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COMMON RAGWEED CONTROL WITH BENTAZON AS INFLUENCED BY IMAZETHAPYR AND THIFENSULFURON TANKMIXES

By

Aaron Gregory Hager

A THESIS

Submitted to
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1993

ABSTRACT

COMMON RAGWEED (*Ambrosia artemisiifolia*) CONTROL WITH BENTAZON AS INFLUENCED BY IMAZETHAPYR AND THIFENSULFURON TANKMIXES

By

Aaron Gregory Hager

Several herbicides control common ragweed postemergence in soybeans. However, when herbicides are tankmixed, synergistic or antagonistic weed responses may occur, and additive selection may influence weed response. Imazethapyr and thifensulfuron can be tankmixed with bentazon for broadleaf weed control, and visual crop injury and cost hectare^{-1} may be reduced compared to a bentazon plus acifluorfen tankmix. Experiments determined common ragweed control from these herbicides and herbicide combinations when applied with various additives. In the greenhouse bentazon at 560 g ha^{-1} reduced common ragweed dry weight 95 to 97%. Common ragweed control with 35 g ha^{-1} of imazethapyr increased 13 and 7% when urea ammonium nitrate (UAN) was applied with nonionic surfactant (NIS) or petroleum oil adjuvant (POA), respectively. Tankmixing thifensulfuron at 4.5 g ha^{-1} or imazethapyr at 35 or 71 g ha^{-1} with bentazon did not enhance nor reduce dry weight of common ragweed compared with bentazon alone. In field research bentazon at 1120 g ha^{-1} reduced common ragweed dry weight 78 to 81%. Tankmixing bentazon with thifensulfuron at 4.5 g ha^{-1} or imazethapyr at 71 or 35 g ha^{-1} reduced common ragweed dry weight by 89 to 91%, thus enhancing control compared to each herbicide applied alone. Adding 28% UAN to bentazon plus imazethapyr or bentazon plus thifensulfuron tankmixes did not increase control compared to NIS or POA alone. By 28 days after treatment (DAT) only 35 or 71 g ha^{-1} of imazethapyr plus 28% UAN plus NIS or POA and bentazon plus imazethapyr tankmixes provided 85% or more control of common ragweed in 1991, and only 71 g ha^{-1} of imazethapyr plus 28% UAN plus POA or 71 g ha^{-1} of imazethapyr plus bentazon provided greater than 78% common ragweed control in 1992. Soybean yields were equal to that of the handweeded control only with the bentazon plus 71 g ha^{-1} of imazethapyr tankmix treatments. Research was conducted to determine the influence of relative humidity (RH), soil moisture, and the presence of bentazon on the absorption and translocation of ^{14}C-imazethapyr in common ragweed (*Ambrosia artemisiifolia* L.). Low soil moisture (-3 bars) reduced ^{14}C-imazethapyr absorption by 6% 24 h after treatment, but did not influence translocation. The absorption and translocation of ^{14}C-imazethapyr when applied alone was not effected by RH 48 and 168 h after treatment. However, when bentazon was present in the spray solution absorption 24 h after treatment was reduced by 51% at 65% RH but was not reduced at 85% RH. Translocation of ^{14}C-imazethapyr out of the treated leaf was reduced significantly at 65% RH, but not at 85% RH in the presence of bentazon.

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LITERATURE REVIEW

Imazethapyr. Imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] is a selective herbicide used to control a wide spectrum of broadleaf and grassy weeds in soybeans (*Glycine max* (L.) Merr.) and other leguminous crops. Imazethapyr belongs to the herbicide family known as the imidazolinones. Soybeans have shown excellent tolerance to imazethapyr applied preemergence, preplant incorporated, or postemergence. Cantwell et al. (1989) reported no yield reduction in soybeans from preplant incorporated, preemergence, or postemergence imazethapyr applications of 0.05 to 0.14 kg ha^{-1}. Mills and Witt (1989) reported that soybeans treated with 70 g ha^{-1} of imazethapyr applied preemergence had yields equivalent to the weed free control. Wilson and Miller (1991) observed no yield reduction in dry edible bean (*Phaseolus vulgaris* L.) from imazethapyr applied preplant incorporated and postemergence at 0.07 and 0.10 kg ha^{-1}.

In a review of the structural requirements for imidazolinone herbicidal activity, Ladner (1990) concluded that a carboxylic acid group or a group which could be readily transformed to a carboxylic acid was necessary for activity and that this group must be ortho to the imidazolinone ring, with methyl and isopropyl substituents on the imidazolinone ring affording superior activity. A pyridine ring as the backbone ring shows the highest level of activity.

The mode of action of a herbicide can be defined as being the manner in which a

action of many herbicides is not known, the biochemical pathway which is inhibited by the imidazolinone herbicides has been identified. In 1984, the site of action of the imidazolinone herbicides was discovered to be the enzyme acetolactate synthase, commonly referred to as ALS (Shaner et al. 1984). ALS is the first enzyme in the pathway leading to the synthesis of the branched-chain amino acids valine, leucine, and isoleucine. For valine and leucine synthesis, two molecules of pyruvate are condensed to form 2-acetolactate, while for isoleucine formation one molecule of pyruvate reacts with 2-ketobutyrate in a similar reaction (Durner et al. 1991). Like many of the amino acid biosynthetic enzymes, ALS is nuclear encoded and located in the plastid (Miflin 1974). The inhibition of the ALS enzyme by the imidazolinone herbicides causes a disruption in protein synthesis which in turn interferes with DNA synthesis and cell growth (Shaner and Reider 1986). The meristematic tissues of the plant die first followed by a slow necrosis of mature tissue.

Numerous studies have investigated the inhibitory action of the imidazolinone herbicides with agreement that ALS is the site of action. Anderson and Hibbard (1985) reported that the analysis of free amino acid levels of corn (*Zea mays* L.) suspension cell cultures indicated that levels of leucine and valine were substantially decreased in cells exposed to 10 μM of imazapyr [(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid], another imidazolinone herbicide. Quantities of leucine and valine after 48 hours of exposure to the herbicide were 52 and 27%, respectively, of the levels seen in untreated cell cultures. Supplementation of suspension culture growth media with leucine and valine

plus isoleucine was carried out to determine if reversion of the growth inhibition would occur. These supplemented amino acids reversed the growth inhibitory effects of imazapyr at levels ranging from 10 nM to 1 mM. These results lead Anderson to suggest a specific interaction of the herbicide with leucine, valine, and isoleucine synthesis. Muhitch et al. (1987) found that ALS activity in crude extracts of excised maize leaves and cultured suspension cells was reduced 85 and 58%, respectively, by incubation of the tissue with 100 μM (excised leaves) and 5 μM (suspension cultures) of imazapyr. Muhitch also found that when ALS activity was measured over a 4 hour assay period in the presence of various imazapyr concentrations, inhibition was found to increase with time, an indication of a tight binding inhibitor. Stidman and Shaner (1990) reached similar conclusions when they demonstrated that the level of inhibition by three concentrations of imazapyr increased over a 4 hour time period, approaching a final steady-state level of inhibition between 3 and 4 hours. From their results the authors postulated two explanations of this slow-binding behavior: 1) the enzyme undergoes conformational changes upon initial binding with the herbicide and the change results in an increased stabilization of the enzyme-herbicide complex, and 2) the inhibitor experiences some transformation on the surface of the enzyme that results in a modified inhibitor. Pillmoor and Caseley (1987) found that imazamethabenz-methyl [(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-4(and5)-methylbenzoic acid (3:2)] inhibited the ALS enzyme, however the inhibition appeared to be dependent upon the conversion of the parent herbicide to the free acid form. LaRossa et al. (1987) theorized that a build-up of ∝-ketobutyrate to toxic levels caused by a blockage of the ALS enzyme may be the actual cause of plant death, not depletion

of amino acid levels.

Van Ellis and Shaner (1988) investigated the mechanism of cellular absorption of the imidazolinone herbicides in soybean leaf discs. Since the amino acid synthesis pathway is located in the plastid the herbicide must transverse the plasmalemma by 1) passive diffusion, 2) active uptake via a carrier, or 3) ion trapping of a weak acid. The uptake of the three imidazolinone herbicides imazapyr, imazethapyr, and imazaquin [2-4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid] was sensitive to the pH of the uptake solution, uptake into the leaf discs was linear with respect to external concentration, and metabolic inhibitors and uncouplers decreased uptake 58 to 85%. The Q_{10} for uptake between 13 and 23 C was 1.7. There were differences in uptake of the three herbicides across the pH ranges from pH 4 to pH 7 and these differences were postulated to be reflective of the differences in lipophilicity of the herbicides at pH 4 and pH 7. The authors final conclusion was that the uptake of these imidazolinone herbicides could best be explained by ion trapping.

To reach the site of action, postemergence herbicides must be absorbed by the plant foliage. The main barrier to herbicide absorption is the plant cuticle and diffusion of the herbicide through the cuticle appears to be the rate-limiting step in foliar absorption (Wanamarta and Penner 1989). The thickness of the cuticle varies by plant species and environmental conditions. Differences in the amount of foliar absorption of the imidazolinone herbicides has been observed for different plant species. Shaner and Robson (1985) reported that ^{14}C-imazaquin did not penetrate velvetleaf (*Abutilon theophrasti* Medicus) foliage as well as it did soybean or common cocklebur (*Xanthium* *strumarium* L.) leaves. Absorption of imazaquin by velvetleaf was decreased when the herbicide was applied to the leaves as compared to application to the cotyledons. Wilcut et al. (1988) reported differences in ^{14}C-imazaquin absorption 3 hours after application for the weed species evaluated. The order of absorption from greatest to least was soybean 78%, sicklepod (*Cassia obtusifolia* L.) 71%, Florida beggarweed (*Desmodium tortuosum* (Sw.) DC.) 61%, peanut (*Arachis bypogaea*) 59%, and common cocklebur 53%. Differences in absorption by species were no longer evident after 24 hours, and by 72 hours the amount absorbed exceeded 90% of that applied for all species with no differences between species. Cole et al. (1989) noted differences in absorption of ^{14}C-imazethapyr 3 hours following foliar application. Soybeans had absorbed 80% of the amount applied and this maximum amount was followed by sicklepod which absorbed 77% and then by peanut, Florida beggarweed, and redroot pigweed (*Amaranthus retroflexus* L.), the three of which absorbed an average of 55%. By 24 hours after application, Florida beggarweed had only absorbed 77%, while absorption among the remaining species was 92% with no differences between species. Acropetal and basipetal movement of ^{14}C-imazethapyr away from the treated leaf was apparent in all species (soybean, peanut, sicklepod, Florida beggarweed, and redroot pigweed) evaluated. At 72 hours after treatment, approximately 6% of the applied imazethapyr had been translocated out of the treated leaf of peanut, sicklepod, and Florida beggarweed, while 12 and 15% were translocated out of the treated leaf of redroot pigweed and soybean, respectively. Following root uptake of soil applied ^{14}C-imazethapyr, all species except peanut had translocated greater than 85% of the absorbed imazethapyr into the shoot. Peanut had translocated 72% of the absorbed ^{14}C-imazethapyr. Shaner and Robson (88) found that based on the distribution of ^{14}C-imazaquin applied to the foliage or roots, imazaquin was both xylem and phloem mobile in velvetleaf, common cocklebur, and soybean. Wilcut et al. (99) found both symplastic and apoplastic translocation of ^{14}C-imazaquin in soybean, peanut, Florida beggarweed, common cocklebur, and sicklepod.

The mechanism of plant selectivity to a herbicide could be the result of differences in the rate of absorption, translocation, metabolism, and/or sensitivity of the site of action to the herbicide. Bauer et al. (11) demonstrated that enzyme sensitivity differences to imazethapyr could not explain the difference in sensitivity of two pinto bean varieties. Studies by Shaner and Robson (88), Cole et al. (25), and Wilcut et al. (99) have shown that crop selectivity is based upon differential rates of metabolism among various species. The half-life of imazethapyr in soybeans, a tolerant crop, is 1.6 days[1], while the half-life in redroot pigweed, a susceptible species, was shown by Cole et al. (25) to be 32.1 days. Wilcut et al. (99) determined the half-life of imazaquin in soybeans to be 4.4 days, while the half-life in common cocklebur is 39.8 days. The metabolic pathway of imazethapyr in soybeans has been suggested by Lee et al. (1991). Based on metabolic profiles of extractable residues from soybean plants, oxidative hydroxylation at the α-carbon of the ethyl substituent on the pyridine ring is believed to be the primary site for initial metabolic conversion of the parent compound, yielding α-hydroxyethyl imazethapyr which then reacts with glucose, yielding a glucose

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[1]AC 263,499 Experimental herbicide technical information report. 1985. American Cyanamid Co., Princeton, NJ 08540.

conjugate as the final metabolite.

The imidazolinone herbicides possess soil activity in addition to foliar activity. The soil activity and persistence of this class of herbicides may have a negative effect on subsequent crops planted where imidazolinone herbicide applications were made during a previous growing season. Various factors contribute to the field persistence of imazethapyr. Goetz et al. (1990) examined the effects of photodecomposition, volatilization, temperature, soil type, and soil moisture on the degradation and persistence of imazethapyr. Volatilization accounted for less than 2% of the dissipation of imazethapyr, and losses from photodecomposition were less than 10% when imazethapyr was applied to the soil. Photodecomposition losses up to 52% occurred from application to a glass slide, free of soil. Degradation of imazethapyr increased under conditions of increased soil moisture which was attributed to greater soil microorganism activity. Elevated soil temperatures conducive to enhanced microbial activity and soil types which were low in clay and organic matter were also found to be conditions for enhanced degradation. Stougaard et al. (1990) evaluated the effects of soil type and pH on adsorption, mobility, and efficacy of imazaquin and imazethapyr, finding that adsorption of both herbicides increased as soil pH decreased. These observations were attributed to protonation of the basic quinoline and pyridine moieties of imazaquin and imazethapyr, respectively, resulting in ionic binding to soil colloids at the lower soil pH. Consistent with the findings of Goetz et al.(1990), Stougaard observed greater mobility of both herbicides in soils of low clay and organic matter content. Renner et al. (1988) concluded that adsorption of imazaquin and imazethapyr increased as soil pH decreased from pH 8.0 to 3.0 in laboratory studies. The authors postulated that protonation of the imidazolinone nitrogens, or the nitrogen of the quinoline or pyridine ring of imazaquin and imazethapyr, respectively, may have resulted in cationic binding of the herbicides to soil at low soil pH values. Cantwell et al. (1989) investigated abiotic and biotic factors influencing the biodegradation characteristics of imazaquin and imazethapyr. Using gamma-irradiated soil as a sterilized soil, 95% of the applied radioactivity could be extracted as parent herbicide following 12 weeks of incubation. Extensive degradation of the parent herbicide occurred in the unsterilized soil, leading the authors to conclude that the primary mechanism of imidazolinone degradation in soil was microbial.

Acifluorfen. Acifluorfen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid] is a selective herbicide used for the preemergence and/or postemergence control of broadleaf weeds and grasses in soybeans, peanuts, and rice (*Oryza sativa* L.). Acifluorfen is active as a preemergence treatment but high rates are required for effective weed control (Johnson et al. 1978).

Acifluorfen belongs to the class of herbicides known as the diphenyl ether herbicides. This class of herbicides is characterized by two phenyl rings joined by an ether linkage. The members of this herbicide family differ from one another by the different substituent groups present at various locations on the phenyl rings. The patterns of the various substituent groups are the cause of the different effects demonstrated by the diphenyl ethers (Kunert et al. 1987).

The major use of acifluorfen is as a postemergence herbicide. The application rate

table for acifluorfen begins at a rate of 285 g ha^{-1} and concludes at a maximum use rate of 850 g ha^{-1}. Several annual grass species are included in the label, such as fall panicum (*Panicum dichotomiflorum* Michx.), shattercane (*Sorghum bicolor* (L.) Moench), and giant foxtail (*Setaria faberi* Herrm.), but the majority of acifluorfen is applied for broadleaf weed control.

Lee and Oliver (1982) studied the efficacy of acifluorfen on broadleaf weeds. Their research concentrated on ascertaining the best time and method for postemergence acifluorfen applications. They concluded that the most efficient control of the weed species evaluated occurred when acifluorfen was applied when the weeds were in the early stages of growth. If applications were delayed until the weeds were at a later stage of growth, increased application rates of acifluorfen were required to obtain satisfactory control. They observed greater control of hemp sesbania (*Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill), pitted morningglory (*Ipomoea lacunosa* L.), and smooth pigweed (*Amaranthus hybridus* L.) when acifluorfen was applied in the dark (2100h) than at sunup (0600h) or mid-day (1200h). The postulation was put forth that the greater control from dark applications may have resulted from the observed increase in relative humidity that may have enhanced herbicide penetration. Volume of spray solution was evaluated also. The conclusions were that higher spray volumes are required when complete coverage of foliage is necessary for acceptable control in species such as pitted morningglory, but lower volumes are necessary to prevent runoff of spray solution from the waxy leaf surfaces of species such as hemp sesbania.

Ritter and Coble (1984) examined the influence of crop canopy, weed maturity, and rainfall on acifluorfen activity. Consistent with Lee and Oliver (58), Ritter and Coble found more consistent weed control when applications of acifluorfen were made when the weed species were small. Topical applications of acifluorfen plus surfactant gave the greatest control. Rainfall occurring shortly after herbicide application resulted in less control than when rainfall was delayed several hours. They concluded that several factors influenced acifluorfen activity, including amount, length, intensity of rainfall, and size of droplet.

In a separate study, Ritter and Coble (1981) examined the influence of temperature and relative humidity on acifluorfen activity. Control of the weed species evaluated was greater at high temperatures (32 C day, 22 C night) than at low temperatures (26 C day, 16 C night). Treatments made at high relative humidity (85% ± 5%) provided better control than treatments made at low (50% ± 5%) relative humidity. When the same herbicide treatments were compared across all four regimes, high temperature and high humidity provided the best control. They concluded, however, that relative humidity was a more important factor than temperature, as relative humidity affects the ability of the herbicide to penetrate the plant leaf cuticle. This conclusion is in agreement with that reached by Willingham and Graham (1988) who found that relative humidity had the greatest effect on penetration of acifluorfen into velvetleaf. Penetration into velvetleaf increased from 1 to 10% as relative humidity increased from 40 to 90%. Temperature was the second most important factor. They theorized that higher temperatures may soften the leaf cuticle and aid in penetration, but higher temperatures may also accelerate the drying of the spray droplets and cause more loss due to volatility.

Wills and McWhorter (1981) considered the effect of environment on the translocation and toxicity of acifluorfen to showy crotalaria (*Crotalaria spectabilis* Roth). They discovered that acifluorfen applied postemergence provided greater control at high (100%) than at low (40%) relative humidity. The control was also greater at high (27 and 35 C) than at low (18 C) temperature. Translocation of radiolabeled acifluorfen was influenced more by air temperature than by relative humidity.

Several studies have examined the use of mefluidide [*N*-[2,4-dimethyl-5-[[(trifluoromethyl)sulfonyl]amino]phenyl]acetamide] as a pretreatment or in conjunction with acifluorfen treatments. Mefluidide is classified as a plant growth regulator (107).

Hook and Glenn (1984) examined penetration, translocation, and metabolism of ^{14}C-acifluorfen following pretreatment with mefluidide in soybean and various weed species. Results varied between weed species and soybeans. In ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.), pretreatment with mefluidide 3, 5, or 7 days prior to radiolabeled acifluorfen application increased penetration, decreased metabolism, and did not affect translocation of acifluorfen. In velvetleaf, pretreatment 0, 3, 5, or 7 days increased penetration while the 3, 5, and 7 day pretreatments decreased metabolism of acifluorfen by velvetleaf. Penetration and translocation of radiolabeled acifluorfen in soybeans was unaffected by pretreatment of melfuidide, but metabolism of acifluorfen was decreased by the 0 day pretreatment. In a separate study, Hook and Glenn (1984) investigated the interactions of mefluidide and acifluorfen. No statistical differences ($P>0.05$) were found when the data were averaged over all acifluorfen rates and sequences of application in either injury or dry weight reduction of ivyleaf morningglory, velvetleaf, or common cocklebur using either 0.1 or 0.3 kg ha^{-1} of mefluidide. Treatments included individual applications at each herbicide rate as well as tank mixtures and sequential applications. This study was conducted in the greenhouse. Field studies by Glenn et al. (1985) evaluated control of velvetleaf and common cocklebur in soybeans with sequential applications of mefluidide and acifluorfen. Field results from 1981 and 1983 showed that 6 weeks after application there was no difference in velvetleaf control between sequential early-post treatments and acifluorfen applied alone. In 1981, all sequential late-post treatments of mefluidide and acifluorfen were more effective in controlling velvetleaf than late-post applications of acifluorfen alone. There were no differences in common cocklebur control between sequential early-post treatments and acifluorfen applied early-post alone by 6 weeks after application in 1981. All sequential late-post treatments increased common cocklebur control 3 and 6 weeks after application, compared to control obtained with late-post applications of acifluorfen.

Surfactants have been shown to increase the phytotoxicity of acifluorfen. Lee and Oliver (1982) noted that increasing the surfactant concentration enhanced the control of entireleaf morningglory (*Ipomoea hederacea* var. integriuscula) and Texas gourd (*Cucurbita texana* (Scheele) Gray). Ritter and Coble (84) showed that the addition of a nonionic surfactant enhanced control of common cocklebur and common ragweed (*Ambrosia artemisiifolia* L.). Willingham and Graham (103) and Banks et al. (1988) also noted greater control of weed species with the addition of a surfactant to the spray solution with acifluorfen.

The selectivity of acifluorfen is related to crops metabolizing the herbicide to a larger extent than do susceptible species. Ritter and Coble (1981) examined the metabolism of acifluorfen in soybean, common ragweed and common cocklebur. At 7 days after application of radiolabeled acifluorfen, soybeans metabolized more of the parent compound than common cocklebur which metabolized more of the parent compound than common ragweed. The authors also noted that penetration and translocation were more rapid in susceptible weed species as compared to tolerant soybean. Higgins et al. (1988) observed the absorption, translocation, and metabolism of ^{14}C-acifluorfen in pitted morningglory and ivyleaf morningglory, showing metabolism and translocation of radiolabeled acifluorfen were minimal in both species. Penetration of acifluorfen was greater in pitted than in ivyleaf morningglory, and this fact may account for the greater tolerance of ivyleaf morningglory to acifluorfen. The pubescent leaf surface of ivyleaf morningglory appears to be more restrictive to absorption of acifluorfen than the glabrous leaf surface of pitted morningglory.

Frear et al. (1983) examined and defined the pathway of soybean metabolism of acifluorfen. From 85 to 95% of the absorbed radiolabeled acifluorfen was metabolized in less than 24 hours. The first reaction in this metabolic pathway is the cleavage of the diphenyl ether bond. This cleavage results in a reactive phenolic intermediate and a homoglutathione conjugate. The phenolic intermediate is conjugated with glucose and further acylated to form a malonyl-*B*-D-glucoside, which was labeled metabolite I. The homoglutathione conjugate was identified at metabolite II. Further metabolism of II results in a cysteine conjugate, identified as metabolite III.

The ortho-substituted diphenyl ether herbicides require light for activation (Matsunaka 1969). This activation process appears to be a photobiochemical process. Matsunaka (1969) examined the susceptibility of white or yellow mutant rice plants to nitrofen [2,4-dichloro-1-(4-nitrophenoxy)-4-(trifluoromethyl)benzene] to determine which pigments were responsible for the photoactivation process. The author found that green or yellow rice plants were susceptible to nitrofen, but white plants were tolerant. From the results, Matsunaka concluded that chlorophylls or yellow pigments, especially xanthophylls, were the acceptors of light energy in the photoactivation of nitrofen. Fadayomi and Warren (1976) found results in agreement with Matsunaka (1969) when they observed that nitrofen and oxyfluorfen [2-chloro-1-(3-ethoxy-4-notrophenoxy)-4-(trifluoromethyl)benzene] were much less active on white mutants of corn, but active on normal and greenish yellow plants. The authors also found that plants kept in the dark after herbicide application showed no signs of injury, but when these plants were moved into the light, injury symptoms appeared after 4 hours. Devlin et al. (1983) conducted a study to lend support to the hypothesis of carotenoid pigments being the photoactivators of diphenyl ether herbicides. The author theorized that if carotenoid pigments were in fact responsible for the photoactivation process, plants treated with norflurazon [4-chloro-5-(methylamino)-2-(3-(trifluoromethyl)phenyl)-3(2*H*)-pyridazolinone], which inhibits carotenoid synthesis, should be tolerant to diphenyl ether herbicides. The results of this study revealed that corn seedlings treated with norflurazon were partially tolerant to oxyfluorfen, lending evidence to the proposed theory of carotenoid involvement.

Many theories have been proposed and examined concerning the mode of action of the diphenyl ether herbicides, and in particular, acifluorfen. Orr and Hess (1981) characterized the herbicide injury by acifluorfen in excised cucumber (*Cucumis sativus* L.) cotyledons. Using $^{86}Rb^{+}$ to monitor membrane disruption, the authors found that upon exposure to light, $^{86}Rb^{+}$ efflux increased, indicating a disruption of the cellular membranes. Significant increases in efflux occurred within ten to fifteen minutes if plants were kept in the dark after application, owing to the fact that the longer dark period allowed more herbicide to reach its site(s) of action. The efflux of various substances after treatment seemed to indicate that the disruption of the membranes was general in nature. In a separate study, Orr and Hess (1982) attempted to investigate if the formation of lipophilic free radicals, formed after acifluorfen application, were responsible for the membrane disruptions. The authors found that acifluorfen was much less active in cotyledons held in an atmosphere of nitrogen, and that with the addition of alpha-tocopherol, a known scavenger of lipophilic free radicals, membrane damage was reduced. Duke et al. (1984) proposed that after an initial interaction of acifluorfen with a carotenoid, the mitochondria was involved in the production of free radical species that caused the membrane disruption. Ensminger and Hess (1985) concluded that photosynthesis was not involved in the mechanism of action of diphenyl ether herbicides, which is in disagreement with Gillham and Dodge (1987) who found that diphenyl ether herbicides were activated by photosynthetic electron transport in the vicinity of ferredoxin. After accepting an electron from ferredoxin, the reduced diphenyl ether then went on to initiate lipid peroxidation. Kenyon et al. (1985)

monitored the lipid peroxidation indicators malondialdehyde and ethane after treatment of cucumber cotyledon discs with acifluorfen and discovered an increase in their concentration within 1 hour after exposure of the treated discs to light. The authors also noted early decreases in photosynthesis after acifluorfen application, and proposed that the chloroplast envelope may be a primary target of acifluorfen in the green cucumber cotyledons. Matringe and Scalla (1988) proposed that the phytotoxicity of diphenyl ether herbicides is caused by their ability to induce abnormal accumulations of tetrapyrroles, which induce lethal photooxidative reactions. Tetrapyrroles are a chemical group consisting of four pyrrole rings joined either in a straight chain or in a ring. In their study, Matringe and Scalla found that acifluorfen exerts most of its phytotoxicity in the blue region of the light spectrum, which matches the absorption spectrum of protoporphyrin IX, a tetrapyrrole. This finding suggested that protoporphyrins are the photoreceiptors that activate acifluorfen. These tetrapyrroles are light-dependent generators of singlet oxygen which is responsible for the peroxidation of membrane fatty acids. Witkowski and Halling (1988) also found an increased level of photodynamic tetrapyrroles after treatment with acifluorfen. In a different study, Matringe and Scalla (1988) enhanced the evidence of acifluorfen induced porphyrin accumulation when it was demonstrated that cucumber cotyledons treated with 4,6-dioxheptanoic acid, an inhibitor of tetrapyrrole biosynthesis, were more resistant to the effects of diphenyl ether herbicides.

Protoporphyrinogen, an intermediate common to the heme and chlorophyll synthesis pathways, is oxidized to protoporphyrin (Jacobs and Jacobs 1987). The enzyme that catalyses this reaction is protoprophyrinogen oxidase, and Matrine et. al. (1989) have proposed that its activity is a target site of diphenyl ether herbicides. Jacobs et al. (1991) found that protoporphyrinogen oxidase activity in barley root mitochondria and etioplast extracts was more than 90% inhibited by assay in the presence of acifluorfen. Sato et al. (1991) also found that acifluorfen enhanced the accumulation of protoporphyrin IX.

Thifensulfuron. Thifensulfuron [3-[[[[(4-methoxy-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid] is a selective postemergence herbicide used for control of broadleaf weeds in cereals and soybeans. It soon may also be registered for use in corn.

Thifensulfuron belongs to the class of herbicides known as the sulfonylureas. This class of herbicides is characterized by controlling a large spectrum of weeds at low use rates. The potential for this chemical class to be used as herbicides was first reported in 1966 (Beyer et al. 1987), but further research was minimal until the mid-1970's when George Levitt began to investigate the herbicidal properties once again. This work led to further development of the sulfonylurea chemical class to be used as herbicides.

The sulfonylurea molecule consists of three parts: (1) an aryl group, (2) a sulfonylurea bridge, and (3) a heterocyclic ring (Hay 1990). Each of these three parts contributes to the herbicidal activity of the compound. Those compounds with an ortho-substituent on the aryl ring show the highest degree of herbicidal activity. The changing of various substituent groups to different positions on the aryl, sulfonylurea bridge, or heterocyclic parts of the molecule results in the diversity of compounds with herbicidal activity within the sulfonylurea class.

Sulfonylureas are weak acids with pKa values ranging from 3 to 5 (43). Because sulfonylureas are weak acids, pH greatly influences their water solubility and partition coefficients. As the pH of the solution increases, more of the herbicide molecule will exist in the deprotonated or anionic form which is more water soluble. This increase in water solubility at higher pH values has the concomitant effect of lowering the herbicide partitioning into octonal.

Sulfonylureas undergo two major chemical reactions that are relevant to their use as herbicides: (1) hydrolysis and (2) salt formation (13). As weak acids, sulfonylureas form stable metal salts in the presence of bases, alkali or alkaline earth hydroxides, or carbonates (43). The hydrolysis reaction of sulfonylureas is greatly dependent on pH. Hydrolysis is more rapid under acidic conditions when the herbicide molecule is in the protonated form. Cleavage of the sulfonylurea bridge part of the molecule is the predominant hydrolysis reaction, which results in the formation of the sulfonamide, the aminoheterocycle, and carbon dioxide from the parent molecule.

In the soil environment, the sulfonylurea herbicides are subject to chemical hydrolysis and microbial attack as the two main degradation pathways (Brown, 1990). Blair and Martin (1988), in their review of the sulfonylurea class of herbicides, referred to evaluation experiments using chlorsulfuron [2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide] to determine soil conditions optimal for the degradation of the herbicide. The determining factor of chlorsulfuron

persistence was soil pH, with the most rapid degradation occurring at acid pH values. It was concluded that under acid soil conditions, both hydrolysis and microbial activity were functioning to degrade the chlorsulfuron, but under basic soil conditions, hydrolysis was greatly reduced and microbial activity became the dominant factor, thus resulting in a longer persistence of the chlorsulfuron. Brown (16) discussed a model for sulfonylurea herbicide degradation originally proposed by Hamaker and Goring (41). According to the model, when first applied the herbicide initially undergoes microbial and chemical (hydrolysis) breakdown. Over time, a small amount of the herbicide moves into soil compartments too small for microbial entry. Thus, after the microbial populations have degraded all herbicide available to them, long term soil degradation is dependent upon chemical breakdown, which is again a function of soil pH.

Numerous studies have been conducted to determine the mode of action of the sulfonylurea herbicides. Conclusive evidence has been presented that identifies the mode of action as the inhibition of the biosynthesis of the branched-chain amino acids valine, leucine, and isoleucine. The sulfonylurea herbicides inhibit the first common enzyme in the biosynthetic pathway of these amino acids; this enzyme is acetolactate synthase, also known as acetohydroxyacid synthase. Beyer et al. (1988) described the function of the acetolactate synthase enzyme as follows: acetolactate synthase catalyzes the condensation of two molecules of pyruvate to form CO_2 and α-acetolactate, which leads to valine and leucine synthesis, and the condensation of one molecule of pyruvate with α-ketobutyrate to form CO_2 and α-aceto-α-hydroxybutyrate, which leads to isoleucine formation. Chaleff and Mauvais (1984) conducted experiments in which

sulfonylurea susceptible and resistant tobacco plants were crossed and the ALS enzyme from the progeny extracted and tested for sensitivity to chlorsulfuron and sulfmeturon methyl[2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid]. Through the crosses, it was shown that the ALS enzyme proved to be the site of action of the sulfonylureas as resistance or susceptibility was not accounted by another enzyme or group of enzymes. Ray (1984) identified the site of action of chlorsulfuron to be the ALS enzyme. Using excised pea (*Pisum sativum*) roots, as little as 2.8 μM of chlorsulfuron inhibited root growth while supplementation of the media with 100 μM each of valine and isoleucine protected the roots from growth inhibition. These results showed that chlorsulfuron interfered with the synthesis of these amino acids, but supplementation of pyruvate and threonine in the presence of chlorsulfuron did not alleviate growth inhibition so it was reasoned that the site of action was an earlier step in the synthesis of these amino acids. Following extraction of the ALS enzyme, treatment with chlorsulfuron was shown to strongly inhibit the activity of the enzyme, with the resultant inhibition of the biosynthesis of valine, leucine, and isoleucine.

Research has determined the basis of selectivity of sulfonylurea herbicides to crop species. Sweeter et al. (1982) investigated the selectivity of cereal crops to chlorsulfuron. No correlations occurred between the amount of ^{14}C-chlorosulfuron penetration and translocation and the selectivity of tolerant and susceptible species. The authors found a good correlation between plant sensitivity and the rate of herbicide metabolism. Using sugar beet (*Beta vulgaris* L.) as a sensitive plant and wheat as a tolerant plant, ^{14}C-chlorsulfuron was applied to a leaf of each species. By 24 hours after treatment, 97% of the radioactivity in the sugar beet leaf was recovered as parent chlorsulfuron, while only 5% of the radioactivity in the wheat leaf was unmetabolized chlorsulfuron. Brown and Neighbors (1987) investigated soybean tolerance to chlorimuron ethyl [2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid]. Their results also point to metabolism by tolerant species as the major factor determining selectivity. Soybeans were shown to metabolize chlorimuron ethyl rapidly, with a half-life of only 1 to 3 hours. Susceptible species such as common cocklebur and redroot pigweed metabolized the chlorimuron ethyl slower, with half-lives over 30 hours. Brown et al. (1990) then investigated soybean tolerance to thifensulfuron methyl. The authors found the half-life of thifensulfuron methyl in soybean seedlings to be 4 to 6 hours, while the half-life in susceptible species such as velvetleaf, pigweed, and lambsquarters (*Chenopodium album* L.) was typically greater than 36 hours. The conclusion was that rapid metabolism by a deesterification reaction to yield herbicidally inactive thifensulfuron acid was the basis for soybean tolerance.

Fielding and Stoller (1990) investigated the effects of various additives on thifensulfuron methyl efficacy, uptake, and translocation using soybean, velvetleaf, and common lambsquarters as the test species. The results showed that 28% UAN gave greater control of velvetleaf than treatments without 28% UAN, but that adding 28% UAN increased soybean injury and control of common lambsquarters was not improved. In controlled environment studies, uptake of ^{14}C-thifensulfuron into velvetleaf without the addition of an additive was less than 4% by 84 hours after treatment, but with the

addition of a nonionic surfactant or 28% UAN, uptake was increased to 33 and 45%, respectively, 84 hours after treatment. When both nonionic surfactant and 28% UAN were included in the spray solution, uptake was 76% by 84 hours after treatment. Translocation was also enhanced when both additives were present. Beckett and Stoller (1991) examined the effects of methylammonium and 28% UAN on foliar uptake of thifensulfuron by velvetleaf and found that in the absence of nitrogen only 15% of the applied ^{14}C-thifensulfuron was taken up into the plant 24 hours after treatment, but with the addition of UAN or methylammonium nitrate, uptake was increased to 38 and 59%, respectively. Following these increases in uptake, translocation of ^{14}C-thifensulfuron also increased. Ahrens (1990) reported an enhancement of soybean injury and weed control when thifensulfuron was tank-mixed with various organophosphate or carbamate insecticides. Since thifensulfuron is metabolized in soybean by a deesterification reaction, and the organophosphate and carbamate insecticides are esterase inhibitors, the author postulated that the insecticides partially hindered the normal metabolic detoxification process of thifensulfuron in soybean. Ahrens also speculated that if the proper rate of herbicide and insecticide could be found, this interaction could enhance weed control from thifensulfuron.

Corn has shown tolerance to applications of thifensulfuron and Eberlein et al. (1989) examined the tolerance of several corn genotypes to thifensulfuron. A tolerant line (A671) and a susceptible line (A619) were selected to evaluate the mechanism of tolerance by this crop. Differences in whole plant spray retention, differential susceptibility of ALS, or differences in absorption did not explain the differential tolerance between the two lines. However, 23% of the parent compound remained in the treated leaves of the tolerant line (A671) 5.5 hours after treatment compared to 78% of the parent compound remaining in the treated leaves of the susceptible line (A619). Therefore, it was concluded that differential rates of metabolism was the basis for different corn genotype tolerance of thifensulfuron.

Zhao et al. (1990) examined factors that affect thifensulfuron efficacy, using velvetleaf and corn as test species. Velvetleaf was more susceptible to foliar applications versus root exposure, and greatest control was achieved when treatments were applied to young plants. Addition of nonionic surfactant increased velvetleaf control and reduced loss of activity when rainfall occurred shortly after application. Gast et al. (1990) examined the best application timing of thifensulfuron for wild garlic (*Allium vineale* L.) control. Applications in late March to early April or when offset bulb initiation began provided the best control of wild garlic and reduced the number of new bulbs formed. Kells (1989) applied thifensulfuron for control of mayweed chamomile (*Anthemis cotula* L.) in winter wheat (*Triticum aestivum* L.). Thifensulfuron at 8.8 g ha^{-1} controlled 89% or more mayweed chamomile at heights from 3 to 18 cm with no visible wheat injury. Ostermeyer and Meier (1989) investigated thifensulfuron use in pasture for control of *Rumex* species. *Rumex* species control exceeded 90% with little damage to grasses in pastures.

Bentazon. Bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] is a selective postemergence herbicide used in a wide variety of crops for broadleaf weed control. Bentazon is effective through contact action and thus thorough

spray coverage of the target plants is essential for good control.

Bentazon selectivity to tolerant crops has been investigated extensively and it appears that no one factor completely governs this differential selectivity. Connelly et al. (1988) examined the basis for soybean tolerance to bentazon among soybean genotypes considered tolerant and those considered susceptible. Following the application of 1 kg ha^{-1} of bentazon, the photosynthetic rate of all genotypes was significantly reduced at 3 and 6 hours after bentazon application compared to the untreated control plants. By 9 hours after application the photosynthetic rate of the tolerant genotypes was not significantly different than the controls, but the susceptible genotypes never recovered and photosynthesis stopped after 48 hours. Tolerant and susceptible genotypes could not be separated on the basis of differences in the amount of absorption or translocation of ^{14}C-bentazon. Metabolites of ^{14}C-bentazon were compared from the tolerant and susceptible genotypes to determine if differential metabolism was the basis of tolerance. The tolerant genotypes metabolized bentazon to form glycosyl conjugates of 6- and 8- hydroxybentazon. Neither of these metabolites were extracted from the susceptible genotypes. Thus, bentazon tolerance in soybean was a function of a particular genotype's ability to metabolize bentazon to these two glycosyl conjugates. Wills (1976) determined the effect of environment on bentazon toxicity to resistant and susceptible soybean cultivars. 'Hurrelbrink' soybeans were found to be more sensitive to bentazon than 'Hill' soybeans in greenhouse studies. Overall translocation of ^{14}C-bentazon increased from 11 to 19% in Hill and from 48 to 62% in Hurrelbrink as the temperature increased from 24 to 35 C. There was also

greater basipetal translocation of ^{14}C-bentazon in the Hurrelbrink cultivar than in the Hill cultivar, giving overall greater translocation and a wider distribution of the radiolabel in the susceptible Hurrelbrink cultivar. The author concluded that the tolerance level of these two soybean cultivars was directly associated with the amount of herbicide translocation occurring in the plant. Mahoney and Penner (1975) studied the translocation and metabolism of bentazon in soybean and navy bean. Foliar application of ^{14}C-bentazon to the unifoliate leaves of navy bean resulted in both acropetal and basipetal movement of the bentazon, while foliar applications made to the center leaflet of the first trifoliate resulted in acropetal movement only. Metabolism of the ^{14}C-bentazon was much slower in the unifoliate leaves than in the center leaflet of the first trifoliate after 1 day and it was theorized that both these factors, translocation and metabolism, may explain why injury occurred in the field following bentazon applications to unifoliate navy beans. Movement of ^{14}C-bentazon in soybean was primarily acropetal with some basipetal movement. Translocation and metabolism were considered as the basis of selectivity. In a separate study, Mahoney and Penner (1975) found that the trifoliate leaves of navy bean retained less bentazon from foliar applications than the unifoliate leaves. Bentazon metabolism was similar in the unifoliate and trifoliate leaves, however, a significantly greater amount of ^{14}C-bentazon remained as unmetabolized bentazon in the unifoliate leaves as compared to the trifoliate leaves. Baltazar et al. (1984) reported on the selectivity of bentazon in hot pepper (*Capsicum chinense* L.) and sweet pepper (*Capsicum annuum* L.). Yields in 1982 showed that all rates of bentazon, 0.6 to 6.7 kg ha^{-1} reduced sweet pepper yield,

but only the highest rate of bentazon significantly reduced hot pepper yields. Hill reaction sensitivity was equally susceptible in both species due to similar I_{50} values, and thus the authors concluded that hot pepper tolerance to bentazon was not due to resistance at the chloroplast level. Irons and Burnside (1982) examined the absorption, translocation, and metabolism of bentazon in sunflower (*Helianthus annuus* L.). The addition of a surfactant to the spray solution greatly increased the absorption and translocation of ^{14}C-bentazon. Mine et al. (1975) examined the mechanism of bentazon selectivity between the tolerant rice crop and the susceptible *Cyperus serotinus*. Differences in absorption and translocation did not provide evidence for differential selectivity as the tolerant rice crop actually absorbed more ^{14}C-bentazon than the susceptible *Cyperus serotinus* and the translocation patterns were similar in both plants. Metabolism of bentazon was then investigated as the possible mechanism of selectivity. The tolerant rice plant metabolized 80-85% of the radioactivity within the first 24 hours after treatment while the susceptible *Cyperus serotinus* metabolized only 20-30% of the radioactivity after 7 days. Thus, difference in the rates of metabolism of the parent compound between tolerant and susceptible species was the mechanism of bentazon selectivity. Sterling and Blake (1988) examined bentazon metabolism using suspension-cultured cells of soybean and velvetleaf. Following 6 hours of incubation in 1 μM of bentazon, soybean and velvetleaf cells accumulated similar amounts of bentazon. Extraction of the radiolabel revealed that all the radiolabel remained as parent bentazon in velvetleaf cells whereas only 21% of the radiolabel remained as parent bentazon in soybeans. Differential rates of metabolism explained the selectivity of these two species to bentazon. Penner (1974) investigated the selectivity of bentazon between soybean and Canada thistle (*Cirsium arvense* (L) Scop.). Soybeans tolerated 5.6 kg ha^{-1} of bentazon under greenhouse conditions, but when plants were grown under conditions of excess soil moisture, soybean injury from bentazon applications became apparent. It was suggested that under excessive soil moisture conditions root absorption of bentazon deposited on the flooded soil surface from the spraying application may have caused the observed soybean injury. The photosynthetic rate of Canada thistle 3 hours after bentazon application was reduced by 70% and respiration was also reduced one day after treatment in both plant species. However, soybean respiration began to recover by 6 days after treatment, possibly indicating metabolism of the bentazon to a noninjurious metabolite. Spray retention was much greater in Canada thistle than soybeans and the selectivity of bentazon between soybean and Canada thistle may be due in part to differences in spray retention and rate of metabolism.

Mine and Matsunaka (1975) examined the mode of action of bentazon, classifying it as a photosynthetic inhibitor from the results of their research. Bentazon was applied to tolerant rice and susceptible *Cyperus serotinus* plants under flooded conditions as a foliar or flooded-water treatment at a rate of 2 kg ha^{-1}, which is a common application rate for bentazon in Japan. Injury from bentazon application to *Cyperus serotinus* appeared 6 to 9 days after a flooded-water treatment. Time needed for translocation was the explanation given for the slow appearance of injury. Desiccation and death of the treated leaves occurred within 2 to 4 days following foliar applications of bentazon. The effects of bentazon on CO_2 fixation and the Hill reaction were investigated. By 4 hours after a foliar application of 1000 ppm bentazon, inhibition of CO_2 fixation was approximately 90% in both species. The susceptible *Cyperus serotinus* showed no recovery of photosynthetic capacity and the plants were killed in 9 days. Bentazon was found to inhibit the Hill reaction in isolated chloroplasts by 50% at 4.0×10^{-3} to 4.8×10^{-5} M concentration. If bentazon was actually inhibiting photosynthesis, the authors questioned if an exogenous supply of carbohydrate material would lessen the effects of bentazon to the plant. Susceptible *Cyperus serotinus* plants that were supplied with exogenous sucrose were much more tolerant to bentazon than were plants that received no sucrose. Since bentazon inhibited the Hill reaction of photosynthesis and rapidly inhibited photosynthetic CO_2 fixation, herbicidal injury developed slowly in flooded-water treatments, and exogenous carbohydrate supplies protected plants from bentazon injury, Mine and Matsunaka concluded that the mode of action of bentazon was the inhibition of photosynthesis. This conclusion was also given by Böger et al. (1977) after studying the long-term effects of bentazon on the photosynthetic system in isolated chloroplasts from the algae *Bumilleriopsis filiformis*.

Suwanketnikom et al. (1982) used isolated spinach (*Spinacea oleracea* L.) chloroplasts to determine the location of electron transport inhibition by bentazon. From the results, the authors postulated that the site of inhibition was at the reducing side of photosystem II, between the primary electron acceptor Q and plastoquinone.

Potter and Wergin (1975) examined the role of light in bentazon toxicity to cocklebur. The first visible signs of injury following an application of 0.25 kg ha^{-1} of bentazon were necrotic spots on the leaves. The appearance of these spots was

accelerated by increasing the amount of light the plants received or increasing the rate of bentazon. Plants that were placed in darkness for 48 hours after application never developed necrosis. Net photosynthesis stopped within 1 hour after treatment and this length of time was independent of the amount of illuminance. However, this time period could be reduced further with increased rates of bentazon. The data suggested that cellular damage was caused by photoinduced toxic by-products that resulted from photosynthesis cessation.

Sterling et al. (1990) examined the uptake and accumulation of bentazon by cultured soybean and velvetleaf cells in an attempt to determine the mechanism of uptake and accumulation into cells. Uptake of bentazon into the cells was linearly related to the external bentazon concentration and bentazon was able to freely diffuse out of the cells, implying that movement into the cells was not carrier mediated. From these results, the authors concluded that bentazon entered the cell by passive diffusion, a process not requiring energy. Accumulation of bentazon in the cell did, however, require metabolic energy and was also pH dependent, with greatest accumulation of bentazon occurring at pH 4.6 and the least accumulation occurring at pH 6.6. Since bentazon is a weak acid with a pKa of 3.45 and accumulation was found to be pH dependent, the authors proposed an ion trapping phenomenon to explain bentazon accumulation. Bentazon would diffuse across the cell membrane as an undissociated molecule due to the lower pH of the extracellular environment, and then dissociate and become "trapped" once inside the cell due to the higher pH environment.

In 1974, a report by Andersen et al. presented the results of early field research with bentazon concerning weed control and soybean tolerance. Their results showed that optimal application timing for control of wild mustard (*Brassica kaber* (DC.) L. C. Wheller), common ragweed, velvetleaf, Pennsylvania smartweed (*Polygonum pensylvanicum* L.), common cocklebur, and common sunflower was when the soybeans were in the first trifoliate growth stage. Addition of a nonionic surfactant to 0.84 kg ha^{-1} of bentazon did not improve weed control because of the exceptionally good control achieved with bentazon alone except when rainfall occurred after application. In eight yield studies, soybean yields were not reduced by bentazon at up to 3.36 kg ha^{-1} as compared to the weed free control.

Growth chamber and greenhouse experiments by Nalewaja et al. (1975) determined the influences of environmental factors on redroot pigweed control with bentazon with and without oil (linseed and petroleum) adjuvants. Control of redroot pigweed by 0.4 kg ha^{-1} of bentazon was reduced by simulated rainfall up to 24 hours after application compared to the control of plants receiving no rainfall after application. Redroot pigweed control was 60, 65, and 70% for bentazon alone, bentazon plus petroleum oil, and bentazon plus linseed oil, respectively. The addition of oil adjuvants reduced the influence of rainfall on the control of redroot pigweed. Control was reduced 21, 12, and 7% for bentazon alone, bentazon plus petroleum oil, and bentazon plus linseed oil, respectively. Wetting the plants after treatment with 180 L ha^{-1} of water increased control of redroot pigweed, possibly by redissolving the herbicide which would allow for further plant uptake. In growth chambers, the greatest control of redroot pigweed was obtained under conditions of high relative humidity at 10 C. Oil adjuvants did not increase redroot pigweed control at any temperature when the humidity level was high. The addition of an oil adjuvant reduced the deleterious influence of low humidity on redroot pigweed control. Nalewaja and Adamczewski (1977) found that a water-soluble linseed oil formulation enhanced absorption and translocation of ^{14}C-bentazon by redroot pigweed more than did emulsifiable linseed oil, petroleum oil, or a surfactant. Uptake and translocation of ^{14}C-bentazon was greater at 30 C than at 10 C and at high humidity compared to low humidity. Doran and Andersen (1975) attempted to determine the rain-free period required for acceptable weed control by bentazon and also examined the possibility of using oil adjuvants to reduce the critical rain-free period. The authors concluded that to avoid loss of activity from bentazon on velvetleaf and common cocklebur, applications should be avoided if rainfall is expected within 24 hours. In greenhouse studies, adjuvants (vegetable and petroleum oil) reduced the detrimental effects of rainfall after application of bentazon, and soybean yields were not reduced by the application of 1.68 kg ha^{-1} of bentazon plus an oil adjuvant.

Campbell and Penner (1982) reported enhanced injury to soybean and navy bean from postemergence applications of bentazon plus organophosphate insecticides. Injury occurred if the applications were split by as much as 48 hours. No corn injury was observed from postemergence applications of bentazon plus insecticide or soil applied insecticide prior to bentazon application. The proposed theory to explain the enhanced soybean injury was the possibility of the insecticides interfering with bentazon metabolism in soybean and navy bean.

Andersen and Koukkari (1978) examined the movement of velvetleaf leaves in greenhouse and growth chamber studies during various periods of the day to determine if these changes in leaf orientation might affect bentazon phytotoxicity. The leaves were found to move from a horizontal position during the day to a near vertical position at night. As the leaves departed from the horizontal position, the amount of bentazon retained on the leaf surface decreased, with a concomitant decrease in velvetleaf control. These results are similar to those obtained by Doran and Andersen (1976) who found that bentazon effectiveness in controlling common cocklebur and velvetleaf was partially dependent on the time of day the application was made. Velvetleaf control was influenced more by the time of day the application was made than was common cocklebur.

Herbicide Interactions. In recent years, applying two or more herbicides in combination has become a common practice with crop producers. Several reasons exist for combining herbicides including reduced application costs, an increase in the spectrum of weeds controlled, increased crop safety by using lower amounts of each herbicide, and to delay the appearance of resistant weed species. Many times, when two or more herbicides are combined, the weed control spectrum appears as expected based on the performance of each herbicide applied separately. However, in some instances, the results of combining two or more herbicides may not be as expected. In the latter case, the herbicides may be said to have interacted. In statistical terms, an interaction may be defined as occurring when the effect of one factor is not independent in the presence of another factor (Zar 1984). In other words, the difference in response between the levels of one factor is not the same at all levels of the second factor.

Two scenarios of herbicide interaction are commonly encountered. In the first, a particular herbicide may control a particular weed species when applied alone, but not when tankmixed with a second herbicide. Alternatively, when two herbicides are combined weed control can be far superior than when either of the herbicides are applied alone. The first situation represents an interaction described as antagonistic, while the second situation may be described as synergistic. Hatizos and Penner (42) defined antagonism as "a type of joint action of two agrochemicals such that the observed response of a test organism to their combined application appears to be less than the response predicted to occur by an appropriate reference model." Synergism was defined as the "cooperative action of two agrochemicals such that the observed response of a test organism to their joint application appears to be greater than the response predicted to occur by an appropriate reference model." The two reference models commonly used in weed science are the additive model and the multiplicative model. The additive model equates the response to the application of a combination of chemicals to the sum of the response when each chemical is applied alone. The multiplicative model equates the percentages or proportions of response to the application of a combination of chemicals to the product of the corresponding percentages or proportions when the two chemicals are applied alone.

The most widely used equation in weed science to describe the effect of a herbicide mixture on plants is one proposed by Colby (24). The formula is:

$$E = \frac{X * Y}{100}$$

where E, X, and Y are the expected response as a percent of control, response as a percent of control obtained from herbicide A applied singly, and response as a percent of control from herbicide B applied singly, respectively. If the observed responses are equal, greater than, or less than the expected value, the herbicide combination exhibits an additive, synergistic, or antagonistic response, respectively.

With increasing use of herbicides to control weeds, more herbicide combinations will be developed. These combinations may interact, producing responses previously described. An understanding of the mechanisms of interactions is essential in order to provide crop producers with the necessary information required to choose herbicide options for the weed spectrum in the field.

Additives. The efficacy of postemergence herbicides can often be enhanced by the addition of an additive. Adjuvants may be defined as "any substance in a herbicide formulation or added to the spray tank to improve herbicide activity or application characteristics (WSSA Herbicide Handbook). Adjuvants are commonly used to enhance foliar penetration of a herbicide, improve spray delivery to the plant foliage, and increase retention of spray droplets on the plant foliage (76). The effectiveness of an additive can be specific for a particular herbicide or weed species. Nalewaja and Adamczewski (70) found greater absorption and translocation of ^{14}C-bentazon in redroot pigweed when applied with oil additives as compared to applications with no additive. Irons and Burnside (47) observed an increased rate and quantity of ^{14}C-bentazon absorption in common sunflower (*Helianthus annuus* L.) when applied with a surfactant. Fielding and Stoller (35) noted improved velvetleaf control with thifensulfuron when 28% UAN was added, and Kent et al. (52) found enhanced absorption and translocation of ^{14}C-imazethapyr in pitted morningglory (*Ipomoea lacunosa* L.) when applied with ammonium sulfate.

Common Ragweed. Common ragweed is a native species of North America (Bassett and Terasmae 1962). The plant is an erect annual with a tap root system. Stems are branched and hairy, bearing leaves on short petioles. The plant is monoecious with male flowers born on terminal inflorescences and female flowers born in the leaf axils (Ackerly and Jasieński 1990). Ragweed are short-day plants, withholding flowering until the day length has shortened to their requirements (Allard 1943).

Common ragweed is a pioneer weed species in abandoned fields and roadsides. Raynal and Bazzaz (1975) studied the life-cycle strategy of common ragweed in abandoned fields in Illinois. The plant typically occurred in disturbed sites for a single growing season, during which time it produced seeds that provided a source of plants for future years. When common ragweed was observed growing in competition with neighboring winter annuals, there was no measurable increase in mortality, but there was a measurable reduction in the size of the plants, which the authors termed as phenotypic plasticity. Seed production of common ragweed was determined to be 18 seeds/plant when the ragweed was growing in competition with winter annuals and 182 when the winter annuals were removed. Raynal and Bazzaz (1975) also examined the interference of the winter annuals *Erigeron annuus* and *Conyza canadensis* on common ragweed in early successional fields. The winter annuals were shown to overwinter in a rosette stage and when growth resumed in the spring, these weeds had a distinctive spacial advantage both above and below the ground. This advantage translated into enhanced light interception, water extraction, and nutrient usage early in the season by the developed winter annuals. After establishment of common ragweed in fields with winter annuals, the ragweed was observed to undergo population regulation through phenotypic plasticity that enabled the available resources to be utilized by the existing ragweed population. No density-dependent thinning was observed in common ragweed. The ragweed that underwent this phenotypic plasticity, although smaller in size, did produce seeds that would remain viable for many years, thus ensuring future generations of common ragweed.

Willemsen and Rice (1972) investigated the mechanism of seed dormancy of common ragweed, focusing on the relationship between germination inhibitors and promotor compounds within the seed. Stratification for 8 weeks at 5 C broke seed dormancy, while leaching and scarification did not. Germination was greater in light than in darkness. Working with the hypothesis that auxin and gibberellin were promoters of germination and that abscisic acid was a germination inhibitor, extractions and assays were performed to determine if changes in concentration of these compounds before and after stratification could explain the germination response. Following the period of stratification, the concentration of abscisic acid declined while the concentrations of auxin and gibberellin increased. The germination inhibitor was absent in ragweed seeds placed in a favorable germination environment after the stratification period. Exogenous gibberellin increased germination of dormant seeds and this effect was greatly enhanced following scarification which suggested that the seed coat was impervious to gibberellin. Since leaching did not enhance germination, the authors concluded that the pericarp may contain a nonleachable inhibitor. The increase in gibberellin following stratification may increase the activity of hydrolytic enzymes which would make stored carbohydrates available to the developing embryo, while the increased auxin content may stimulate protein synthesis. The inhibitor, abscisic acid, may cause a reduction in enzyme activity necessary for germination. Willemsen (1975) determined the effects of stratification and germination temperature on the germination and induction of secondary dormancy in common ragweed seeds. The stratification temperatures evaluated were -5, 4, and 10 C, with percent germination determined in continuous darkness and light at 5/15, 10/20, 15/25, and 20/30 C, with the higher temperatures corresponding to a 16 hour light period. The time of stratification ranged from 3 to 15 weeks. The results indicated that optimal germination occurred after stratification at 4 C in both light and darkness and at all temperatures. Stratification at -5 C resulted in the least germination, and germination in light was superior to that in darkness at all germination and stratification temperatures. The ability of the seeds to germinate was enhanced by increased length of time of the stratification period up to 12 weeks. It was noted that germination decreased after 15 weeks of stratification when seeds were placed at high germination temperatures, especially when germinated in the dark. This was attributed to the onset of a secondary dormancy period which required an additional period of stratification to break. Willemsen used this observation to propose a model of how common ragweed succeeds in invading fields. Mechanical

disturbance of the soil in the spring exposed seeds to light and seeds germinated that were stratified over the winter. This exposure in early spring when temperatures are low may enhance common ragweed germination. Seeds that did not receive adequate light for germination may enter secondary dormancy and thus insure a source of viable seed in the following years. Willemsen (1975) continued his work by evaluating common ragweed germination in the field. Stratified seeds were placed at 3 intervals in the soil: on the soil surface, a depth of 5 cm, and a depth of 10 cm. There appeared to be no differences in the time required for stratification at any of the soil levels used, likely resulting from small differences in soil temperature at the various levels during January. When the seeds began to germinate, germination was initially higher at the higher temperatures on the soil surface. When secondary dormancy occurred, it was first noted with seeds on the soil surface and decreased with increasing depth of burial. The author did not attribute this to lack of light, low oxygen levels, or volatile inhibitors, but rather due to low moisture levels. With the ability of seeds near the soil surface being readily able to germinate after the stratification over the winter and the secondary dormancy of seed buried several centimeters below the soil surface, common ragweed insures that there will be a supply of viable seeds in the soil for many years. Baskin and Baskin (1980) found that germination of viable common ragweed seeds was low when the seeds were buried in the soil while those seeds on the soil surface showed good germination. The results indicated that failure of the buried seeds to germinate in the spring was due to the low temperatures of the soil at depths below the soil surface and the lack of light. Buried seeds did not germinate because they were induced into secondary dormancy when the soil temperature was optimal for germination but the seeds still lacked the required light. The seeds that entered secondary dormancy required another period of stratification before they were once again able to germinate, and by this mechanism of secondary dormancy, viable seed could remain in the soil for several years.

Interference. Coble et al. (1981) described common ragweed interference in soybean. Various densities of common ragweed (0, 2, 4, 8, or 16 equidistantly spaced plants/10 m of soybean row) were established to determine damage threshold populations for full-season weed infestations. Based on linear regression calculations for soybean yield reduction, a damage threshold of 4 weeds 10 m^{-1} of soybean row was found to reduce soybean yields compared to the weed-free control plots. Soybean yields were not reduced if common ragweed were kept out of the crop for the first 4 weeks of the growing season, or if common ragweed were allowed to grow from the time of crop emergence and then eliminated prior to 8 weeks into the season. Plant height measurements made at various times after crop emergence showed that common ragweed were taller than the soybeans at all times measured. At 8 weeks after crop emergence, the common ragweed plants intercepted 24% of the photosynthetically active radiation, leading the authors to conclude that light competition may be a contributing factor to soybean yield losses. Shurtleff and Coble (1985) also found that common ragweed were substantially taller than soybean when grown at densities of 0, 2, 4, 8, and 16 weeds/10 m of row. Consistent with Coble et al. (23), Shurtleff and Coble concluded that aboveground factors such as competition for light may be an

important contributing factor in the competitive ability of common ragweed.

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Common ragweed (*Ambrosia artemisiifolia*) control in soybeans (*Glycine max*) with bentazon as influenced by imazethapyr or thifensulfuron tankmixes.

AARON HAGER and KAREN RENNER

__Abstract__. Several herbicides control common ragweed postemergence in soybeans. However, when herbicides are tankmixed, synergistic or antagonistic weed responses may occur, and additive selection may influence weed response. Imazethapyr and thifensulfuron can be tankmixed with bentazon for broadleaf weed control, and visual crop injury and cost hectare^{-1} may be reduced compared to a bentazon plus acifluorfen tankmix. Experiments determined common ragweed control from these herbicides and herbicide combinations when applied with various additives. In the greenhouse bentazon at 560 g ha^{-1} reduced common ragweed dry weight 95 to 97%. Common ragweed control with 35 g ha^{-1} of imazethapyr increased 13 and 7% when urea ammonium nitrate (UAN) was applied with nonionic surfactant (NIS) or petroleum oil adjuvant (POA), respectively. Tankmixing thifensulfuron at 4.5 g ha^{-1} or imazethapyr at 35 or 71 g ha^{-1} with bentazon did not enhance nor reduce dry weight of common ragweed compared with bentazon alone. In field research bentazon at 1120 g ha^{-1} reduced common ragweed dry weight 78 to 81%. Tankmixing bentazon with thifensulfuron at 4.5 g ha^{-1} or imazethapyr at 71 or 35 g ha^{-1} reduced common ragweed dry weight by 89 to 91%, thus enhancing control compared to each herbicide applied alone. Adding 28% UAN to bentazon plus imazethapyr or bentazon plus thifensulfuron

tankmixes did not increase control compared to NIS or POA alone. By 28 days after treatment (DAT) only 35 or 71 g ha^{-1} of imazethapyr plus 28% UAN plus NIS or POA and bentazon plus imazethapyr tankmixes provided 85% or more control of common ragweed in 1991, and only 71 g ha^{-1} of imazethapyr plus 28% UAN plus POA or 71 g ha^{-1} of imazethapyr plus bentazon provided greater than 78% common ragweed control in 1992. Soybean yields were equal to that of the handweeded control only with the bentazon plus 71 g ha^{-1} of imazethapyr tankmix treatments.

Nomenclature: Bentazon, 3-(methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2,dioxide; imazethapyr, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid; thifensulfuron, 3[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid; acifluorfen, 5-[2-chloro-4-trifluromethyl)phenoxy]-2-nitrobenzoic acid; common ragweed, *Ambrosia artemisiifolia* L.; soybean, *Glycine max* (L.) Merr.

INTRODUCTION

No-till or reduced tillage soybean production are viable alternative soybean production systems. Reduced tillage practices may increase the need for herbicides since mechanical control options are limited. Postemergence weed control has become an attractive option to many producers in reduced tillage systems.

Common ragweed is a predominant weed problem in soybeans and several

postemergence herbicides provide control. Bentazon at 1120 g ha^{-1} controls four-leaf common ragweed (20) and control can be improved by the addition of acifluorfen (19). Acifluorfen also controls redroot pigweed (*Amaranthus retroflexus* L.) and eastern black nightshade (*Solanum ptycanthum* Dun.), two weed species not controlled by bentazon (10, 17). Two other postemergence herbicides have recently been marketed that could potentially replace acifluorfen in a tankmix with bentazon. Thifensulfuron controls redroot pigweed (1, 5, 21), while imazethapyr controls redroot pigweed and eastern black nightshade (3). Common ragweed control may not be adequate if these herbicides antagonize the control provided by bentazon alone.

A reduction in weed control may be overcome by the addition of an additive (8, 13). Nalewaja and Adamczewski (16) found greater absorption and translocation of ^{14}C-bentazon in redroot pigweed when bentazon was applied with oil additives as compared to applications with no additive. Irons and Burnside (9) observed an increase in the rate and quantity of ^{14}C-bentazon absorption in common sunflower (*Helianthus annuus* L.) when applied with a nonionic surfactant. Velvetleaf control with thifensulfuron was enhanced when 28% UAN[1] was applied along with a nonionic surfactant (6), and absorption and translocation of ^{14}C-imazethapyr in pitted morningglory (*Ipomoea lacunosa* L.) increased when ammonium sulfate was applied along with a surfactant (11).

Postemergence applications of diphenyl ether herbicides control common ragweed. However, soybean injury often occurs and producers may desire to use a postemergence

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[1]UAN, urea ammonium nitrate.

herbicide such as thifensulfuron or imazethapyr that is not as injurious to the crop. Tankmixing bentazon with thifensulfuron or imazethapyr may also lower the cost per hectare compared to bentazon plus acifluorfen[2].

The objectives of this research were to 1) determine if the addition of imazethapyr or thifensulfuron to bentazon enhanced or reduced the common ragweed control achieved by bentazon alone, and 2) determine if common ragweed control was enhanced by the addition of various additives or additive combinations.

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[2]Renner, K. A. 1993. SOYHERB: An integrated decision support computer program. Version 2.2. CP-022, Michigan State University.

MATERIALS AND METHODS

Greenhouse studies. Locally collected common ragweed seed were planted in Baccto[3] greenhouse potting soil in 946-ml plastic pots. Following emergence, the plants were thinned to one plant per pot. Environmental conditions were maintained at 25 C ± 4 C with the plants grown in a 16-hour photoperiod of natural lighting supplemented with metal halide lighting giving a midday photosynthetic photon flux density of 1000 μE m^{-2} s^{-1}. Pots were surface watered daily and fertilized once prior to herbicide application with 0.1 g of water soluble fertilizer solution (20% N, 20% P_2O_5, 20% K_2O). All herbicides were applied using a continuous link-belt sprayer equipped with a single 8001 even flat fan nozzle[4] calibrated to deliver 206 L ha^{-1} at a spray pressure of 248 kPa. Bentazon at 560 g ha^{-1}, thifensulfuron at 4.5 g ha^{-1}, imazethapyr at 35 or 71 g ha^{-1}, and bentazon plus thifensulfuron and bentazon plus imazethapyr tankmix combinations were applied to four-leaf common ragweed. Additives or additive combinations included with the herbicide treatments were POA[5], POA plus 28% UAN,

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[3]Baccto Professional Potting Mix. Michigan Peat Company, PO Box 980129, Houston, TX 77098.

[4]Teejet flat fan tips. Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.

[5]Herbimax, 83% petroleum oil, 17% adjuvant, Loveland Industries, Inc. Greeley, Co 80632.

NIS[6], or NIS plus 28% UAN. Control of common ragweed was determined 14 DAT by harvesting, drying, and weighing the common ragweed plants.

The experiment was a randomized complete block design with four replications, repeated in time. Treatments were applied as two separate factorials with bentazon and thifensulfuron and bentazon and imazethapyr. Data were converted to a percent of the untreated control and subjected to arcsine transformation. ANOVA was performed and means separated where appropriate using Fisher's Protected LSD at the 5% level of significance. Non-transformed means are presented. Analysis of the data revealed no significant differences between experiments and the data are combined for discussion.

Field studies. Field experiments were conducted on a sandy clay loam soil at Michigan State University in 1991 and 1992 (Table 1). Field plots were chisel-plowed the previous fall and then spring disked and field cultivated. Elgin 87 soybeans were planted May 14, 1991 and May 13, 1992 at a seeding rate of 407,000 seeds ha^{-1}. Plot size was 3 by 10 m in 1991 and 3 by 8.5 m in 1992 with a crop row spacing of 76 cm. Herbicide treatments were applied with a tractor-mounted compressed air research plot sprayer equipped with 80015 flat fan nozzles spaced 50 cm apart on a boom 56 cm above the crop canopy. Herbicide treatments were applied in a total volume of 187 L ha^{-1} at a spray pressure of 345 kPa. Herbicide treatments consisted of bentazon at 1120 g ha^{-1}, thifensulfuron at 4.5 g ha^{-1}, imazethapyr at 35 or 71 g ha^{-1}, and bentazon plus thifensulfuron and bentazon plus imazethapyr tankmix combinations. Additives used

[6]X-77 Nonionic Surfactant. A mixture of alkylarylpolyoxy-ethylene glycols, free fatty acids, and isopropanol. Valent U.S.A. Corp., Walnut Creek, CA 94956.

for the field experiments were the same as those in the greenhouse. Common ragweed were at the four to six leaf growth stage (2 to 4 cm) at the time of herbicide application. The density of common ragweed ranged from 40 to 70 plants m^{-2} in 1991 and 110 to 160 plants m^{-2} in 1992. Air temperature was 18 C in 1991 and 24 C in 1992 and relative humidity was 65% in 1991 and 45% in 1992 at the time of treatment. Rainfall in the 7 days prior to herbicide application totalled 0.6 cm in 1991 and 6 cm in 1992 (Table 2). Treatments were applied 22 and 28 days after planting in 1991 and 1992, respectively.

Visual injury to soybeans and common ragweed were taken 14 and 28 DAT, respectively. The rating scale ranged from 0 (no visible injury) to 100% (complete plant death). Injury ratings were based on plant stunting, discoloration, chlorosis, and necrosis. In addition, six common ragweed plants per plot that were at a uniform growth stage (plant height and leaf number) were selected prior to herbicide application and marked using plastic garden stakes[7]. These plants were harvested 14 DAT and dry weights recorded. Each year the center two soybean rows were harvested with a Massey 10 plot harvesting combine (October 10, 1991 and October 27, 1992) and seed yields adjusted to 13.5% moisture.

The experimental design each year was a randomized complete block with four replications. The results and discussion of common ragweed control will be based on the dry weight data collected from plants marked prior to herbicide application unless otherwise stated. ANOVA was performed on all data collected and means were

[7]Pylow Plastics, Inc. 211 Ogden Ave., P.O. Box 505, Lisle, IL 60532.

separated where appropriate using Fisher's Protected LSD at the 5% level of significance. The common ragweed dry weight data were converted to a percent of the untreated control prior to analysis and subjected to arcsine transformation. Analysis of the dry weight reduction and soybean yield data revealed no significant differences between years and the data are combined for discussion. Analysis of the common ragweed dry weights and 28 DAT visual rating of common ragweed were subjected to arcsine transformation and revealed differences between years and the data are therefore presented separately. Non-transformed means are presented.

RESULTS AND DISCUSSION

Greenhouse studies. Bentazon reduced dry weight of common ragweed by 95 to 97% with no difference between POA and POA + 28% UAN (Table 3). Ideal growing conditions in the greenhouse may have improved bentazon efficacy, as such large reductions in dry weight would not be expected under field conditions with 560 g ha^{-1} of bentazon.

Thifensulfuron reduced common ragweed dry weight by 72 to 77% when applied with POA, POA + 28% UAN, or NIS + 28% UAN (Table 3). Only a 58% reduction in common ragweed dry weight resulted from thifensulfuron applied with NIS. Tankmixing thifensulfuron with bentazon did not improve control over that of bentazon alone, regardless of additive.

Common ragweed control was greater from 71 g ha^{-1} of imazethapyr compared with 35 g ha^{-1} when applied with POA, POA + 28% UAN, or NIS (Table 4). Greatest common ragweed dry weight reduction occurred from 71 g ha^{-1} of imazethapyr plus POA + 28% UAN. Tankmixing imazethapyr with bentazon did not improve dry weight reduction compared to bentazon alone or imazethapyr at 71 g ha^{-1} plus POA + 28% UAN.

These greenhouse results show that common ragweed control with bentazon was not adversely effected when imazethapyr was added, regardless of additive. When bentazon was tankmixed with thifensulfuron the addition of POA, POA + 28% UAN or NIS + 28% UAN was necessary for common ragweed control to equal that of bentazon alone.

Field studies. Only slight discoloration (yellowing) of plant tissue was observed 14 DAT from bentazon, thifensulfuron, imazethapyr, and tankmix treatments. Visual injury from these treatments did not exceed 5% in 1991 and 11% in 1992 (data not presented). Acifluorfen at 560 g ha^{-1} caused 7% injury (leaf chlorosis and necrosis) in 1991 and 20% injury in 1992. The increased soybean injury in 1992 from acifluorfen may have been the result of the higher temperature at the time of application. Higher temperatures increase soybean and weed response to acifluorfen (12, 18).

Common ragweed dry weight 14 DAT was reduced 78 and 81% from 1120 g ha^{-1} of bentazon + POA and bentazon + POA + 28% UAN, respectively (Table 5). This application rate of bentazon was twice that applied in the greenhouse, yet common ragweed dry weights were 15% greater in this field study. Thifensulfuron reduced dry weight of common ragweed 71 to 77%. There were no significant differences in common ragweed dry weight reductions due to additive selection, as NIS alone was as effective as the other additives (Table 5), thus differing from the greenhouse results (Table 3). When bentazon was tankmixed with thifensulfuron dry weight of common ragweed was reduced 89 to 91% which was significantly greater control than when either of these herbicides were applied alone. The addition of 28% UAN did not improve control over that of POA or NIS alone.

Imazethapyr at 35 or 71 g ha^{-1} reduced dry weight of common ragweed 79 to 81% with no differences between additives (Table 5). Increasing the imazethapyr rate did not reduce common ragweed dry weight more, unlike the greenhouse studies. When bentazon was tankmixed with 35 or 71 g ha^{-1} of imazethapyr, dry weight of common ragweed was reduced 89 to 91% which was significantly greater than that achieved with either of these herbicides alone (Table 5). No differences were observed between additives.

Visual evaluations of common ragweed control 28 DAT were less than 58% for bentazon or thifensulfuron in 1991 and 1992, with no differences due to additives. This lack of common ragweed control in the field by bentazon has been observed in previous years (personal observation). Tankmixing bentazon with thifensulfuron + NIS or NIS + 28% UAN improved common ragweed control over that of bentazon or thifensulfuron alone in both years (Table 5). However, common ragweed control was still less than 72%, and regrowth of many common ragweed plants was evident.

Common ragweed control 28 DAT for imazethapyr alone was 76 to 87% in 1991

and 61 to 78% in 1992 (Table 5). Imazethapyr at 35 g ha^{-1} plus POA provided less control both years, and only in 1991 did the addition of 28% UAN improve control to equal that of 71 g ha^{-1} of imazethapyr. Therefore, by 28 DAT an imazethapyr rate response was evident that was not observed 14 DAT.

Imazethapyr plus bentazon controlled common ragweed longer than thifensulfuron plus bentazon. This could be due to more complete control of the common ragweed emerged at the time of herbicide application and/or greater soil residual control of the common ragweed that germinated after herbicide application. The half-life of thifensulfuron in the soil has been reported to be less than 1 week (4) while the half-life of imazethapyr in the soil has been reported to be up to ten months (7). Since acifluorfen which has limited soil activity provided 84 and 93% control 28 DAT in 1991 and 1992, respectively, regrowth of existing common ragweed is the more likely explanation.

Soybeans treated with thifensulfuron, bentazon, and thifensulfuron plus bentazon yielded less than the handweeded control (Table 5). Little soybean injury was observed from these herbicide treatments and reduced yields were most likely a reflection of poor common ragweed control at 28 DAT. Soybeans treated with 35 or 71 g ha^{-1} of imazethapyr or 35 g ha^{-1} of imazethapyr plus bentazon also yielded less than the handweeded control (Table 5). Only soybeans treated with 71 g ha^{-1} of imazethapyr plus bentazon plus POA, NIS, or NIS + 28% UAN had yields equivalent to the handweeded control or the acifluorfen plus NIS treatment.

In the field studies, little visible soybean injury was observed 14 DAT from any bentazon or thifensulfuron treatment. However, common ragweed control from bentazon plus thifensulfuron, regardless of additive selection, would not be acceptable since soybean yields were at least 18% below that of the handweeded control. Only bentazon plus 71 g ha^{-1} of imazethapyr plus POA, NIS, or NIS + 28% UAN controlled common ragweed and resulted in soybean yield equal to the acifluorfen treatment or the handweeded control. A bentazon plus imazethapyr tankmix would provide broadspectrum weed control with little soybean chlorosis or necrosis but would not reduce the cost per hectare as compared to that of bentazon plus acifluorfen since 71 g ha^{-1} is not a reduced rate of imazethapyr.

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Table 1. Soil characteristics for field studies conducted in 1991 and 1992.

--------------------------Year--------------------------	
1991	1992
Sandy clay loam pH 7.0 2.1% organic matter 53% sand 25% silt 23% clay Capac Loam	Sandy clay loam pH 6.7 2.5% organic matter 55% sand 25% silt 23% clay Capac Loam

Table 2. Rainfall accumulation at East Lansing in 1991 and 1992.

Time	1991	1992
	------------------cm------------------	
7 DBP[a]	0.4	0.7
Planting to 7 DBPO	4.0	6.0
7 DBPO to Day of PO	0.6	6.0
0-14 DAPO	3.0	3.0
14-28 DAPO	6.0	2.0

[a]Abbreviations: Days before planting (DBP), Days before posting (DBPO), Days after posting (DAPO).

Table 3. Common ragweed dry weight reduction following application of bentazon, thifensulfuron, and tankmix combinations in the greenhouse.

Herbicide	Rate -g ha^{-1}-	Additive: NIS + 28% UAN	Additive: NIS - 28% UAN	Additive: POA + 28% UAN	Additive: POA - 28% UAN
		--------% of control--------			
Bentazon	560	97 a[b]	95 a	97 a	96 a
Thifensulfuron	4.5	76 c	58 d	77 c	72 c
Bentazon + Thifensulfuron	560 + 4.5	97 a	79 bc	97 a	93 ab

[b]Means followed by the same letter are not significantly different by Fisher's Protected LSD at the 0.05 level of significance. All mean comparisons within the table are valid.

Table 4. Common ragweed dry weight reduction following application of bentazon, imazethapyr, and tankmix combinations in the greenhouse.

Herbicide	Rate -g ha^{-1}-	Additive: NIS + 28% UAN	Additive: NIS - 28% UAN	Additive: POA + 28% UAN	Additive: POA - 28% UAN
		--------% of control--------			
Bentazon	560	97 a[c]	95 ab	97 ab	96 ab
Imazethapyr	71	84 c	79 cd	91 b	81 c
Imazethapyr	35	81 c	68 e	80 c	73 de
Bentazon + Imazethapyr	560 + 71	96 ab	97 ab	96 ab	96 ab
Bentazon + Imazethapyr	560 + 35	97 ab	93 ab	97 ab	95 ab

[c]Means followed by the same letter are not significantly different by Fisher's Protected LSD at the 0.05 level of significance. All mean comparisons within the table are valid.

Table 5. Common ragweed dry weight reduction, visual evaluations 28 DAT, and soybean yield.

Treatment	Rate (g ha^{-1})	Dry wt reduction	Control 28 DAT		Soybean yield
		14 DAT[d]	1991	1992	
		------------%------------			-kg ha^{-1}-
Bentazon + POA	1120 + 1%	78	48	50	2700
Bentazon + POA + 28%	1120 + 1% + 4%	81	53	46	2820
Thifensulfuron + POA	4.5 + 1%	75	47	52	2870
Thif[e] + POA + 28%	4.5 + 1% + 4%	77	53	57	2930
Thifensulfuron + NIS	4.5 + 0.125%	73	51	57	2840
Thif + NIS + 28%	4.5 + 0.125% + 4%	71	53	53	2760
Bent + Thif + POA	1120 + 4.5 + 1%	89	57	66	2790
Bent + Thif + POA + 28%	1120 + 4.5 + 1% + 4%	89	70	63	2940
Bent + Thif + NIS	1120 + 4.5 + 0.125%	91	61	66	3030
Bent + Thif + NIS + 28%	1120 + 4.5 + 0.125% + 4%	91	71	66	3060
Imazethapyr + POA	71 + 1%	80	83	70	3390
Imazethapyr + POA + 28%	71 + 1% + 4%	80	87	78	3260
Imazethapyr + NIS	71 + 0.25%	81	83	76	3050
Imazethapyr + NIS + 28%	71 + 0.25% + 4%	81	85	74	3190
Imazethapyr + POA	35 + 1%	80	76	63	3320
Imazethapyr + POA + 28%	35 + 1% + 4%	79	85	61	3280
Bent + Imep + POA	1120 + 71 + 1%	91	88	85	3560
Bent + Imep + POA + 28%	1120 + 71 + 1% + 4%	90	91	82	3390
Bent + Imep + NIS	1120 + 71 + + 0.25%	90	95	81	3500
Bent + Imep + NIS + 28%	1120 + 71 + + 0.25% + 4%	89	92	84	3450
Bent + Imep + POA	1120 + 35 + 1%	91	85	69	3290
Bent + Imep + POA + 28%	1120 + 35 + 1% + 4%	91	86	75	3380

[d]DAT = Days after treatment.

[e]Bent, Thif, and Imep are the approved codes for bentazon, thifensulfuron, and imazethapyr, respectively. 1991. NCWSS Proc. 46:164.

Table 5 (cont).

Acifluorfen + NIS	560 + 0.125%	91	84	93	3450
Handweeded control		0	0	0	3730
$LSD_{0.05}$		6	7	7	290

Influence of Relative Humidity and Soil Moisture on Absorption and Translocation of Imazethapyr in Common Ragweed (*Ambrosia artemisiifolia*).

AARON HAGER, KAREN RENNER, and DONALD PENNER

Abstract. Research was conducted to determine the influence of relative humidity (RH), soil moisture, and the presence of bentazon on the absorption and translocation of ^{14}C-imazethapyr in common ragweed (*Ambrosia artemisiifolia* L.). Low soil moisture (-3 bars) reduced ^{14}C-imazethapyr absorption by 6% 24 h after treatment, but did not influence translocation. The absorption and translocation of ^{14}C-imazethapyr when applied alone was not effected by RH 48 and 168 h after treatment. However, when bentazon was present in the spray solution absorption 24 h after treatment was reduced by 51% at 65% RH but was not reduced at 85% RH. Translocation of ^{14}C-imazethapyr out of the treated leaf was reduced significantly at 65% RH, but not at 85% RH in the presence of bentazon.

Nomenclature: Bentazon, 3-(1-methylethyl)-(1*H*)-2,1,3-benzothiodiazin-4(3*H*)-one 2,2-dioxide; imazethapyr, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid; common ragweed, *Ambrosia artemisiifolia* L.

Additional index words: absorption, relative humidity, soil moisture, translocation

INTRODUCTION

For postemergence herbicides to exert a toxic affect, the herbicide must reach its site of action. Foliar absorption of the herbicide through the plant cuticle proceeds by passive diffusion (32). Environmental conditions, eg. RH and soil moisture, prior to or at the time of herbicide application may affect the diffusion process by altering the plant cuticle. Generally, as relative humidity and soil moisture increase the absorption of herbicides also increases.

Wills (37) observed greater absorption and translocation of ^{14}C-sethoxydim [2-[1-ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one] in common bermudagrass (*Cynodon dactylon* (L.) Pers.) at 100% RH compared to 40% RH. Absorption of ^{14}C-acifluorfen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid] in showy crotalaria (*Crotalaria spectabilis* Roth) was three to four fold greater at 100% than at 40% RH (38). Ritter and Coble (28) observed a significant increase in acifluorfen phytotoxicity and a decrease in common ragweed and common cocklebur (*Xanthium strumarium* L.) dry weight at high RH (85%) as compared to lower RH (50%). High RH (95-100%) increased control of kochia (*Kochia scoparia* (L.) Schrad.) with imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] compared to low RH (45-50%) (25). Absorption and translocation of ^{14}C-imazethapyr in pitted morningglory (*Ipomoea lacunosa* L.) was greater at 100% RH than at 40% (18), and control of redroot pigweed (*Amaranthus*

retroflexus L.) with bentazon was greater at high RH (100%) than at low RH (30-52%) (24).

Plants under moisture stress have been shown to absorb less herbicide than plants grown under adequate soil moisture. Baker and Procopiou (3) found that a prolonged period of soil moisture stress induced formation of a thicker plant cuticle. This increased cuticular development may adversely effect the absorption of foliar applied herbicides. Kells et al. (17) reported reduced quackgrass (*Elytrigia repens* (L.) Nevski) control with fluazifop-butyl [{butyl ester of (±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoate}] under moisture stress (6-10% (w/w)). Autoradiographs of plants treated with ^{14}C-fluazifop-butyl suggested that more extensive distribution of the herbicide occurred under adequate soil moisture. Low soil moisture (-6.5 bars) following application of the methyl ester of diclofop [{2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid}] to wild oat (*Avena fatua* L.) reduced herbicide activity as compared to the control achieved at higher moisture levels (-0.3 bars) (2). Dortenzio and Norris (8) noted a similar reduction in control of yellow foxtail (*Seteria glauca* (L.) Beauv), wild oat, littleseed canarygrass (*Phalaris minor* Retz.), and barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) at low soil moisture conditions following the application of the methyl ester of diclofop. Reduced absorption and control of barnyardgrass under low soil moisture conditions following the application of glyphosate [*N*-(phosphonomethyl)glycine] has also been reported (1).

When herbicides are tankmixed, a reduction in absorption and translocation of one of the herbicide components may occur. Several studies have reported reduced

herbicide absorption in the presence of bentazon (4, 5, 11, 16, 33, 34). Formation of sodium salts of anionic herbicides when bentazon is present has been implicated as the mechanism involved in reduced absorption (33).

The objectives of this research were to 1) examine the effects of soil moisture and RH on the absorption and translocation of imazethapyr in common ragweed, and 2) determine what effect the addition of bentazon had on imazethapyr absorption and translocation in common ragweed.

MATERIALS AND METHODS

Greenhouse studies were conducted to examine the effects of RH and soil moisture level on the absorption and translocation of ^{14}C-imazethapyr applied alone or tankmixed with bentazon. Treatments were arranged in a factorial design with two humidity levels and two soil moisture levels. Locally collected common ragweed seeds were planted in 0.5-L plastic pots containing a sandy clay loam soil (64% sand, 21% silt, 12% clay) with a pH of 6.9 and 2.1% organic matter. Plants were initially grown under greenhouse conditions at 25 C ±4 C with a 16 hour photoperiod of natural lighting supplemented with metal halide lighting giving a midday photosynthetic photon flux density of 1000 $\mu E\ m^{-2}\ s^{-1}$. Pots were surface watered daily.

The soil used in these experiments was air dried for 7 days prior to planting, and

450 g of soil was then placed into each pot. Through previous research by Zollinger[1], a soil moisture retention curve was developed for this particular soil. Using this curve, the soil water content (g/g) was determined for the high soil moisture level (- ⅓ bars (field capacity)) and the low soil moisture level (-3 bars). Seven days prior to herbicide application the plants were transferred into growth chambers with day/night temperatures of 26/22 C. Experiments at high RH were conducted at 85% ± 4% while experiments at low RH were conducted at 65% ± 4%. The growth chamber was initially programmed at 85% RH. The experiment was repeated at this humidity, and then the chamber was programmed to the lower RH (65%) and the experiment conducted twice. The chamber was maintained at a 16-hour photoperiod from fluorescent and incandescent lighting with a photosynthetic photon flux density of 750 $\mu E\ m^{-2}\ s^{-1}$. Pots were watered daily to 19 and 9% (wt/wt) soil moisture which corresponds to soil moisture potentials of -⅓ and -3 bars, respectively. These values were established from the soil moisture curve described previously.

At the time of herbicide application the common ragweed plants were at the 6 leaf growth stage. A single 2 μL droplet containing 1110 Bq of ^{14}C-imazethapyr was applied to one of the four true leaflets of the common ragweed using a microsyringe[2]. The spotting solution contained ^{14}C-imazethapyr (pyridine ring-labelled, 6th position with a specific activity of 784.4 MBq/g) with the appropriate amounts of formulation blank, petroleum oil adjuvant, bentazon (when appropriate) and distilled water to simulate a

[1]Zollinger, Richard K. 1989. Perennial sowthistle (*Sonchus arvensis* L.) distribution, biology and control in Michigan. Ph.D. Dissertation, Michigan State University.

[2]Hamilton microsyringe. Hamilton Co. Reno, NV 89520-0012.

spray solution of 71 g ha^{-1} of imazethapyr, 1120 g ha^{-1} of bentazon (when appropriate), and POA at 1% (v/v) in a total spray volume of 206 L ha^{-1}.

Plants were harvested at 0, 24, 48, and 168 hours after treatment. At each harvest time, the treated leaf was excised and rinsed in a 20 ml glass scintillation vial containing 3 ml of methanol : distilled water (2:1 v/v) for 45 seconds to remove herbicide not absorbed into the cuticular wax. The unabsorbed ^{14}C-imazethapyr was quantified using liquid scintillation counting[3]. Plants were then removed from the soil and the soil was removed from the roots by gentle shaking. Plants were sectioned into the following parts: treated leaf, above the treated leaf, growing point, below the treated leaf, and roots. The plant parts were combusted in a biological oxidizer[4] and the $^{14}CO_2$ trapped in a solution of scintillator : CO_2 absorber[5] (2:1 v/v). All samples were quantified by liquid scintillation counting. Herbicide absorption was calculated by subtracting the amount of unabsorbed ^{14}C-herbicide recovered in the leaf wash from the total amount ^{14}C-herbicide applied. Herbicide translocation out of the treated leaf was calculated by summation of the total radioactivity recovered in all plant parts, which represents 100% of the radioactivity recovered within the plant. The quantity of radioactivity remaining on the treated leaf was then subtracted from the total amount of radioactivity recovered within the plant to determine translocation out of the treated leaf. Recovery of ^{14}C averaged 84% for the experiments.

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[3]Model 1500. Packard Instrument Corp. Downers Grove, IL 60515.

[4]OX-300. R.J. Harvey Instrument Corp. Patterson, NJ 07642.

[5]Carbo-Sorb II. Packard Instrument Corp. Meriden, CT 06450.

The experiment was arranged as a completely randomized design with four replications, repeated in time. All data were subjected to ANOVA and data presented are combined over time because there were no treatment by time interactions. Mean comparisons were made by Fisher's Protected LSD at the 5% level of significance.

RESULTS AND DISCUSSION

Common ragweed plants grown at field capacity and -3 bars were indistinguishable in physical appearance when RH was 85%. When the RH was decreased to 65%, plants grown at -3 bars were reduced in size (plant height and leaf area but not growth stage) compared to those grown at field capacity in the 7 day period prior to herbicide application. Within a given soil moisture, the plants were uniform.

Absorption. Low soil moisture limited absorption of ^{14}C-imazethapyr in common ragweed. When averaged over the presence of bentazon and RH, absorption of ^{14}C-imazethapyr decreased by 6, 13, and 7% at -3 bars 24, 48, and 168 h after treatment, respectively (Table 1). Bruce et al. (6) found enhanced absorption of ^{14}C-nicosulfuron [2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide] in quackgrass as soil moisture increased from -5 bars to -0.3 bars at day/night temperatures of 26/16 C, but no differences in absorption at 11/6 and 31/26 C. Greater absorption of ^{14}C-glyphosate in johnsongrass (*Sorghum halepense* (L) Pers.) and soybean (*Glycine max* (L)) occurred at field capacity than at a soil moisture near the permanent wilting point (23). Absorption of ^{14}C-glyphosate by barnyardgrass was 20% of that applied at 10% soil moisture whereas absorption was 62% at 40% soil moisture (1).

Absorption of ^{14}C-imazethapyr was influenced by RH and the presence of bentazon (Tables 1 and 2). At 24 h after treatment, 16% more ^{14}C-imazethapyr was absorbed at 65% RH than at 85% RH in the absence of bentazon (Table 2). These results are in contrast to those of Kent et al. (18) who found greater absorption of ^{14}C-imazethapyr in pitted morningglory at 100% RH than at 40% RH. By 48 and 168 h after treatment absorption of ^{14}C-imazethapyr in the absence of bentazon was similar at 85 and 65% RH. This increased absorption of ^{14}C-imazethapyr at low RH cannot readily be explained.

The presence of bentazon in the spray solution decreased the absorption of ^{14}C-imazethapyr 51, 35, and 35% at 24, 48, and 168 h after treatment, respectively, at 65% RH (Table 2). Absorption of ^{14}C-imazethapyr was only reduced 14% 48 h after treatment when bentazon was applied with ^{14}C-imazethapyr at 85% RH. Absorption of ^{14}C-imazethapyr in the presence of bentazon reached a maximum of 57% of that applied at 168 h after treatment at 85% RH.

Translocation. There were no differences in translocation of ^{14}C-imazethapyr due to soil moisture (Table 1). Kells et al. (17) reported no differences in translocation of ^{14}C-fluazifop-butyl in quackgrass under adequate soil moisture (field capacity) compared to plants grown under moisture stress (6-10% (w/w)), and Akey and Morrison (2) reported that soil moisture level did not effect the translocation of ^{14}C-diclofop in wild oat. Similarly, Dortenzio and Norris (8) reported no consistent changes in ^{14}C-diclofop translocation in wild oat at differing soil moisture levels.

Translocation of ^{14}C-imazethapyr out of the treated leaf was influenced by RH and the presence of bentazon 48 and 168 h after treatment (Tables 1 and 2). In the absence of bentazon, no differences in ^{14}C-imazethapyr translocation occurred. McWhorter (21) reported no differences in translocation of ^{14}C-metriflufen [2-[4-(4-trifluoromethylphenoxy)phenoxy]propanoic acid] in johnsongrass at 100 or 40% RH at 35 C. Ritter and Coble (28) concluded that humidity level was not a critical factor affecting translocation of ^{14}C-acifluorfen in common cocklebur. Lauridson et al. (20) observed no differences in translocation of ^{14}C-picloram [4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid] or ^{14}C-dicamba [3,6-dichloro-2-methoxybenzoic acid] in Canada thistle (*Cirsium arvense* (L) Scop.) at three soil moisture levels ranging from -6.6 to -15 bars.

Bentazon reduced the translocation of ^{14}C-imazethapyr out of the treated leaf at 65% RH only (Table 2). At 65% RH, 29 and 26% more ^{14}C-imazethapyr remained in the treated leaf in the presence of bentazon than when ^{14}C-imazethapyr was applied alone at 48 and 168 h after treatment, respectively (Table 2).

These results of decreased absorption and translocation of imazethapyr in the presence of bentazon are in agreement with those reached by Bauer et al. who reported reduced absorption and translocation of ^{14}C-imazethapyr in pinto bean (*Phaseolus vulgaris* L.) (4) and redroot pigweed (5) when tankmixed with bentazon. Numerous other studies have also reported reduced herbicide absorption in the presence of bentazon (11, 16, 33, 34). It has been proposed that the formation of a sodium salt of sethoxydim in the presence of sodium bentazon may be the mechanism responsible for the reduced absorption of sethoxydim in quackgrass (33). Bauer et al. (4) demonstrated a similar reduction in absorption of ^{14}C-imazethapyr in pinto bean when applied with either sodium acetate or sodium bentazon. Imazethapyr is a phloem mobile herbicide and translocation of a phloem mobile herbicide may be reduced when the production and translocation of photoassimilates is inhibited (10, 7). Bentazon inhibits photosynthesis, thereby inhibiting the non-cyclic flow of electrons in photosystem II (9, 31). This block of electron flow would inhibit the reduction of $NADP^+$ to NADPH at the reducing end of photosystem I, thus depleting the source of reducing equivalents for CO_2 fixation during the carbon assimilation reactions of photosynthesis. Ultimately, photoassimilation and movement into the phloem would cease and concomitantly reduce the translocation of a phloem mobile herbicide such as imazethapyr.

Experiments investigating the effects of RH on herbicide absorption are typically conducted at only two levels, a low level (generally less than 40%) and a high level (generally greater than 85%) (13, 15, 18, 21, 22, 23, 28, 29, 35, 36, 37, 38, 40). The herbicides and weed species evaluated have been diverse, however, none of these experiments have reported decreased herbicide absorption at lower RH. From these studies, the response of herbicide absorption to increasing RH appears to proceed in a linear manner. However, evaluations using only two levels of humidity may not correctly indicate a linear response. Smith and Buchholtz (30) and Wills et al. (39) demonstrated reduced rates of transpiration in resistent and susceptible species using

high rates of atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine]. In contrast, increases in plant growth and plant protein have been reported following exposure to micromolar concentrations of *s*-triazine herbicides in laboratory studies (12, 14, 27). Ladlie et al. (19) examined the effect of atrazine on soybean tolerance to metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one]. Atrazine at 10^{-6} M was found to reduce translocation and stomatal opening in soybean. This reduced the uptake of ^{14}C-metribuzin into the shoot of the soybean. When the atrazine concentration was reduced to 10^{-7} or 10^{-8} M, transpiration was increased over that of the control and more metribuzin moved into the shoot. While others had demonstrated reduced rates of transpiration at high atrazine concentrations (30, 39), Ladlie et al. (19) demonstrated that over a wide range of atrazine concentrations, atrazine actually reduced *and* enhanced transpiration rates in soybean. The response of transpiration to atrazine concentration would not be explained as a linear response, but rather as a quadratic response.

In studies examining the effects of RH, weed species, herbicide selection, and spray additives may all influence the pattern of herbicide absorption or level of weed control. This was most clearly demonstrated in the work of Reed et al. (26) who investigated the influence of RH and temperature on the phytotoxicity of thifensulfuron [3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]2-thiophenecarboxylic acid] and surfactant applications on two soybean cultivars (Asgrow 1937, Williams 82) and three weed species (velvetleaf (*Abutilon theophrasti* Medicus), ivyleaf morningglory (*Ipomea hederacea* (L) Jacq.), common lambsquarters

(*Chenopodium album* L.). Examination of fresh weight data averaged over all thifensulfuron treatments indicated that ivyleaf morningglory fresh weight was significantly reduced at 30 C and 35% RH over that at 30 C and 80% RH. This observation was reversed at 15 C. Velvetleaf fresh weight was reduced more at 30 C and 80% RH than at 30 C and 35% RH, however, there were no differences at 15 C. Furthermore, no differences in common lambsquarters fresh weight were observed at either RH regardless, of temperature. When the data was examined for all thifensulfuron treatments and environmental conditions, more differences became apparent. Greater reductions in fresh weight of velvetleaf occurred at lower RH with thifensulfuron plus 0.25% (v/v) NIS at 15 C and thifensulfuron plus 0.25% NIS plus 28% N (4% (v/v)) at 30 C. Similarly, greater reduction in fresh weight of ivyleaf morningglory occurred at low RH with thifensulfuron plus 0.25% NIS at 30 C, thifensulfuron plus 0.125% NIS at 15 C, and thifensulfuron plus 0.25% NIS plus 28% N at 15 C, while common lambsquarters fresh weight was reduced more at low RH with thifensulfuron plus 0.25% NIS at 15 C and thifensulfuron plus 28% N at 30 C. It was demonstrated by Kent et al. (18) that the reduced absorption of ^{14}C-imazethapyr in pitted morningglory at low RH could be increased 32% by the addition of ammonium sulfate.

It can be concluded that herbicide absorption as influenced by RH is dependent on the herbicide, additive, and weed species evaluated. It would be difficult to conclude from studies of RH at only two levels that herbicide absorption proceeds as a linear response or as some other response such as quadratic. If herbicide absorption actually

proceeds as a quadratic response, maximal absorption of ^{14}C-imazethapyr in common ragweed may occur at approximately 65% and then decline slightly at higher RH.

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Table 1. Effect of soil moisture, RH, and bentazon on absorption and translocation of imazethapyr in common ragweed.

	Absorption			Translocation		
	-----------Time (h)----------					
Factor	24	48	68	24	48	168
Soil Moisture						
-1/3 bars	47	49	56	22	28	28
-3 bars	41	36	49	17	25	27
Significance	*	**	**	NS	NS	NS
Relative Humidity						
65%	41	40	43	21	20	27
85%	47	45	61	18	32	29
Significance	*	*	**	NS	**	NS
Herbicide Trmt						
Imazethapyr	58	54	63	27	34	36
Imazethapyr + Bentazon	30	30	42	12	18	19
Significance	**	**	**	**	**	**
Soil Moisture * RH	NS	NS	NS	NS	NS	NS
Soil Moisture * Herb	NS	NS	NS	NS	NS	NS
RH * Herb	**	**	**	NS	**	*
Soil Moist * RH * Herb	NS	NS	NS	NS	NS	NS

Table 2. Effect of RH and bentazon on absorption and translocation of imazethapyr in common ragweed.

	Absorption			Translocation		
	---------------Time (h) ---------------					
Factor	24	48	168	24	48	168
RH * Herb Trmt						
Imep 65% RH	66	57	61	30	35	40
Imep + Bent 65% RH	15	22	26	12	6	14
Imep 85% RH	50	52	65	24	34	33
Imep + Bent 85% RH	45	38	57	12	31	24
Significance	12	12	11	NS	6	14

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