducing rates of chlorimuron is desirable where postemergence treatments follow preemergence treatments of chlorimuron plus linuron or chlorimuron plus metribuzin package mixes. Under these circumstances soil residual concentrations of chlorimuron may preclude rotation to sensitive crop species following soybeans. Both thifensulfuron

and chlorimuron have little to no soil activity at the concentrations reported in these studies (18). Due to the short half-life of thifensulfuron (approx. 7-21 DAT) and the limited amount of sprayed product reaching the soil, it is not anticipated that this herbicide will pose any threat to rotational crop species (18).

Common lambsquarters. Despite a history of heavy infestation, common lambsquarters was not present in experiments conducted in 1987. Low common lambsquarters populations in 1987 were possibly in response to high soil temperatures and low soil moisture at time of soybean planting. Experiments conducted in 1988 and 1989 had adequate soil moisture and soil temperatures for optimum common lambsquarters germination and emergence.

Common lambsquarters control varied with year and rate of thifensulfuron. Thifensulfuron at 2.3 g ha^{-1} provided 99% common lambsquarters control in 1988 and 86% control in 1989 (Tables 3.11 and 3.12). Common lambsquarters control increased with increasing rates of thifensulfuron, with 4.5 g ha^{-1} providing 99% control in 1988 and 95% in 1989 (Tables 3.11 and 3.12). As with smooth pigweed, complete death of common lambsquarters generally occured 21 to 30 DAT, while growth inhibition was present at 7 and 21 DAT (Tables 3.11 and 3.12). Chlorimuron, alone, did not control or reduce the growth of common lambsquarters (Tables 3.11 and 3.12). Chlorimuron and thifensulfuron tank-mixtures did not appear to influence thifensulfuron activity on common lambsquarters in 1988 or 1989 (Tables 3.11 and

3.12). Thifensulfuron was not as active on common lambsquarters in 1989 as in 1988. While common lambsquarters control increased with thifensulfuron rate, control did not exceed 95% in 1989. Differences in thifensulfuron activity in 1988 and 1989 may be related to differences in relative growth stage of common lambsquarters. In 1989, the majority of the common lambsquarters were in the eight-leaf stage versus the cotyledon to four leaf stage in 1988. Differences in common lambsquarters control between years suggest the need for early applications and use of not less than 4.5 g ha^{-1} thifensulfuron for consistent common lambsquarters control in soybeans.

Ivyleaf morningglory. In all years, ivyleaf morningglory control increased with increasing rate of both thifensulfuron and chlorimuron alone and in combinations (Tables 3.13, 3.14, and 3.15). Plant growth was inhibited within 7 DAT, however, control 35 DAT did not exceed 52% with thifensulfuron alone in any year of this study (Tables 3.13, 3.14, and 3.15). In 1987, ivyleaf morningglory control increased over time, with chlorimuron providing 77% control 35 DAT with the labeled use rate of 9.1 g ha^{-1}. Thifensulfuron at 9.1 g ha^{-1} was 30% less active than chlorimuron on ivyleaf morningglory in 1987 (Table 3.13). Ivyleaf morningglory control in 1988 and 1989 decreased over time due to recovery of treated plants and was 30 to 40% below that of 1987 (Tables 3.13, 3.14, and 3.15). Rainfall within 4 h of herbicide application probably contributed to lower levels of morningglory control in both 1988 and 1989. The addition of 2.3 g ha^{-1} and 4.5 g ha^{-1} thifensulfuron to 1.1, 2.3 and 4.5

g ha^{-1} chlorimuron in 1988 increased the activity on ivyleaf morningglory versus either rate alone. Combinations of chlorimuron with thifensulfuron did not increase the activity of either herbicide on ivyleaf morningglory in 1989 (Table 3.15). The lower use rates (1.1 to 4.5 g ha^{-1}) of both herbicides alone or in combination did not provide acceptable ivyleaf morningglory control, therefore, additional herbicides and/or cultivation would be required to control this weed.

Soybean yield analysis. Soybean yield varied with year and herbicide treatment. July and August rainfall in 1987 was one-quarter that of 1988 and 1989 (Table 3.2). Low relative soil moisture and seasonally high temperatures caused overall seed yields for 1987 to be 25 to 50% of those obtained in 1988 and 1989 (Tables 3.16 and 3.17). The untreated weedy check produced higher yields than all herbicide treatments in 1987. The weeds present in the untreated check plots were stunted and under severe drought stress. The additional herbicide stress on soybean plants probably contributed to the lower yields in treated plots. In the untreated check plots, soybeans may have provided ground cover limiting the amount of moisture lost to soil evaporation and underlying water stressed weed species. By measuring cotton and velvetleaf (*Abutilon theophrasti* Medic. #ABUTH) transpiration, Salisbury and Chandler (16) determined that an overtopping canopy can diminish the water use of underlying species regardless of soil moisture status (16).

Soybeans treated with thifensulfuron alone at 1.1 to 9.1 g ha^{-1} had in general,

lower seed yields than those treated with chlorimuron alone or chlorimuron combinations with thifensulfuron in all years of this study (Tables 3.16 and 3.17). In 1988 and 1989, no difference between the untreated plot yield and any rate of thifensulfuron alone were recorded (Table 3.17). Addition of chlorimuron increased control of ivyleaf morningglory and increased soybean yield in both 1988 and 1989 (Table 3.17). Increasing chlorimuron concentration increased both ivyleaf morningglory control and yield in each year of this study (Tables 3.14, 3.15, 3.16, and 3.17). Soybean injury and control of both common lambsquarters and smooth pigweed did not appear to influence yield in 1987, 1988, or 1989. Soybean yields with chlorimuron and combinations in 1987, 1988, and 1989 are probably due to the higher level of ivyleaf morningglory control obtained with chlorimuron and chlorimuron combinations as compared to thifensulfuron alone. Vines of ivyleaf morningglory remained green well after the crop had matured delaying harvest in each year of this study. Vines also became entangled with the reel and feeder housing of the combine interferring with thrashing of the soybean plants and causing further delays in harvest.

The combinations of 4.5 g ha^{-1} thifensulfuron with 1.1 to 4.5 g ha^{-1} chlorimuron provided greater than 85% control of seedling common lambsquarters and 99% control smooth pigweed. Control of ivyleaf morningglory with chlorimuron was not influenced by the addition of thifensulfuron. Activity of both herbicides

alone or in combinations provided no more than 77% ivyleaf morningglory control in 1988 or 1989. Additional research will be required to characterize the interactions of other herbicides with thifensulfuron to provide a broader spectrum of weed control.

LITERATURE CITED

1. Banks, Van E. 1988. Influence of soybean oil carrier and method of application on weed control in soybean (*Glycine max*). Weed Sci. 36:504-509.

2. Bartlett, M.S. 1947. The use of transformations. Biometrics. 3:39-51.

3. Brown, H.M., V.A. Wittenbach, D.R. Forney, and S.D. Strachan. 1990. Basis for soybean tolerance to thifensulfuron methyl. Pestic. Biochem. Physiol. 37:303-313.

4. Crook, Teresa M. and Karen A. Renner. 1990. Common lambsquarters (*Chenopodium album*) competition and time of removal in soybeans (*Glycine max*). Weed Sci. 38:358-364.

5. Croon, K.A. and M.G. Merkle. 1988. Effects of bentazon, imazaquin, and chlorimuron on haloxyfop and fluazifop-P efficacy. Weed Tech. 2:36-40.

6. Eberlein, C.V., K.M. Rosow, J.L. Geadelmann, and S.J. Openshaw. 1989. Differential tolerance of corn genotypes to DPX-M6316. Weed Sci. 37:651-657.

7. Forney, D.R., K.S. Amuti, J.S. Claus, J.D. Long, J.M. Green, L.L. Saari, H.M. Brown, and S. Sebastian. 1988. DPX-M6316, A new postemergence soybean herbicide; activity, selectivity and soil residual considerations. Abst. Weed Sci. Soc. Am. 28:17.

8. Hartley, H.O. 1950. The maximum F-ratio as a short-cut test of heterogeneity of variance. Biometrika. 37:308-312.

9. Hartzler, R.G. and C.L. Foy. 1983. Compatability of BAS 90520H with aciflurofen and bentazon. Weed Sci. 31:597-599.

10. Higgins, J.M., T. Whitwell, E.C. Murdock, and J.E. Toler. 1988. Recovery of pitted morningglory (*Ipomoea lacunosa*) and ivyleaf morningglory (*Ipomoea hederacea*) following application of acifluorfen, formesafen and lactofen. Weed Sci. 36:345-352.

11. Gerwick, B. Clifford, Jr. 1988. Potential mechanisms for bentazon antagonism with haloxyfop. Weed Sci. 36:286-290.

12. Lee, S.A. and L.R. Oliver. 1982. Efficacy of acifluorfen on broadleaf weed. Times and methods of application. Weed Sci. 30:520-526.

13. Lentner, M. 1986. Experimental design and analysis. Valley Book Company. Blacksburg, VA 24060 p.565.

14. McWhorter, C.G. and J.M.Anderson. 1976. Bentazon applied postemergence for economical control of common cocklebur in soybeans. Weed Sci. 24:391-396.

15. Rhodes, G.N., Jr. and H.D.Coble. 1984. Influence of application variables on antagonism between sethoxydim and bentazon. Weed Sci. 32:436-441.

16. Salisbury, C.D. and J.M.Chandler. 1989. A stem flow gauge to measure water

use by weeds and crops. Proc. South. Weed Sci. Soc. 43:294.

17. Waters, M. 1990. Postemergence lactofen with bentazon, chlorimuron, imazaquin in soybeans. Proc. Northeast. Weed Sci. Soc. 44:41.

18. Weed Science Society of America. 1989. Herbicide Handbook. 6th edition. pp. 54-55, 117-119. Weed Sci. Soc. Am., Champaign, IL 61820.

19. Wilcut, J.W., D.N. Horton, and L.D. Fortner. 1990. Postemergence combinations with imidazolinone and sulfonylurea herbicides in soybeans. Proc. Northeast. Weed Sci. Soc. 44:40.

20. Wilson, H.P., and T. E. Hines. 1987. Snapbean (*Phaseolus vulgaris*) and common lambsquarters (*Chenopodium album*) response to acifluorfen. Weed Tech. 1:18-21.

Table 3.1. Treatment information for postemergence applications of thifensulfuron in conventional soybeans for control of smooth pigweed (AMACH), ivyleaf morningglory (IPOHE), and common lambsquarters (CHEAL).

Planting date	Soybean variety	Application time	Species	Growth stage	Density
		DAP[a]		leaf	no. m^{-2}
5 June 1987	Essex	13	soybean	V3[b]	19[c]
			AMACH	cot-3	286
			IPOHE	1 - 4	54
8 June 1988	Asgrow 4906	17	soybean	V3	19
			AMACH	cot-4	378
			CHEAL	cot-4	88
			IPOHE	3 - 4	61
19 May 1989	Essex	17	soybean	V3	19
			AMACH	cot-4	241
			CHEAL	cot-8	80
			IPOHE	cot-4	35

[a] DAP = days after planting.
[b] Fehr, W.R. *et al.* 1971. Stage of development descriptions for soybeans. Crop Sci. 11:929-931.
[c] Soybeans planted m^{-1}.

Table 3.2. Growing season precipitation from 1987 through 1989 at Painter, VA.

Month	1987	1988	1989
		c m	
April	7	8	11
May	4	8	7
June	11	8	11
July	3	12	18
August	2	13	23
September	5	8	7
October	7	8	9
Total	39	65	86
Monthly average	6	9	12

Table 3.3. Maximum and minimum growing season temperatures from 1987 through 1989 at Painter, VA.

Month	1987		1988		1989	
	Max.	Min.	Max.	Min.	Max.	Min.
	C					
April	17	7	18	7	18	6
May	26	13	23	13	23	13
June	29	15	28	17	29	20
July	32	21	31	21	30	21
August	31	20	30	22	27	19
September	28	18	26	16	27	18
October	19	7	18	7	22	11

Combination of Thifensulfuron ...

Table 3.4. Soybean injury 7 and 35 days after foliar treatment (DAT) and height 60 DAT with combinations of thifensulfuron and chlorimuron in 1987[a].

Thifensulfuron rate	Chlorimuron rate	DAT		Soybean height
		7	35	
g ha^{-1}	g ha^{-1}	%		cm
1.1	—	1	0	88
2.3	—	4	0	87
4.5	—	8	0	89
9.1	—	14	0	89
—	1.1	0	0	89
—	2.3	0	0	88
—	4.5	7	0	88
—	9.1	8	0	88
1.1	1.1	3	0	88
1.1	2.3	9	0	89
2.3	2.3	6	0	89
2.3	4.5	8	0	88
2.3	9.1	13	0	88
4.5	2.3	8	0	86
4.5	4.5	13	0	89
4.5	9.1	15	0	87
9.1	9.1	12	0	89
untreated check		0	0	88
LSD (0.05)		4	NS	NS

[a]All treatments contained 0.125% v/v nonionic surfactant.

Table 3.5. Soybean injury 7 and 35 days after foliar treatment (DAT) with combinations of thifensulfuron (THIF) and chlorimuron in 1988[a].

Time	THIF rate	Chlorimuron g ha^{-1} 0	1.1	2.3	4.5	LSD(0.05)
DAT	g ha^{-1}	%				
7	0	0	26	27	45	4
	1.1	23	36	37	42	NS
	2.3	38	40	44	54	13
	4.5	39	49	50	54	NS
	LSD(0.05)	13	14	16	9	
35	0	0	0	0	0	NS
	1.1	0	0	0	0	NS
	2.3	0	0	0	0	NS
	4.5	0	0	0	0	NS
	LSD(0.05)	NS	NS	NS	NS	

[a]Means are average of 4 replications.

Table 3.6. Soybean injury 7 and 35 days after foliar treatment (DAT) with combinations of thifensulfuron (THIF) and chlorimuron in 1989[a].

Time	THIF rate	Chlorimuron gha^{-1} 0	1.1	2.3	4.5	LSD(0.05)
DAT	g ha^{-1}	%				
7	0	0	20	24	42	4
	1.1	9	26	54	50	9
	2.3	48	50	57	64	NS
	4.5	72	69	69	80	3
	LSD(0.05)	9	9	9	10	
35	0	0	0	0	0	NS
	1.1	0	0	0	0	NS
	2.3	0	0	0	0	NS
	4.5	0	0	0	0	NS
	LSD (0.05)	NS	NS	NS	NS	

[a]Means are average of 4 replications.

Table 3.7. Soybean height 60 days after treatment (DAT) with combinations of thifensulfuron (THIF) and chlorimuron in 1988 and 1989.

Year	THIF rate	Chlorimuron g ha^{-1} 0	1.1	2.3	4.5	LSD (0.05)
	g ha^{-1}	cm				
1988[b]	0	98	99	99	99	NS
	1.1	96	96	98	97	2
	2.3	94	96	96	99	2
	4.5	93	97	98	98	NS
	LSD(0.05)	2	2	NS	NS	
1989	0	110	110	110	109	NS
	1.1	108	110	108	107	NS
	2.3	108	109	106	108	NS
	4.5	107	110	107	109	NS
	LSD(0.05)	NS	NS	NS	NS	

[a]All treatments contained 0.125% v/v nonionic surfactant.
[b]Means are average of 4 replications.

Combination of Thifensulfuron ...

Table 3.8. Smooth pigweed control 7 and 35 days after foliar treatment (DAT) with combinations of thifensulfuron and chlorimuron in 1987[a].

Thifensulfuron rate	Chlorimuron rate	DAT	
		7	35
g ha^{-1}	g ha^{-1}	%	
1.1	—	99	99
2.3	—	99	99
4.5	—	99	99
9.1	—	99	99
—	1.1	99	89
—	2.3	99	88
—	4.5	99	87
—	9.1	99	98
1.1	1.1	99	95
1.1	2.3	99	99
2.3	2.3	99	99
2.3	4.5	99	99
2.3	9.1	99	98
4.5	2.3	99	99
4.5	4.5	99	99
4.5	9.1	99	99
9.1	9.1	99	99
LSD (0.05)		NS	6

[a]All treatments contained 0.125% v/v nonionic surfactant.

Combination of Thifensulfuron ...

Table 3.9. Smooth pigweed control 7 and 35 days after treatment (DAT) with combinations of thifensulfuron (THIF) and chlorimuron in 1988[a].

Time	THIF rate	Chlorimuron g ha^{-1} 0	1.1	2.3	4.5	LSD (0.05)
DAT	g ha^{-1}	%				
7[b]	0	0	50	54	95	15
	1.1	58	90	90	90	10
	2.3	97	90	97	97	NS
	4.5	95	98	98	98	NS
	LSD(0.05)	27	5	5	NS	
35[b]	0	0	82	74	98	5
	1.1	68	96	96	97	10
	2.3	98	97	99	99	NS
	4.5	99	99	99	99	NS
	LSD(0.05)	27	5	5	NS	

[a]All treatments contained 0.125% v/v nonionic surfactant.
[b]Means are average of 4 replications.

Combination of Thifensulfuron ...

Table 3.10. Smooth pigweed control 7 and 35 days after treatment (DAT) with combinations of thifensulfuron (THIF) and chlorimuron in 1989[a].

Time	THIF rate	Chlorimuron g ha^{-1} 0	1.1	2.3	4.5	LSD (0.05)
	g ha^{-1}	%				
7[b]	0	0	67	88	98	5
	1.1	98	97	98	98	NS
	2.3	98	98	98	98	NS
	4.5	98	98	98	98	NS
	LSD(0.05)	30	8	5	NS	
35	0	0	81	95	99	4
	1.1	99	99	99	99	NS
	2.3	99	99	99	99	NS
	4.5	99	99	99	99	NS
	LSD(0.05)	10	2	3	NS	

[a]All treatments contained 0.125% v/v nonionic surfactant.
[b]Means are average of 4 replications.

Combination of Thifensulfuron ...

Table 3.11. Common lambsquarters control with thifensulfuron and chlorimuron combinations 35 days after treatment (DAT) in 1988[ab].

Thifensulfuron rate	Chlorimuron rates	Control 7	35
g ha^{-1}	g ha-1	%	
0	0, 1.1, 2.3, 4.5	0	0
1.1	0, 1.1, 2.3, 4.5	60	88
2.3	0, 1.1, 2.3, 4.5	81	99
4.5	0, 1.1, 2.3, 4.5	88	99
LSD(0.05)		5	7

[a]Means are averaged across all rates of chlorimuron.
[b]All treatments contained 0.125% v/v nonionic surfactant.

Combination of Thifensulfuron ...

Table 3.12. Common lambsquarters control 7 and 35 days after treatment (DAT) with combinations of thifensulfuron (THIF) and chlorimuron in 1989[ab].

	THIF rate	Chlorimuron g ha^{-1} 0	1.1	2.3	4.5	LSD (0.05)
	g ha^{-1}	%				
7	0	0	0	0	0	NS
	1.1	38	41	44	43	NS
	2.3	58	59	58	61	NS
	4.5	70	72	69	71	NS
	LSD(0.05)	3	4	2	4	
35	0	0	0	0	0	NS
	1.1	83	81	84	80	3
	2.3	86	90	85	90	4
	4.5	95	95	93	95	3
	LSD(0.05)	3	4	2	4	

[a]All treatments contained 0.125% v/v nonionic surfactant.
[b]Means are average of 4 replications.

Combination of Thifensulfuron ...

Table 3.13. Ivyleaf morningglory control 21 and 35 days after foliar treatment (DAT) with combinations of thifensulfuron and chlorimuron in 1987[a].

Thifensulfuron rate	Chlorimuron rate	DAT	
		21	35
g ha^{-1}	g ha^{-1}	%	
1.1	—	7	43
2.3	—	11	43
4.5	—	28	47
9.1	—	58	48
—	1.1	22	48
—	2.3	42	55
—	4.5	60	78
—	9.1	57	77
1.1	1.1	25	65
1.1	2.3	38	79
2.3	2.3	36	83
2.3	4.5	47	86
2.3	9.1	77	90
4.5	2.3	60	80
4.5	4.5	47	86
4.5	9.1	83	87
9.1	9.1	72	85
LSD (0.05)		10	18

[a]All treatments contained 0.125% v/v nonionic surfactant.

Combination of Thifensulfuron ...

Table 3.14. Ivyleaf morningglory control 7 and 35 days after treatment (DAT) with combinations of thifensulfuron (THIF) and chlorimuron in 1988[ab].

Year	THIF rate	Chlorimuron g ha^{-1} 0	1.1	2.3	4.5	LSD (0.05)
	g ha^{-1}	%				
7	0	0	10	10	65	10
	1.1	5	40	52	55	23
	2.3	4	25	75	81	18
	4.5	5	80	85	83	16
	LSD(0.05)	NS	20	22	12	
35	0	0	24	19	64	14
	1.1	8	34	44	60	NS
	2.3	0	19	62	69	18
	4.5	0	77	69	77	12
	LSD(0.05)	NS	26	19	NS	

[a]All treatments contained 0.125% v/v nonionic surfactant.
[b]Means are average of 4 replications.

Combination of Thifensulfuron ...

Table 3.15. Ivyleaf morningglory control 7 and 35 days after treatment (DAT) with combinations of thifensulfuron (THIF) and chlorimuron in 1989[ab].

Year	THIF rate	Chlorimuron g ha^{-1} 0	1.1	2.3	4.5	LSD (0.05)
	g ha^{-1}	%				
7	0	0	35	54	64	7
	1.1	2	39	41	55	8
	2.3	17	42	50	61	8
	4.5	36	44	51	66	5
	LSD(0.05)	7	NS	NS	NS	
35	0	0	43	58	65	7
	1.1	31	46	53	70	8
	2.3	42	53	59	72	8
	4.5	52	56	62	73	5
	LSD(0.05)	7	8	NS	NS	

[a]All treatments contained 0.125% v/v nonionic surfactant.
[b]Means are average of 4 replications.

Combination of Thifensulfuron ...

Table 3.16. Soybean yield following foliar treatments with combinations of thifensulfuron and chlorimuron applied at the V3 growth stage in 1987[a].

Thifensulfuron rate	Chlorimuron rate	Year 1987[b]
g ha^{-1}	g ha^{-1}	kg ha^{-1}
1.1	—	580
2.3	—	642
4.5	—	681
9.1	—	545
—	1.1	545
—	2.3	676
—	4.5	606
—	9.1	726
1.1	1.1	776
1.1	2.3	627
1.1	4.5	—
2.3	1.1	—
2.3	2.3	594
2.3	4.5	821
2.3	9.1	792
4.5	1.1	—
4.5	2.3	790
4.5	4.5	690
4.5	9.1	790
9.1	9.1	742
untreated check		1037
LSD (0.05)		290

[a]All treatments contained 0.125% v/v nonionic surfactant.
[b]Means are average of 4 replicates.

Combination of Thifensulfuron ...

Table 3.17. Soybean yield as influenced by combinations of thifensulfuron (THIF) with chlorimuron in 1988 and 1989[ab].

Year	THIF rate	Chlorimuron g ha^{-1} 0	1.1	2.3	4.5	LSD (0.05)
	g ha^{-1}	kg ha^{-1}				
1988[b]	0	2348	3160	2855	3386	NS
	1.1	2336	3090	2905	2893	594
	2.3	2533	2756	3165	3090	245
	4.5	2348	3264	3189	3250	235
	LSD(0.05)	NS	520	NS	NS	
1989	0	1164	1440	1502	1557	214
	1.1	1058	1231	1398	1685	198
	2.3	1005	1302	1429	1529	378
	4.5	1118	1326	1331	1730	256
	LSD(0.05)	112	NS	NS	NS	

[a]All treatments contained 0.125% v/v nonionic surfactant.
[b]Means are average of 4 replications.

Combination of Thifensulfuron ...

CHAPTER IV

TOLERANCE OF SOYBEAN (Glycine max) VARIETIES TO FOLIAR-APPLIED THIFENSULFURON

Abstract. Tolerance of eight soybean varieties to foliar-applied methyl ester of thifensulfuron was evaluated in greenhouse studies in 1988. Five concentrations of thifensulfuron (0, 1.1, 2.3, 4.5, and 9.1 g ha^{-1}) were applied to soybeans in the third trifoliolate leaf stage (V4)[1]. Ten days after application, 2.3 to 4.5 g ha^{-1} thifensulfuron reduced shoot fresh weight of all cultivars tested. Soybean shoot fresh weights decreased with increasing thifensulfuron concentration. Interaction of soybean cultivars by thifensulfuron concentration was observed ($P<0.1$). Cultivars 'Vance' and 'York' were the most thifensulfuron-sensitive across rates 1.1 to 9.1 g ha^{-1} (27 to 53 and 21 to 47% shoot fresh weight reduction, respectively). Cultivars 'FFR 561' and 'Williams 82' were the most thifensulfuron-tolerant across rates 1.1 to 9.1 g ha^{-1} (0 to 28 and 8 to 25% shoot fresh weight reduction respectively).

Nomenclature: Thifensulfuron, 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid; soybean, Glycine max (L.) Merr. 'Essex', 'Vance', 'Williams 82', 'York', 'Bay', 'FFR 561', 'Deltapine 105', 'Hutcheson'

Additional index words. DPX-M6316, thiameturon, postemergence.

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[1]Fehr, W.R. *et al.* 1971. Stage of development descriptions for soybeans. Crop Sci. 11:929-931.

INTRODUCTION

Thifensulfuron, a sulfonylurea herbicide originally developed for broadleaf weed control in small grains (1, 11), has been evaluated for broadleaf weed control in corn (2, 5, 6) and soybean (8, 9, 10, 15, 17, 20, 21). Research indicates that corn and soybean cultivars respond differently to sulfonylurea herbicides, in particular chlorimuron, 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl) amino]carbonyl] amino]sulfonyl]benzoic acid, (14, 16, 17), thifensulfuron (6), CGA-136872, 3-[4,6-bis(difluoromehtoxy)-pyrimidin-2-yl-1-(2-methoxy carbonyl-phenylsulfonyl)-urea, and nicosulfuron, 2-[[[4,6-dimethoxypyrimidin-2-yl]aminocarbonyl]aminosulfonyl]-N,N-dimethyl-3-pyridinecarboxamide monohydrate (14). Eberlein (6) found similar inhibition of acetolactate synthase (ALS; EC 4.13.18) in both tolerant and sensitive corn genotypes and concluded that differential metabolism was responsible for differences in tolerance of inbred corn genotypes to foliar-applied thifensulfuron. Sebastian and Chaleff (17) screened soybeans for chlorsulfuron, 2-chloro-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl]amino] carbonyl] benzenesulfonamide, and chlorimuron-tolerant mutants. As with corn, no differences in ALS sensitivity was found between sensitive and tolerant mutants. Pomeranke and Nickell (16) crossed the chlorimuron-tolerant soybean strain 'Elgin' with the two sensitive strains 'BSR

101 and M74-462' and concluded that sensitivity was conferred by a single recessive gene. Although soybean is considered tolerant to 1.1 to 4.5 g ha^{-1} thifensulfuron, reports indicate that temporary soybean injury can occur within 7 to 21 days after treatment (DAT) (8, 9, 10, 13, 17, 20, 21). Soybean injury can be expressed as reduced internode length, chlorosis of newly expanded leaflets, reddening of leaf midvein, petiole, and stem. When injury was found in field studies, soybeans generally recovered within 21 DAT (20, 21). Little information is available on the sensitivity of soybean genotypes to thifensulfuron. The soybean variety 'Essex' constitutes approximately 30 to 40% of the total soybean hectareage planted annually in Virginia (19). Essex is also a parent to a number of other commonly planted soybean varieties (Table 4.1) (4, 18). The objectives of this research were 1) to evaluate the growth response of selected soybean genotypes under greenhouse conditions within 10 days of treatment with foliar-applied thifensulfuron and 2) to determine if thifensulfuron sensitivity of 'Essex' or soybean cultivars with 'Essex' parentage differs between other cultivars.

MATERIALS AND METHODS

In August of 1988, soybean varieties (Table 4.1) were seeded in 950 ml styrofoam cups containing 1.3 kg of soil and thinned to four plants per container. Studies were conducted using a State sandy loam soil (Typic Hapladults) consisting

of 67% sand, 28% silt, 5% clay, and 1% organic matter with a pH of 6.1. Average maximum and minimum greenhouse temperatures throughout the studies were 35 and 20 C. Solar irradiance was recorded with photysnthetic photon flux densities ranging between 300 to 800 uE m^{-2} s^{-1} with approximately 15 h day/ 9 h nights were recorded. Plants were watered as necessary and fertilized weekly with a complete, water-soluble fertilizer[2] at 125 mg cup^{-1} in 50 ml water. Soybeans were treated at the third trifoliolate leaf stage [V4] (7). Thifensulfuron was applied to the foliage with a propane-pressurized backpack sprayer delivering 190 L ha^{-1} spray mix at 220 kPa pressure using flat fan tips[3]. Thifensulfuron was applied at 0, 1.1, 2.3, 4.5, and 9.1 g ha^{-1}. A nonionic surfactant[4] was included at 0.125% of the spray volume.

Plants were treated and arranged on greenhouse benches in a completely randomized design. Treatments were replicated three times and the study was repeated one week following initiation of the first. Soybean leaves and stems were harvested 10 days after herbicide application by cutting stems at the soil surface. Shoot fresh and dry weights were obtained. Injury was evaluated as reduction in

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[2]Peter's Professional[R] all-purpose 20-20-20. Peters Fertilizer Products. W.R.Grace & Co.-Conn., Pogelsville, PA 18051.

[3]Teejet 8003 tips. Spraying Systems Co., Wheaton, IL 60287.

[4]X-77, Chevron Chem. Co., San Francisco, CA 94119. Currently available from Valent USA Corporation. Walnut Creek, CA 94596. Principal functioning agents are alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol.

fresh and dry weights in relation to untreated control for each genotype.

Homogeneity of variance (12) allowed combination of experiments over time. Data were converted to percent of control, transformed to the arcsine, and subjected to analysis of variance and regression analysis. Means were separated using Duncan's multiple range test at the 0.05 significance level where appropriate.

RESULTS AND DISCUSSION

Visual observations of soybean injury 7 and 10 days after treatment (data not shown) were similar to those previously observed in the field (20, 21). Shoot fresh weights (Figure 4.1) differed by cultivar. Williams 82 produced the greatest shoot fresh weight and Vance produced the least in these studies. Statistical analyses of shoot fresh weight data indicated cultivar by concentration interaction ($P < .10$) (Table 4.2). Increasing the concentration of thifensulfuron from 1.1 to 9.1 g ha^{-1} reduced shoot fresh weight. On a shoot fresh weight basis Williams 82 was the most tolerant cultivar to thifensufuron at 9.1 g ha^{-1} (25% shoot fresh weight reduction) while Vance was the most sensitive cultivar (53% reduction) (Table 4.2). Vance, York, and Essex were the most sensitive cultivars to 1.1 g ha^{-1} with 27, 21, and 21% shoot fresh weight reduction, respectively (Table 4.2). At 2.3 g ha^{-1}, Vance and York were again the most sensitive (40 and 37% shoot fresh weight reduction); Williams 82, Deltapine 105, Essex, and Hutcheson were moderately tolerant (12, 16, 16, and 27% shoot fresh

weight reduction); while, FFR 561 was tolerant (0% shoot fresh weigh reduction) (Table 4.2). At 4.5 g ha^{-1}, York and Hutcheson were the most sensitive cultivars (42 and 41% shoot fresh weight reduction); Bay, Vance, and Deltapine 105, were intermediate (36, 33, and 32% shoot fresh weight reduction); Essex and Williams 82 were moderately tolerant (26 and 25% shoot fresh weight reduction); while FFR 561 was the most tolerant (11% shoot fresh weight reduction). Of the cultivars tested, Vance and York appear to be the most sensitive to thifensulfuron, while Williams 82 and FFR561 were the most tolerant (Table 4.2). At 9.1 g ha^{-1}, Vance shoot growth was reduced by 53%, where, Williams 82 and FFR 561 were only reduced by 25 and 26%, respectively (Table 4.2). In general, across all rates FFR 561 was the most tolerant to thifensulfuron and Vance was the most sensitive.

The sensitivity of cultivars as related to parentage was not evident. Shoot fresh weight reductions from increasing thifensulfuron concentrations occurred and were consistent across Essex and cultivars with Essex parentage (Tables 4.1 and 4.2). FFR 561, Williams 82, and Essex were the most tolerant varieties at the commercial use rate of 4.5 g ha^{-1} (22), whereas Vance and York were sensitive at all rates (Table 4.2). Deltapine 105 and Hutcheson were generally intermediate in tolerance to thifensulfuron. Essex, Deltapine 105 and FFR 561 are relatively pubescent cultivars, and the trichomes are coarse in texture. Vance and Hutcheson have a fine mat of short trichomes, similar to that of velvetleaf. Sensitivity to thifensulfuron may be

Varietal Tolerance ...

related to trichome density as it influences herbicide retention and absorption following application (9, 10). Differential sensitivity is more likely related to differential rates of metabolism among soybean cultivars (9, 10). Both Brown et al. (3) and Eberlein et al. (6) suggest that differences in weed and crop sensitivity to thifensulfuron are based not on uptake and translocation, but on differential rates of metabolism. Investigation of ^{14}C-distribution in Essex and Vance cultivars following application with radiolabeled thifensulfuron (Chapter V) found no differences between cultivar uptake or translocation.

Field analysis of Essex tolerance to thifensulfuron at 1.1 to 4.5 g ha^{-1} indicates that 40 to 65% injury can occur 7 to 14 days after treatment, but no reduction in soybean yield has been reported in response to this injury (8, 9, 10, 21). Hutcheson is a newly released cultivar (1988) that has performed well in Virginia field trials. It is anticipated that Hutcheson will be planted extensively in the future[5]. Current plantings of Hutcheson have been limited by seed availability. Further, much of the Hutcheson registered and certified seed stock is sold out of state; thus indicating the potential use of this variety at the regional or national level[5]. Williams is currently

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[5] Glen Buss 1989, Personal communication. Virginia Polytechnic Institute & State University, Dept. Crops, Soils, and Environ. Sci., Blacksburg, Va. 24061.

the most widely planted soybean cultivar in the United States[6] and explains its use as a standard herbicide screening variety[7]. Variability in soybean sensitivity to sulfonylurea herbicides has been the basis for research to introduce or select for tolerance to sulfonylurea herbicides (17). Selection methods developed by Sebastian (17) isolated W20, a sulfonylurea tolerant strain of Williams. The susceptibility of Hutcheson, Vance, and York to thifensulfuron warrants further research to determine the potential affect on seed yield. If Hutcheson becomes widely accepted, it may warrant the introduction of gene(s) for sulfonylurea resistance.

While, York and Vance were found to be the most sensitive to thifensulfuron in these studies, it is possible that these cultivars will recover within 21 DAT. Soybean plants in this study were harvested during the peak of soybean injury (10 DAT). It is possible that all cultivars tested will recover within 21 to 30 DAT. Essex and Asgrow cultivars were planted in field trials and expressed high levels of injury (17 to 54%) 7 DAT, yet no injury 35 DAT and no affect on yield. Current recommendations should caution the user of potential differences in cultivar

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[6] Raymond Forney 1988, personal communication. E.I.Dupont de Nemours & Company (Inc.), Agricultural Products Department, Research Division, Stine-Haskell Laboratory, P.O. Box 30, Newark, DE 19714.

[7] Scott Sebastian 1988. personal communication. E.I. Dupont de Nemours & Company (Inc.), Agricultural Products Department, Research Division, Stine-Haskell Laboratory, P.O. Box 30, Newark, DE 19714.

sensitivity to thifensulfuron. Additional research should characterize thifensulfuron effect on cultivar seed yield to permit specific precautionary statements for sensitive cultivars when warranted.

Varietal Tolerance ...

LITERATURE CITED

1. Ambach, R.M., B.M. Toole, S.A. Zadorozny, K.D. Johnson, T.S. Ulrich, R.M. Gorrell, and S.E. Schehl. 1984. DPX-M6316: A new herbicide for use in cereals. Proc. North Cent. Weed Control Conf. 39:120.

2. Amuti, K.S., D.C. Drake, and G.L. Leek. 1985. DPX-M6316: Postemergence broadleaf weed control in corn. Proc. North Cent. Weed Control Conf. 40:47.

3. Brown, H.M., V.A. Wittenbach, D.R. Forney, and S.D. Strachan. 1990. Basis for soybean tolerance to thifensulfuron methyl. Pestic. Biochem. Physiol. 37:303-313.

4. Buss, G.R., H.M.Camper, Jr., and C.W.Roane. 1987. Registration of 'Toana' soybean. (Reg. No. 202). Crop Sci. 27:1092.

5. Dekker, J.H., J.F. Lux, and R.G. Burmester. 1986. Mulch-till soybean weed control. North Cent. Weed Control Conf. Res. Rep. 43:274-276.

6. Eberlein, C.V., K.M. Rosow, J.L. Geadelmann, and S.J. Openshaw. 1989. Differential tolerance of corn genotypes to DPX-M6316. Weed Sci. 37:651-657.

7. Fehr, W.R., C.E. Caviness, D.T. Burmood, and J.S. Pennington. 1971. Stage of development descriptions for soybeans. Crop Sci.11:929-931.

8. Fielding, R.J. and E.W. Stoller. 1990. Effects of additives on the

efficacy, uptake, and translocation of the methyl ester of thifensulfuron. Weed Sci. 38:172-178.

9. Forney, D.R., K.S. Amuti, J.S. Claus, J.D. Long, J.M. Green, L.L. Saari, H.M. Brown, and S. Sebastian. 1988. DPX-M6316: A new postemergence soybean herbicide: activity, selectivity, and soil residual considerations. Abst. Weed Sci. Soc. Am. 28:17.

10. Green, J.M., D. Berengut, M.B. King, and P.A. Brown. 1989. Influence of nonionic surfactant properties on DPX-M6316 performance in corn and soybeans. Abst. Weed Sci. Soc. Am. 29:23.

11. Hammes, G.G., J.L. Saladini, and D.T. Ferguson. 1989. Weed control in winter wheat with DPX-R9674. Abst. South. Weed Sci. Soc. 42:36.

12. Hartley, H.O. 1950. The maximum F-ratio as a short-cut test for homogeneity of variance. Biometrika. 37:308-312.

13. Harvey, R.G., S.J. Halstead, J.W. Albright, and T. Anthon. 1986. Postemergence: soybean herbicide study. North Centr. Weed Control Conf. Res. Rep. 43:220-221.

14. Lloyd, J.L. and L.M. Wax. 1984. Screening for soybean varieties sensitive to DPX-F6025. Proc. North Central Weed Control Conf. 39:95.

15. Ngouajio, M. 1990. Thesis: Evaluation of CGA-136872 and DPX-V9360 for postemergence use in corn. VPI&SU. Dept. PPWS. Blacksburg, VA 24061

16. Pomeranke, G.J. and C.D. Nickell. 1988. Inheritance of chlorimuron ethyl sensitivity in the soybean strains BSR 101 and M74-462. Crop Sci. 28:59-60.

17. Sebastian, S.A. and R.S. Chaleff. 1987. Soybean Mutants with increased tolerance for sulfonylurea herbicides. Crop Sci. 27:948-952.

18. Smith, T.J. and H.M. Camper. 1973. Registration of Essex soybean Crop Sci. 13:495.

19. Virginia Crop Reporting Service. 1982-1988 Virginia Crop Survey. U.S. Dept. Ag. and Virginia Dept. Ag., Richmond, VA 23213.

20. Walker, L.M., H.P. Wilson and T.E. Hines. 1988. Thiameturon postemergence in soybeans. Proc. Northeast. Weed Sci. Soc. 42:20.

21. Walker, L.M., H.P. Wilson, and E.S. Hagood. 1989. DPX-M6316 and chlorimuron mixtures for postemergence broadleaf weed control in soybeans. Proc. Weed Sci. Soc. Am. 29:18.

22. Weed Science Society of America. 1989. Herbicide Handbook. 6th edition. p 54-55, 117-119. Weed Sci. Soc. Am., Champaign, IL 61820.

23. Wilson, H.P. and T.E. Hines. 1986. Research summary. VPI&SU. Eastern Shore Ag. Res. Center, Painter, VA 23420. pp.106.

Table 4.1. Soybean cultivars, pedigree, maturity, and % of Virginia hectareage planted in 1987 and 1988.

Cultivar	Pedigree[a]	Maturity group	Virginia hectareage[b]	
			1987	1988
Essex	Lee x S5-7075	V	39.6	30.0
Hutcheson	V68-1034 x Essex	V	> 1.0	> 1.0
Vance	Essex x Glycine soja	V	> 1.0	> 1.0
Deltapine 105	Dare x Essex	V	4.9	4.2
FFR 561	Essex x V68-920	V	2.7	7.0
Bay	York x R62-550	V	4.9	2.7
York	Dorman x Hood	V	5.0	2.0
Williams 82	Wayne x L57-0034	III	> 1.0	> 1.0
other			38.5	34.9

[a]R.R. Bernard 1987.USDA Soybean Germplasm Collection: Origin of Public Varieties: Group V to IX. 1945 to 1986.

[b]G.Buss. 1989. Virginia Dept. Ag. Crop Survey. 1987, 1988. VPI&SU, Dept. Crop Soils and Environ. Sci., Blacksburg, VA 24061.

Varietal Tolerance ...

Table 4.2. Shoot fresh weight of eight soybean cultivars 10 days after treatment (DAT) with thifensulfuron[a].

Soybean variety	Thifensulfuron rate (g ha^{-1}) 0	1.1	2.3	4.5	9.1
	Fresh weight (g)				
Williams 82	24	22(8)	21(12)	18(25)	18(25)
Bay	22	18(18)	19(14)	14(36)	14(36)
FFR 561	18	18(0)	18(0)	16(11)	13(28)
Hutcheson	22	18(18)	16(27)	13(41)	12(45)
Deltapine 105	19	18(5)	16(16)	13(32)	12(37)
Essex	19	15(21)	16(16)	14(26)	10(47)
York	19	15(21)	12(37)	11(42)	10(47)
Vance	15	11(23)	9(40)	10(33)	7(53)
LSD (5%)	3	3	3	3	3

Source	DF	P>F
Experiment	1	0.0001
Variety	7	0.0001
Exp x Var	7	0.9311
Rate	4	0.0001
Exp x Rate	4	0.8424
Var x Rate	28	0.0571
Exp x Var x Rate	28	0.1329

[a]Values within parentheses are % shoot weight reduction.

Varietal tolerance ...

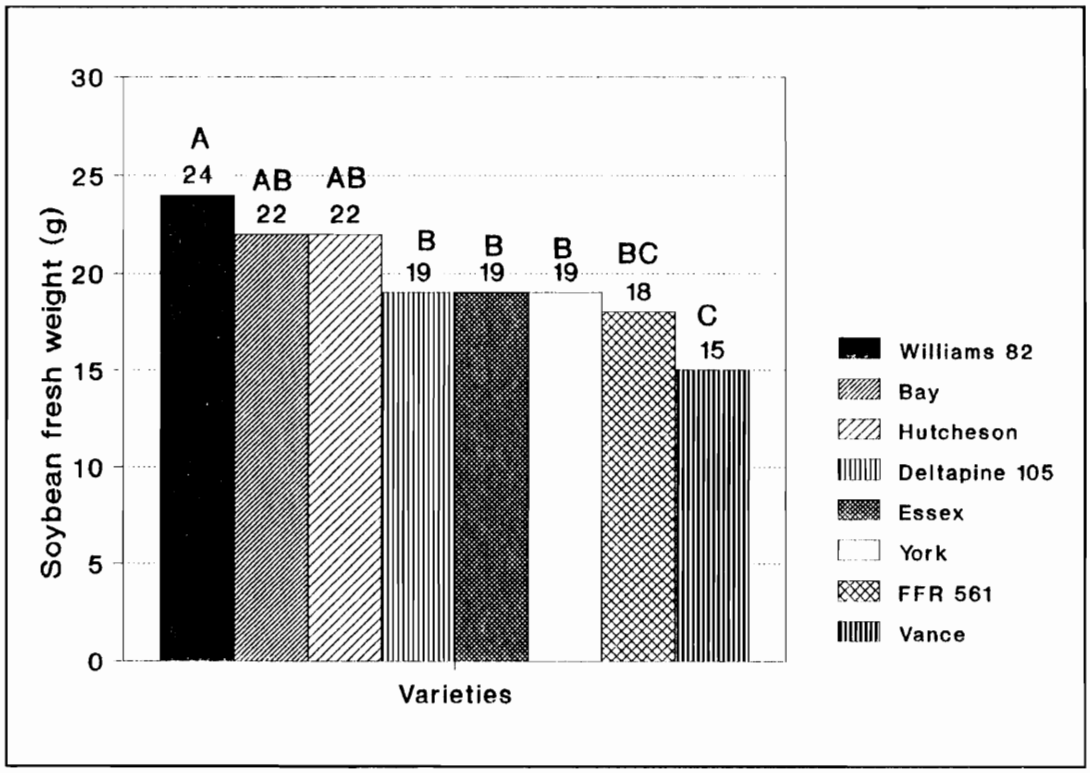

Figure 4.1. Soybean fresh weight response to thifensulfuron at 10 DAT[a].
[a]Means are average of two experiments with eight varieties and three replications per experiment.

Varietal tolerance ...

CHAPTER V

UPTAKE, TRANSLOCATION, AND METABOLISM OF THIFENSULFURON-METHYL IN SOYBEAN (Glycine max), SPURRED ANODA (Anoda cristata), AND VELVETLEAF (Abutilon theophrasti)

Abstract. Laboratory research was conducted to determine the uptake, translocation, and metabolism of the methyl ester of [Thiophene-^{14}C]-thifensulfuron in two soybean varieties (Essex and Vance) and two weed species (spurred anoda and velvetleaf). The radiolabeled carbon was not rapidly absorbed by leaves or excised stems of any plant species examined. Less than 5% of ^{14}C applied was absorbed by excised shoots 2 h after treatment, while only 16 to 56% of foliar-applied radiolabel was absorbed 5 days after treatment (DAT). Less than 15% of absorbed ^{14}C was translocated out of the treated leaf of any species. No differences between species absorption or translocation of ^{14}C were observed ($P > 0.1$). Soybeans metabolized greater than 80% of absorbed thifensulfuron 3 DAT, while both sensitive velvetleaf and tolerant spurred anoda metabolized less than 50% of absorbed herbicide 3 DAT. Results indicate that spurred anoda tolerance to thifensulfuron is primarily due to absorption followed by metabolism of absorbed thifensulfuron. Nomenclature: Thifensulfuron, 3-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino] carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid; soybean, Glycine max (L.)

var.'Essex','Vance'; spurred anoda, Anoda cristata (L.) Schlecht. #[1] ANVCR; velvetleaf, Abutilon theophrasti Medic. # ABUTH.

Additional index words. DPX-M6316, thiameturon, ABUTH, ANVCR.

INTRODUCTION

Thifensulfuron, a selective postemergence sulfonylurea herbicide, is registered for control of broadleaf weeds in cereal grains and soybeans (14). Thifensulfuron provides excellent control of common lambsquarters (Chenopodium album L.) and velvetleaf in soybeans (14). The mechanism of activity of all sulfonylureas, including thifensulfuron, has been determined to be the inhibition of acetolactate synthase, (ALS; EC 4.1.3.18), a key enzyme in the production of the branched chain amino acids valine, leucine and isoleucine (9). Selectivity of thifensulfuron among broadleaf weeds and crop species is still under investigation. Herbicidal selectivity can result from differential uptake and translocation (4, 7, 13), site of action sensitivity (8), metabolic inactivation (2, 6, 11), or placement (10). Long et al.(8) have determined that differential metabolism of thifensulfuron, not absorption and translocation, was responsible for selectivity between soybean 'Williams 82', smooth

[1]Letters following these symbols are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl.2. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

pigweed (Amaranthus retroflexus L.), common lambsquarters, velvetleaf, and tall morningglory [Ipomoea purpurea (L.) Roth]. The objective of this research was to determine if the herbicidal selectivity of thifensulfuron could be accounted for by differences in uptake, translocation, or metabolism between two soybean cultivars, spurred anoda, and velvetleaf.

MATERIALS AND METHODS

Greenhouse studies. Greenhouse studies were conducted in Painter, VA, to determine the effect of thifensulfuron at 1.1 to 9.1 g ha^{-1} on velvetleaf and spurred anoda. In August of 1988, velvetleaf and spurred anoda were seeded in 950 ml styrofoam cups containing 1.3 kg of soil and thinned to four plants of each species per container. Studies were conducted using a State sandy loam soil (Typic Hapladults) consisting of 67% sand, 28% silt, 5% clay, and 1% organic matter with a pH of 6.1. Average maximum and minimum greenhouse temperatures throughout the studies were 35 and 20 C. Solar irradiance was recorded with photoysnthetic photon flux densities ranging between 300 to 800 uE m^{-2} s^{-1} with approximately 15 h day/ 9 h nights were recorded. Plants were watered as necessary and fertilized weekly with a complete, water-soluble fertilizer[2] at 125 mg cup^{-1} in 50 ml water. Weed species were treated at the 4 to 5 true leaf stage. Thifensulfuron was applied

[2]Peter's Professional[R] all-purpose 20-20-20. Peters Fertilizer Products. W.R.Grace & Co.-Conn., Pogelsville, PA 18051.

to the foliage with a propane-pressurized backpack sprayer delivering 190 L ha^{-1} spray mix at 220 kPa pressure using flat fan tips[3]. Thifensulfuron was applied at 0, 1.1, 2.3, 4.5, and 9.1 g ha^{-1}. A nonionic surfactant[4] was included at 0.125% of the spray volume.

Plants were treated and arranged on greenhouse benches in a completely randomized design. Treatments were replicated three times and the study was repeated one week following initiation of the first. Soybean leaves and stems were harvested 10 days after herbicide application by cutting stems at the soil surface. Shoot fresh weights were obtained. Injury was evaluated as % reduction in shoot fresh weights calculated as the [(untreated plants minus the treated) divided by the untreated] multiplied by 100.

Homogeneity of variance (12) allowed combination of experiments over time. Data were converted to percent of control, transformed to the arcsine, and subjected to analysis of variance. Means were separated using Duncan's multiple range test (P=0.05) where appropriate.

Chemicals. The methyl ester of [Thiophene-^{14}C]thifensulfuron (specific activity 10.7 uCi mg^{-1}) were synthesized by New England Nuclear and provided by E.I. du Pont

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[3]Teejet 8003 tips. Spraying Systems Co., Wheaton, IL 60287.

[4]X-77, Chevron Chem. Co., San Francisco, CA 94119. Currently available from Valent USA Corporation. Walnut Creek, CA 94596-8025. Principal functioning agents are alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol.

de Nemours & Co. Inc.. The radiochemical purity of the methyl ester of [thiophene-^{14}C]thifensulfuron was 81 to 93% as determined by thin-layer chromatograph (TLC) (Figures 5.3 and 5.4).

Plant Growth and treatment. Velvetleaf, spurred anoda, and the soybean cultivars 'Essex' and ' Vance' were chosen based on differences in % shoot fresh weight reduction. Plants used for uptake, translocation, and metabolism studies were grown in the greenhouse under 14 h photoperiod with 300 to 800 uE m^{-2} s^{-1} and temperature range of 25 to 30 C. Plants were grown in sterilized sand and transferred to hydroponic culture utilizing full strength hoagland solution 7 days prior to treatment. Radiolabeled thifensulfuron was applied to soybeans in the second trifoliolate growth stage, and velvetleaf and spurred anoda in the 4 to 5 leaf stage.

Uptake and translocation studies. Herbicide uptake studies involved three approaches:

Method 1. The methyl ester of [Thiophene-^{14}C]thifensulfuron was dissolved in 1 ml of acetone:water (80:20 v/v) with nonionic surfactant[5] at 0.125% v/v . Radiolabeled herbicide was applied as a foliar spray using an atomizer. Each plant received approximately 90 nCi of radioactivity. Plants were harvested 8, 24, and 72 h after treatment, washed three times with 5 ml of acetone:water (80:20 v/v), and divided

[5]X-77, Chevron Chem. Co., San Francisco, CA 94119. Principal functioning agents are alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol.

into leaves, stem, and roots, which were weighed, and frozen at -10 C.

Method 2. Five 2 μl droplets of the methyl ester of ^{14}C-thifensulfuron (ca. 90 nCi), dissolved in acetone (80:20 v/v) and combined with 0.125% v/v nonionic surfactant, were applied to the center leaflet of the first trifoliolate leaf on soybean cv. Essex and Vance and to the third true leaf of spurred anoda and velvetleaf. Plants were harvested 24, 72, and 120 h after treatment. Treated leaves were washed with 3 ml of acetone:water (80:20 v/v) to remove unabsorbed herbicide, and separated into treated leaf, other leaves, stem, and roots, which were weighed, and frozen at -10 °C.

Method 3. Plants were carefully removed from hydroponic solution and placed in a water bath at 20 C. Roots were excised under water with a razor blade. Excised stems were transferred to bottles containing 130 ml of Hoagland solution with 90 nCi of methyl ester of ^{14}C-thifensulfuron and 1 μmolar of analytical thifensulfuron methyl. Excised plants were exposed to radiolabeled solutions for 2 h under artificial lighting (300 to 800 uE m^{-2} s^{-1}). Following exposure, plants were dipped in 5 ml acetone:water (80:20 v/v) and returned to untreated nutrient solution. Plants were harvested 8, 24, and 72 h after treatment and separated into leaves and stems, which were weighed, and frozen at -10°C.

Tissue samples were oven-dried at 50°C for 48 h and combusted in a sample

oxidizer[6], and evolved $^{14}CO_2$ trapped in 10 ml of CO_2 absorber[7] plus 10 ml of scintillation cocktail[8]. Percent uptake was calculated as the tissue radioactivity divided by the sum of the tissue, rinsate and nutrient solution radioactivity multiplied by 100. Radioactivity in the acetone rinsate and the nutrient solution was quantified by subsampling these solutions into scintillation fluid[9]. All radioactivity was determined using a liquid scintillation spectrometer[10], with correction for quenching. Recovery of ^{14}C was 92 to 100% of the applied herbicide. Distribution of ^{14}C in each fraction was expressed as disintegrations per minute (DPM) mg^{-1} and percentage of total ^{14}C recovered.

A completely randomized design with two samples was used, and each experiment was repeated once. Statistical analysis on ^{14}C recovered was conducted using analysis of variance with mean separation using Least significant difference test ($P = 0.05$).

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[6]Packard tricarb sample oxidizer, Packard Instruments Co., Inc. Downer Grove, IL 60515.

[7]Carbo-sorb carbon dioxide absorber for scintillation counting, Packard Instrument Co., Inc. Downers Grove, IL 60515.

[8]Permafluor V, Packard Instrument Co., Inc. Downer Grove, IL 60515.

[9]Scintiverse BD, scintillation fluor biodegradable, Fisher

[10]Model LS-505, Beckman Instrument Co., Fullerton, CA 92634.

Metabolism studies. Plants were grown and treated as in absorption and translocation studies method 2. Plants were exposed to 90 nCi of the methyl ester of [thiophene-^{14}C]thifensulfuron (specific activity 10.7 μCi mg^{-1}). Plants were harvested 72 h after treatment. Treated leaves and cut stems were washed with 5 ml acetone (80:20 v/v), weighed, and frozen at -10°C until extraction. Metabolite and parent material extraction followed the methods of Brown et al.(3). Whole plants were frozen in liquid nitrogen and pulverized in a mortar and pestle. Pulverized samples were combined with 20 ml of acetone:water (80:20 v/v) and ground in a blender for 3 min. Extracts were centrifuged for 10 min at 1200 x g, and the supernatant was removed and saved. The pellets were extracted two more times in acetone:water (80:20 v/v) and once with acetone:water (90:10 v/v).

Following extraction, the pellets were oven dried (50°C) and combusted with a model 302 B Tri-Carb sample oxidizer (Packard Instruments). The evolved $^{14}CO_2$ was trapped in 10 ml of CO_2 absorber and mixed with 10 ml of scintillation fluid and quantitated by liquid scintillation spectrometry. The combined supernatant fluids (ca. 80 ml) were concentrated by evaporation of the acetone under CO_2, while being heated in a warm water bath (40 C). The residual aqueous phase was separated into two samples. Both samples were evaporated until the volume was reduced to approximately 1 ml. To determine if extract pH influenced herbicide and metabolite stability, one sample was adjusted to pH 7.0 with 0.1 N NaOH. The other was

adjusted to pH 3.0 with 1 N HCl.

The final samples were brought to a volume of 5 ml with a solution to afford a final concentration of 20% acetonitrile : 80% water (v/v). Samples were filtered (0.45 μm filter[11]) prior to loading of 15 ul onto a 20 μm silica gel reversed-phase TLC plate[12]. The mobile phase was acetonitrile:water:formic acid (75:24.9:0.1 v/v). Following TLC plates were scraped every 1 cm, from origin to solvent front. Each scraping was added to scintillation cocktail. Radioactivity was determined using scintillation spectrometry, and R_f values were calculated for metabolites. Recovery of ^{14}C was 50 to 75% of the applied herbicide.

A completely randomized design with two samples was used. Statistical analyses on R_f values for metabolites was conducted using analysis of variance.

Autoradiography: Translocation of 14C was qualitatively assessed utilizing autoradiography. One plant sample from each harvest interval and application method was autoradiographed. Plants were harvested, cut into uniform segments and glued to white semigloss copy paper. The plants were allowed to air dry in the greenhouse for 24 h. Dried plants were then stacked between aluminum plates and placed in a botanical press in the greenhouse for 48 h. Pressed plants were removed

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[11]Alltech disposable nylon 66 filters, 25mm, 0.45μm. Alltech Associates, Inc. 2051 Waukegan, Road, Deerfield, IL 60015.

[12]Baker number 7015-4. Si-C_{18}-F(19C) TLC plate. J.T. Baker Chem. Co., Phillipsburg, NJ 08865.

from the greenhouse and transferred in the dark to X-ray film. Films were developed 4 weeks after exposure to radiolabel plants.

RESULTS AND DISCUSSION

Greenhouse studies. Differences in soybean cultivars response to thifensulfuron have been recorded (Chapter IV). Foliar application of 1.1 to 9.1 g ha^{-1} thifensulfuron reduced shoot growth (fresh weight) of both Essex and Vance cultivars (Table 5.1). Shoot growth of velvetleaf and spurred anoda was also reduced by foliar application of 1.1 to 9.1 g ha^{-1} thifensulfuron (Table 5.1). Velvetleaf was the most sensitive of the species treated with 78 to 84% reduction in shoot fresh weight 10 DAT. Spurred anoda and Essex soybean responded similarly to thifensulfuron (Table 5.1). Spurred anoda shoot growth was reduced 21 to 47%, while Essex was reduced 16 to 47%. Vance shoot growth differed from Essex at 2.3 to 9.1 g ha^{-1} thifensulfuron (Table 5.1). Vance shoot growth was reduced by 40 to 53%, while Essex was reduced by only 16 to 47%. Although growth reduction occured 7 to 10 DAT, field trials with thifensulfuron found that spurred anoda and Essex soybean recovered within 21 to 30 DAT (data not shown).

Uptake and translocation. Absorption and distribution of ^{14}C was similar among species 1, 3 and 5 days after treatment (Figure 5.1). No species translocated more than 5% of absorbed radioactivity out of the treated leaf 1 and 3 DAT (Figure 5.1 and 5.2). Although analysis of mean absorption did not differ at (P=0.1),

Uptake, translocation, and metabolism ...

considerable variability in absorption was observed within species. Limited time and available radioactive herbicide prevented the running of additional experiments to address the variability. Autoradiographs of treated plants indicate limited movement of thifensulfuron out of the treated leaf of all species. Autoradiographs of ^{14}C movement are not presented due to the faint image, which would not reproduce well in photographic form.

Less than 3% of the available radioactivity was absorbed through excised stem (method 3) of treated species tested (Figure 5.2). The amount of radioactivity absorbed by plants was below detectable limits using combustion, scintillation spectrometry, and autoradiography.

Metabolism. TLC analysis indicated differences in thifensulfuron metabolism between plant species. Extraction efficiency was 50 to 75% for soybeans and spurred anoda, while only 35% for velvetleaf. Quenching, due to the presence of a fluorescence indicator in the TLC gel, reduced scintillation efficiency by 25%. Sample standards of the methyl ester of [^{14}C-thiophene]thifensulfuron were spotted on plates along side extraction samples. Rf values for the standard was 0.9 for all runs (Figures 5.3 and 5.4). Due to its lower polarity and size, the Rf values for the deesterified acid of thifensulfuron is likely 0.8 or metabolite #1. Vance and Essex metabolized more thifensulfuron than either velvetleaf or spurred anoda regardless of sample pH (Figure 5.3 and 5.4). Vance metabolized all thifensulfuron in the

Uptake, translocation, and metabolism ...

extract adjusted to pH 3 and 74% in the extract adjusted to pH 7. Degradation of the radiolabeled compounds may have occured during preparation of the sample at pH 3, rather than by the plant. Thifensulfuron stability is highly dependent upon pH[13]. At pH ranges close to neutral thifensulfuron is more stable. However, at acidic pHs the methyl ester of thifensulfuron is susceptible to chemical hydrolysis[13].

The primary soybean metabolite (unknown #1) had a R_f value of 0.8 for Essex at both extract pHs and Vance at pH 7. Vance, however, differed from Essex when extract was adjusted to pH 3. At pH 3 Vance had a primary metabolite with R_f value of 0.7 (unknown #2 and a secondary and tertiary metabolite (unknown #3 and #4) at R_f 0.5 to 0.6, respectivley (Figure 5.3). Both soybean varieties had residual radioactivity that had R_f values between 0.2 and 0.7 regardless of sample pH. Extracts of Essex adjusted to pH 3 had metabolized approximately 77% of the herbicide 3 DAT, while extracts adjusted to pH7 metabolized only 59% of the herbicide (Figures 5.3 and 5.4). Again, sample pH may have influenced extract degradation prior to TLC separation. However, in both extractions, the major metabolite of Essex separated at a R_f value of 0.8 (Figures 5.3 and 5.4). Metabolism of thifensulfuron was slower in velvetleaf and spurred anoda than either soybean variety. Only 49 and 50% of extracted (pH 3 and 7, respectively) radioactivity was

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[13]Hugh Brown. 1989. personal communication. E.I.Dupont de Nemours Co. Inc. Stine Haskell Ag. Chem. Res. Center, Newark, DE.

metabolized herbicide in velvetleaf 3 DAT (Figures 5.3 and 5.4). Although differences in metabolism between sensitive velvetleaf and tolerant Essex are small (9 to 20%), this difference appears to be enough to provide selectivity between this weed and crop.

Equivalent amounts of unmetabolized radioactivity (49% of recovered ^{14}C) was extracted and separated at pH 3 from spurred anoda and velvetleaf harvested 3 DAT (Figure 5.3). This amount is greater than the radioactivity extracted from tolerant soybean varieties (Figure 5.3 and 5.4). Velvetleaf metabolized similar amounts of thifensulfuron regardless of sample pH (Figures 5.3 and 5.4). The major metabolite (unknown #1) for all species in this study had a R_f of 0.8 (Figures 5.3 and 5.4). It appears that both velvetleaf and spurred anoda metabolize thifensulfuron to similar metabolites (R_f 0.8) possibly via similar mechanisms as soybeans. Both velvetleaf and spurred anoda metabolized less of the absorbed thifensulfuron than the soybean varieties 3 DAT. This indicates that metabolism is an important factor in thifensulfuron selectivity among Essex and Vance soybean cultivars, sensitivity of velvetleaf. It also appears that spurred anoda tolerance to thifensulfuron is not based on differential metabolism as reported for most species (2, 6, 8, 9). It is not clear how spurred anoda tolerates applications of thifensulfuron. No differences in uptake, translocation, or metabolism between susceptible velvetleaf and tolerant spurred anoda were found (Figures 5.1, 5.2, 5.3, and 5.4).

Uptake, translocation, and metabolism ...

Long et al (8), determined that soybeans cv. 'Williams' metabolized 80% of thifensulfuron within 10 h of treatment through excised stem. They also reported that greater than 95% of the remaining radioactivity was present as the de-esterified acid of thifensulfuron (8). The de-esterified acid of thifensulfuron apparently has no herbicidal activity (8). According to Brown[14] the de-esterified metabolite co-migrates with the parent herbicide under conditions of HPLC analysis. Therefore, it is possible that the unknown metabolite #1 (R_f 0.8) is the de-esterified acid of thifensulfuron, considering its vacinity relative to the parent thifensulfuron (R_f 0.9).

The low level of thifensulfuron translocation implies that these studies did not obtain adequate movement of this herbicide to simulate absorption obtained with applications of thifensulfuron methyl in field and greenhouse trials. Brown et al (2, 3) expressed the difficulty of obtaining adequate absorption from cuticular applications of radiolabeled thifensulfuron-methyl. Excised stems were used to eliminate the cuticular barriers to herbicide uptake in their studies. In these studies, less uptake was obtained from excised stems than treated leaves and absorption of radioactivity were below detectable limits due to quenching from the scintillation cocktail. Previous studies have established that rapid metabolic inactivation is the basis for wheat and barley tolerance to chlorsulfuron(12), metsulfuron methyl (1),

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[14] H.M.Brown. 1990. personal communication. E.I. du Pont & Nemours Co. Inc., Stine Haskell Ag. Chem. Research Center, Newark, DE.

and thifensulfuron methyl(4); and soybean tolerance to both thifensulfuron-methyl (3) and chlorimuron ethyl (2).

This research indicates that differential absorption and metabolism are important mechanisms for thifensulfuron selectivity. Differential thifensulfuron metabolism, not absorption, between soybean cv. 'Essex' and 'Vance' and velvetleaf appears responsible for selectivity. Absorption, translocation, and metabolism did not appear responsible for tolerance of spurred anoda to thifensulfuron. Additional research should address the metabolism of thifensulfuron 2 to 24 h after absorption to clarify the difference between spurred anoda and velvetleaf susceptibility to thifensulfuron. To further clarify spurred anoda tolerance to thifensulfuron, ALS from both velvetleaf and spurred anoda should be analyzed for binding affinity to thifensulfuron.

Uptake, translocation, and metabolism ...

LITERATURE CITED

1. Anderson, J. A., T. M. Priester, and L. M. Shalaby. 1989. Metabolism of metsulfuron methyl in wheat and barley. J. Agric. Food Chem. 37:1429.

2. Brown, H. M. and S.M. Neighbors. 1987. Soybean metabolism of chlorimuron ethyl: Physiological basis for soybean selectivity. Pestic. Biochem. Physiol. 29:112-120.

3. Brown, H. M., V. A. Wittenbach, D. R. Forney, and S. D. Strachan. 1990. Basis for soybean tolerance to thifensulfuron methyl. Pestic. Biochem. Physiol. 37:303-313.

4. Cotterman, J. C. and L.L. Saari. 1989. Selectivity of DPX-M6316 in wheat: Differential metabolism in wheat and sensitive weeds. Abst. Weed Sci. Soc. Am. 29:7

5. Devine, M.D. 1989. Phloem translocation of herbicides. *In* Reviews of Weed Science. 4:191-214.

6. Falco, S.C., R.S. Chaleff, K.S. Dumas, R.A. LaRossa, K.J. Leto, C.J. Mauvais, B.J. Mazur, T.B. Ray, J.V. Schloss, and N.S. Yadev. 1985. Molecular Biology of Sulfonylurea Herbicide Activity pp. 313-328. *In* M. Zaitlin, P. Day, and A. Hollaender eds. Biotechnology in Plant Science. Academic Press, Inc., New York.

7. Hess, F.D. 1985. Herbicide absorption and translocation and their relationship

to plant tolerances and susceptibility pp. 191-214. *In* S.O. Duke ed. Weed Physiology, CRC Press, Boca Raton, FL. Vol. II.

8. Long, J.D., K.S. Amuti, J.M. Green, and D.R. Forney. 1988. DPX-M6316 - A new postemergence herbicide for soybeans. Proc. South. Weed Sci. Soc. 41:326.

9. Thomas B. Ray. 1984. Site of action of chlorosulfuron: Inhibition of valine and isoleucine biosynthesis in plants. Plant Physiol. 75:827-831.

10. Ross, M.A. and C.A. Lembi. 1985. Applied Weed Science. Burgess Publishing Company, Minneapolis, Minn. p. 340.

11. Shaner, D.L. 1989. Factors affecting soil and foliar bioavailability of imidazolinones. American Cyanamid Company, P.O. Box 400, Princeton, New Jersey 08540. p. 24.

12. Sweetser, P. B., G. S. Schow, and J. M. Hutchinson. 1982. Metabolism of chlorsulfuron by plants: Biological basis for selectivity of a new herbicide for cereals. Pestic. Biochem. Physiol. 17:8.

13. Wanamarta, G. and D. Penner. 1989. Foliar absorption of herbicides. *In* Reviews of Weed Science 4:215-231.

14. Weed Science Society of America. 1989. Herbicide Handbook. 6th edition. pp. 54-55, 117-119. Weed Sci. Soc. Am., Champaign, IL 61820.

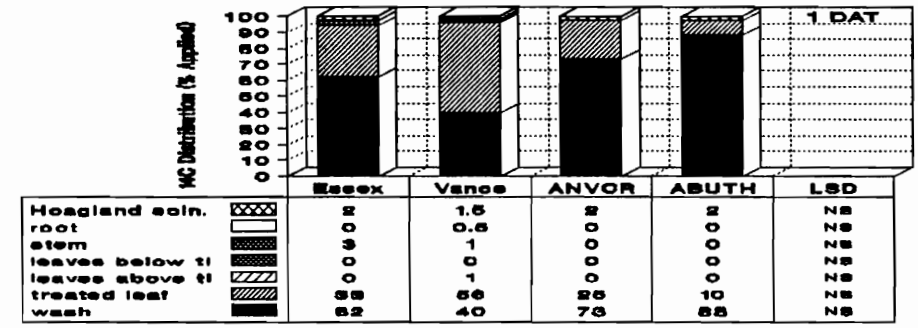
Uptake, translocation, and metabolism ...

Table 5.1. Shoot growth reduction (%) of velvetleaf (ABUTH), spurred anoda (ANVCR), and two soybean cultivars 'Essex' and 'Vance' 10 days after foliar treatment (DAT) with the methyl ester of thifensulfuron.

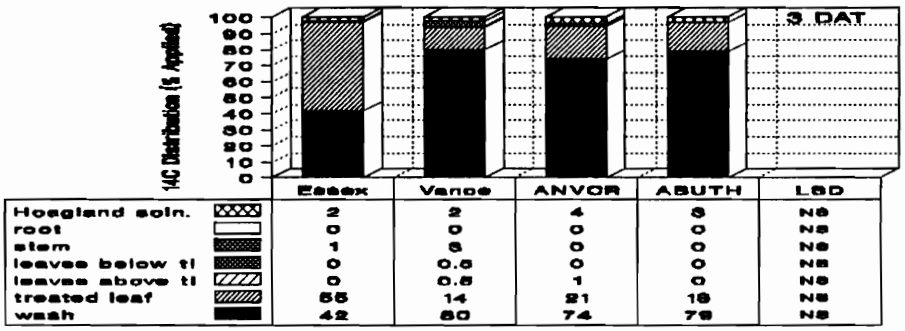
Soybean variety	Thifensulfuron rate (g ha^{-1})			
	1.1	2.3	4.5	9.1
	Growth reduction[a] (%)			
Essex	21	16	26	47
Vance	23	40	33	53
ABUTH	78	79	85	84
ANVCR	21	44	47	31
LSD (0.05)	3	3	3	3

[a]Growth reduction calculated based on fresh weight of untreated plants.

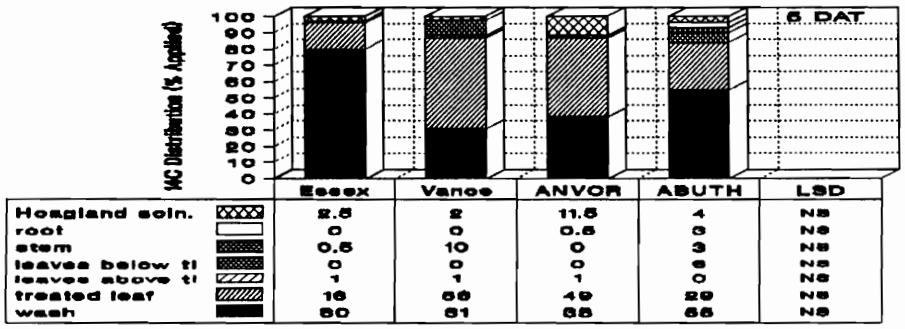
Uptake, translocation, and metabolism ...



	Essex	Vance	ANVOR	ABUTH	LSD
Hoagland soln.	2	1.5	2	2	NS
root	0	0.5	0	0	NS
stem	3	1	0	0	NS
leaves below tl	0	0	0	0	NS
leaves above tl	0	1	0	0	NS
treated leaf	58	56	26	10	NS
wash	52	40	76	88	NS



	Essex	Vance	ANVOR	ABUTH	LSD
Hoagland soln.	2	2	4	3	NS
root	0	0	0	0	NS
stem	1	5	0	0	NS
leaves below tl	0	0.5	0	0	NS
leaves above tl	0	0.5	1	0	NS
treated leaf	55	14	21	18	NS
wash	42	80	74	79	NS



	Essex	Vance	ANVOR	ABUTH	LSD
Hoagland soln.	2.5	2	11.5	4	NS
root	0	0	0.5	3	NS
stem	0.5	10	0	3	NS
leaves below tl	0	0	0	6	NS
leaves above tl	1	1	1	0	NS
treated leaf	16	56	49	29	NS
wash	80	81	88	86	NS

Figure 5.1. Distribution of ^{14}C (% of applied) in two soybean cultivars, Essex and Vance, spurred anoda (ANVCR), and velvetleaf (ABUTH), 1, 3, and 5 days after treatment (DAT) with the methyl ester of [14C-thiophene]thifensulfuron.

Uptake, translocation, and metabolism ...

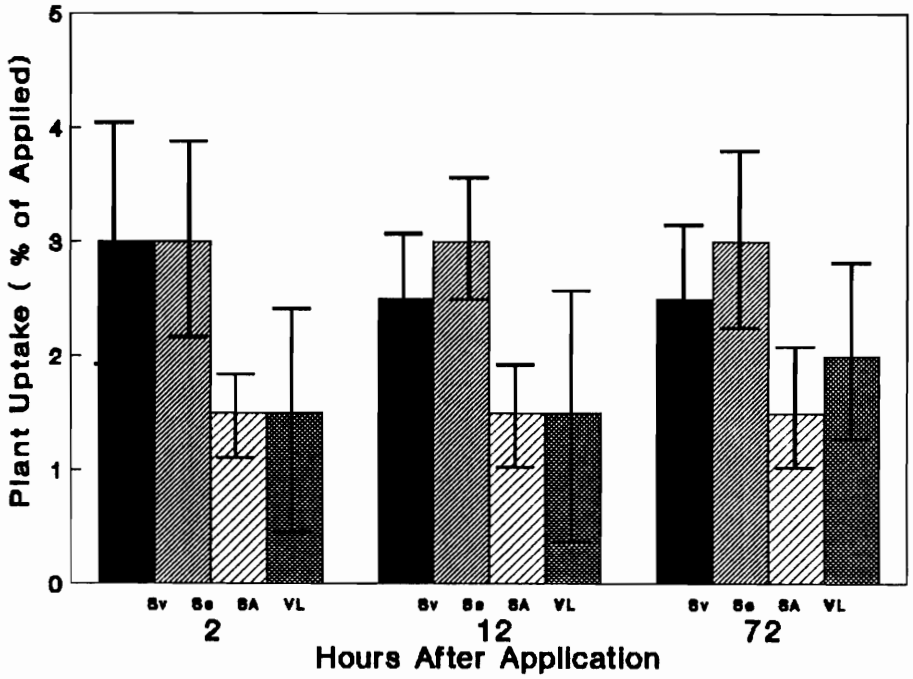


Figure 5.2. Absorption[a] of ^{14}C 2, 12, and 72 h after cut stem exposure of two soybean cultivars, Vance (Sv) and Essex (Se), spurred anoda (SA), and velvetleaf (VL) to a nutrient solution containing the methyl ester of [^{14}C-thiophene]thifensulfuron.

[a]Bars represent mean standard deviation.

Uptake, translocation, and metabolism ...

Figure 5.3. Thin-layer chromatographic separation[a] of recovered ^{14}C from velvetleaf (ABUTH), spurred anoda (ANVCR), Essex and Vance soybean 3 days after treatment (DAT) with the methyl ester of [^{14}C-thiophene] thifensulfuron.
[a]Samples adjusted to pH 3 prior to spotting plates.

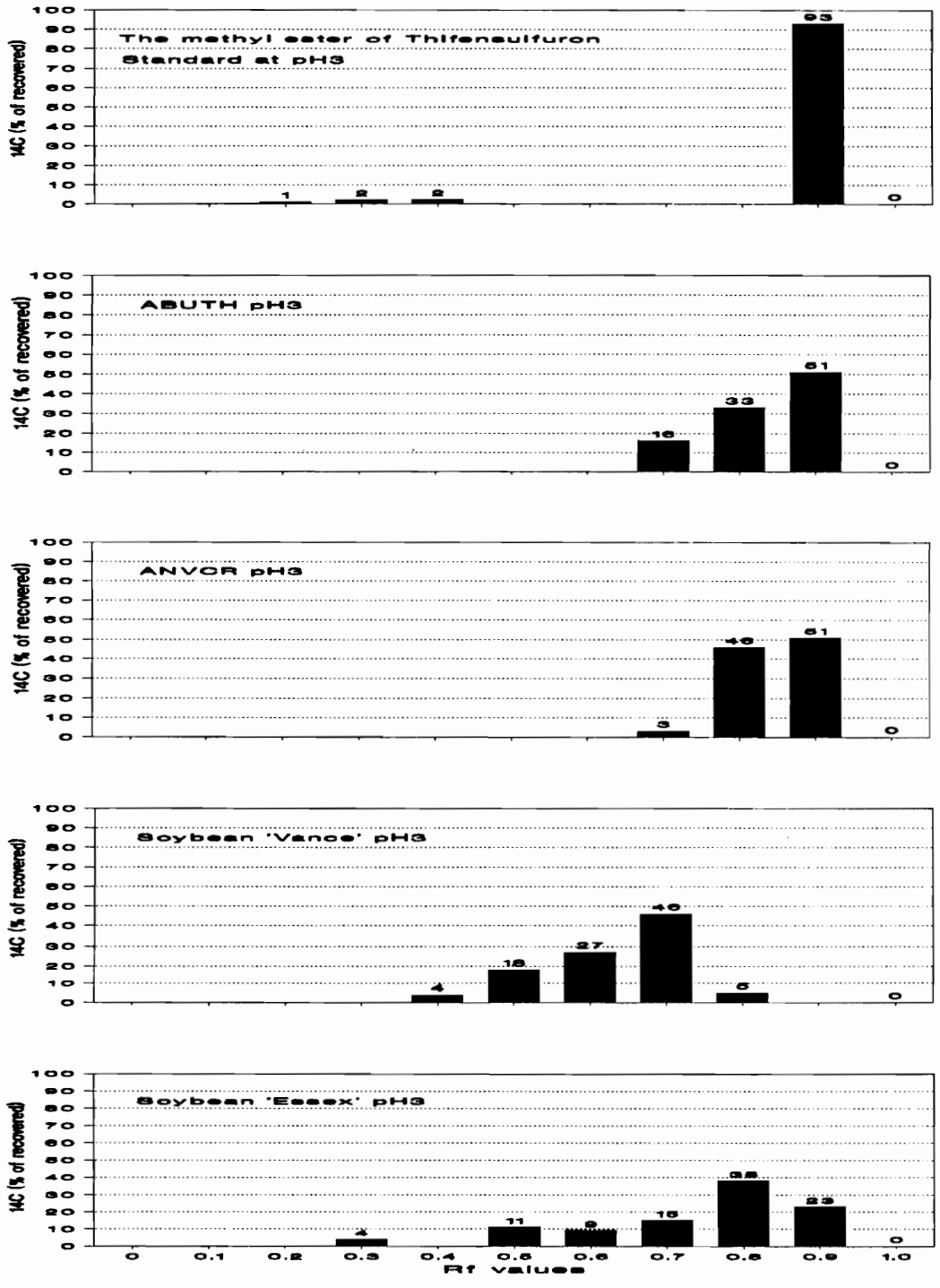
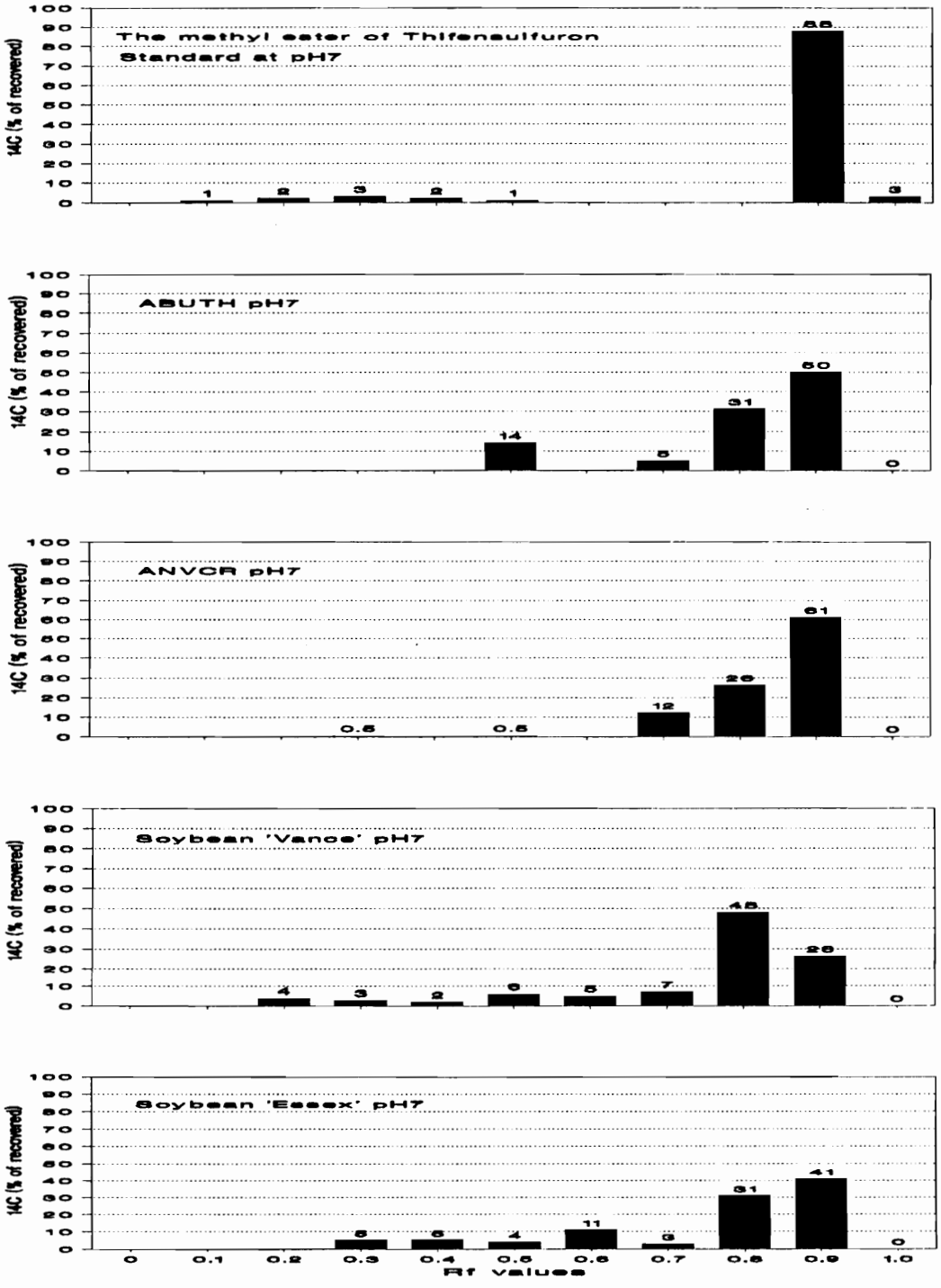

The methyl ester of Thifensulfuron
Standard at pH3
14C (% of recovered)
1
2
2
93
0
ABUTH pH3
16
33
51
0
ANVCR pH3
3
46
51
0
Soybean 'Vance' pH3
4
18
27
46
6
0
Soybean 'Essex' pH3
4
11
9
15
38
23
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Rf values

Figure 5.4. Thin-layer chromatographic separation[a] of recovered ^{14}C from velvetleaf (ABUTH), spurred anoda (ANVCR), Essex and Vance soybean 3 days after treatment (DAT) with the methyl ester of [^{14}C-thiophene] thifensulfuron.
[a]Samples adjusted to pH 7 prior to spotting plates.


The methyl ester of Thifensulfuron
Standard at pH7
14C (% of recovered)
1
2
3
2
1
88
3
ABUTH pH7
14
5
31
50
0
ANVCR pH7
0.5
0.5
12
28
61
0
Soybean 'Vance' pH7
4
3
2
6
5
7
45
26
0
Soybean 'Essex' pH7
5
5
4
11
6
31
41
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Rf values

SUMMARY AND CONCLUSIONS

This research was designed to examine the efficacy of thifensulfuron as a postemergence herbicide for soybean production. Field trials were conducted to investigate the influence of adjuvants and chlorimuron upon the efficacy of thifensulfuron. Soybean varietal response was evaluated to ascertain its role in setting upper limits on rate. Uptake, translocation, and metabolism were evaluated to determine their role in soybean and weed responses.

Field efficacy of thifensulfuron.

Adjuvants. Analysis of data indicate that adjuvant can significantly influence the response of both common lambsquarters and soybean to foliar applications of thifensulfuron. In these studies, thifensulfuron at 4.5 g ha^{-1} plus 0.125% (v/v) nonionic surfactant provided consistent control of both smooth pigweed and common lambsquarters (>98%). Control, however, was slow to develop, requiring 14 to 21 days. Greater than 96% control of smooth pigweed was obtained with thifensulfuron at rates of 2.3 to 4.5 g ha^{-1} without the addition of adjuvants. Common lambsquarters control (>95%) was dependent upon the addition of 0.125% nonionic surfactant to thifensulfuron at 4.5 g ha^{-1}. Ivyleaf morningglory growth was initially inhibited by all rates of thifensulfuron and adjuvant combinations, but plants recovered within 21 DAT. Thifensulfuron at 4.5 g ha^{-1} caused transitory reduction in soybean growth and no reduction in soybean yield. Additional research should identify the response of tank mixing thifensulfuron with existing postemergence grass

and broadleaf herbicides to obtain a broader spectrum of postemergence weed control in soybeans.

Chlorimuron combinations. The combinations of 4.5 g ha^{-1} thifensulfuron with 1.1 to 4.5 g ha^{-1} chlorimuron provided greater than 85% control of seedling common lambsquarters and 99% control of smooth pigweed. Control of ivyleaf morningglory with chlorimuron was not influenced by the addition of thifensulfuron. Neither herbicide alone or in combination controlled ivyleaf morningglory. Additional research will be required to characterize the interactions of other herbicides with thifensulfuron to provide a broader spectrum of weed control, in particular control of ivyleaf morningglory.

Soybean varietal response.

Shoot fresh weight reductions from increasing thifensulfuron concentrations were consistent across cultivars. Essex, FFR 561, and Williams 82 were the most tolerant varieties at the commercial use rate of 4.5 g ha^{-1}, whereas, Vance was sensitive at all rates. Deltapine 105 was generally intermediate in tolerance to thifensulfuron. Essex, Deltapine 105, and FFR 561 are relatively pubescent genotypes and the trichomes are coarse in texture, while Vance, York, and Hutcheson have a fine mat of short trichomes, similar to that of velvetleaf. Sensitivity to thifensulfuron may be related to trichome density as it influences herbicide retention and absorption following application.

SUMMARY AND CONCLUSION

Field analysis of Essex tolerance to thifensulfuron at 1.1 to 4.5 g ha^{-1} indicates that 40 to 65% injury can occur 7 to 14 days after treatment, but no reduction in soybean yield will result. Current recommendations should caution the user of potential differences in cultivar sensitivity to thifensulfuron. Additional research should characterize thifensulfuron affect on cultivar seed yield to provide specific precautionary statements if warranted. Variability in soybean varietal response to sulfonylurea herbicides has been the basis for research to introduce or select for tolerance to sulfonylurea herbicides. Selection methods developed by Sebastian isolated W20, a sulfonylurea tolerant strain of Williams.

Uptake, translocation and metabolism.

This research indicates that differential metabolism, not absorption, appears to be the mechanism for thifensulfuron selectivity. All species in this study absorbed similar amounts of applied radioactivity. Although, <6% of the radioactivity translocated 3 days after treatment, differential thifensulfuron metabolism between soybean var. 'Essex' and 'Vance' and velvetleaf appears to be responsible for selectivity. No differences in absorption, translocation, or metabolism between sensitive velvetleaf and tolerant spurred anoda were found. Additional research, including determination of acetolactate synthase affinity for thifensulfuron, will need to be conducted to characterize the mechanism of spurred anoda tolerance to thifensulfuron.

SUMMARY AND CONCLUSION

VITA

Lewis Meriwether Walker IV was born to Lewis M. Walker III and Jacqueline G. Walker on May 8, 1963 in Petersburg, Virginia. He received a Bachelor of Science degree, majoring in Integrated Pest Management, from Virginia Polytechnic Institute and State University in August 1986. He began working on a Doctor of Philosophy degree in the department of Plant Pathology, Physiology, and Weed Science at Virginia Polytechnic Institute and State University in September 1986 on a graduate research assistantship under the guidance of Drs. Henry P. Wilson, Kriton K. Hatzios, E. Scott Hagood, David J. Parrish, and Jefferey F. Derr.

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