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thesis entitled

WEED CONTROL IN SOYBEANS USING REDUCED
RATES OF POSTEMERGENCE HERBICIDES

presented by

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has been accepted towards fulfillment
of the requirements for

M.S. degree in Crop and Soil Sciences

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Date 4-15-96

WEED CONTROL IN SOYBEANS USING REDUCED RATES OF POSTEMERGENCE HERBICIDES

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

1996

ABSTRACT

WEED CONTROL IN SOYBEANS USING REDUCED RATES OF POSTEMERGENCE HERBICIDES

By

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Weed control programs that use reduced rates of postemergence herbicides offer the potential to decrease producer input costs while maintaining weed control and soybean yield. Experiments were conducted in the greenhouse and field to examine using reduced rates of postemergence soybean herbicides. In the greenhouse, clethodim was more effective in controlling giant foxtail and barnyardgrass at reduced rates than quizalofop or fluazifop-P&fenoxaprop. Fomesafen and lactofen were the most effective herbicides for control of common ragweed at reduced rates. Chlorimuron, thifensulfuron, and fomesafen were the most effective herbicides for control of velvetleaf at reduced rates. In the field, weed control and soybean yield were greater in narrow row soybeans (19 cm) than wide rows (76 cm). All four herbicide tank mixtures applied at reduced rates in a split application (one quarter of a full rate at early postemergence followed by one quarter of a full rate at standard postemergence timing) resulted in weed control and soybean yield equal to that of full rate treatments. Three of four tank mixtures in 1994 and two of four in 1995, applied at one half the full rate at a standard postemergence timing, resulted in weed control and soybean yield equal to that of full rate treatments.

ACKNOWLEDGEMENTS

I would like to extend a sincere thank you to Dr. Karen Renner, my major advisor, for her excellent guidance and support throughout my graduate career at Michigan State University. I would also like to extend my appreciation to Dr. Jim Kells and Dr. Bernie Zandstra, members of my advisory committee, for their valuable contributions towards my degree.

I would like to thank Jason Fausey for his help and friendship during our simultaneous journey through graduate school, as well as for having someone to share the rent with. Special thanks to all of the people who have contributed in many ways to my research and education: Gary Powell, Andy Chomas, Julie Lich, Kelly Nelson, Bob Starke, Karen Novosel, Cory Ransom, Brent Tharp, Eric Spandl, Paul Knoerr, Jim Sherman, Mike Particka, Marla Van Wormer, and Joe Simmons. My experience at Michigan State has been especially enjoyable because of the great friendships and camaraderie that these people have provided me. Lastly, I would like to thank my family and friends for their continued support and encouragement throughout my graduate career.

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Introduction

Weed competition can greatly reduce soybean (*Glycine max* (L.) Merr.) yield (68). Coble et al. (15) reported that as little as four common ragweed (*Ambrosia artemisiifolia* L.) plants per 10 m of row reduced soybean yield 8%. Vail and Oliver (78) reported soybean yield loss of up to 78% from barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) densities of 500 plants per meter of row. Numerous studies have shown soybean yield reductions of 27 to 37% from giant foxtail (*Setaria faberi* Herrm.) densities of 17 to 177 plants per meter of row (32, 43, 72). To attain maximum yields weeds must be controlled. Cultural, mechanical, and chemical means used to control weeds can make up a significant portion of the input costs associated with producing soybeans. Low profit margins associated with producing soybeans have prompted growers to look for ways to decrease their input costs, while maintaining high yields in order to maximize profitability. Weed control equal to using full rates has been achieved using 25 and 50% of the recommended rates of postemergence herbicides (19, 22, 73). Weed control programs that use reduced rates of postemergence herbicides offer the potential to decrease producer input costs while maintaining weed control and soybean yield. This results in increased profit margins and reduced risk of environmental damage such as herbicide runoff into surface water or leaching into ground water. However, growers must be willing to spend more time and management efforts towards weed control and be willing to accept the risk of using below label rates.

Postemergence Herbicide Use in Soybeans

The use of postemergence herbicides has become a common and effective strategy to control weeds in Michigan soybean fields. Postemergence herbicide use gained popularity in the 1980's, as more postemergence herbicides became available (14, 39, 46, 51). Postemergence herbicides give growers more options for controlling weeds in soybeans and provide growers with a way to control weeds if soil applied herbicides fail.

Bentazon (3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide), is a postemergence contact herbicide used in several crops, including soybeans. Bentazon has activity on many annual broadleaf weeds including velvetleaf (*Abutilon theophrasti* Medic.) , common ragweed, common lambsquarters (*Chenopodium album* L.), and common cocklebur (*Xanthium strumarium* L.) (51,71). Bentazon is a benzothiadiazole herbicide. It inhibits photosynthesis in susceptible species by binding at the reducing side of Photosystem II between the primary electron acceptor Q and plastiquinone (74).

Acifluorfen (5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid), fomesafen (5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide), and lactofen ((±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate), are members of the diphenylether herbicide class. These contact herbicides have activity on many annual broadleaf weeds including common ragweed, redroot pigweed (*Amaranthus retroflexus* L.), and eastern black nightshade (2, 39, 49, 63, 77). Diphenylether herbicides act by inhibiting the enzyme protoporphyrinogen oxidase (Protox). This leads to the attack and oxidization of lipids and proteins resulting in the disruption of plant cell membranes (92).

Chlorimuron (ethyl 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoate) and thifensulfuron (methyl 3-[[[[(4-methoxy-6-methyl-1,3-5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylate) are sulfonylurea herbicides. Chlorimuron controls many annual broadleaf weeds in soybeans including common ragweed, redroot pigweed, velvetleaf, and common cocklebur (28). Thifensulfuron controls annual weeds such as common lambsquarters, pigweed species, and velvetleaf (28). These systemic herbicides inhibit acetolactate synthase (ALS), an enzyme necessary for the synthesis of the essential branched chain amino acids, isoleucine, leucine, and valine (92).

Clethodim ((*E*,*E*)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one), is a member of the cyclohexanedione family. Fenoxaprop ((±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoicacid), fluazifop-P ((*R*)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid), and quizalofop-P ((*R*)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid) are members of the aryloxyphenoxy propionate family. Herbicides in these two families are systemic herbicides which control most annual and many perennial grasses in soybeans including giant foxtail and barnyardgrass (7, 45, 70). They act by inhibiting acetyl-CoA carboxylase (ACCase), an essential enzyme in the synthesis of fatty acids, thus stopping the production of lipids in the plant (92).

The efficacy of postemergence herbicides is affected by many factors including environmental conditions. Soil moisture, air temperature, relative humidity and light intensity are some of the environmental conditions which can vary greatly and influence the efficacy of postemergence herbicides (31).

Conditions of moisture stress or high light intensity can cause thickening of the cuticle and epicuticular waxes on plant leaves (31, 66) which may result in reduced herbicide absorption. Boydston (6) reported reduced control of green foxtail (*Setaria viridis* (L.) Beauv.) with fenoxaprop, fluazifop-P, and sethoxydim (2-[-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) when plants were subjected to low soil moisture conditions 10 days before and 7 days after application. Water and light levels may also affect translocation of herbicides. Kells et al. (41) reported greater control of quackgrass with fluazifop when plants were grown under moist conditions compared to plants grown under moisture stress conditions. Radioautographs of treated plants suggest less distribution of the ^{14}C-fluazifop in the moisture stressed plants. The effect of light on control of quackgrass with fluazifop was also investigated. Greater translocation of ^{14}C-fluazifop occurred in plants grown in full light compared to plants grown in shade.

High temperatures at application can increase the activity of some postemergence herbicides. Lee and Oliver (46) investigated weed control with acifluorfen when weeds were grown under high temperature (27 to 35 C) compared to low temperature conditions (18 to 27 C) in the growth chamber. High temperatures increased pitted morningglory (*Ipomoea lacunosa* L.) control by 18-52% and velvetleaf and common cocklebur control by 10%, compared to the low temperature conditions. Kells et al. (41) observed greater control of quackgrass (*Elytrigia repens* (L.) Beauv.) by 0.28 kg/ha of fluazifop when plants were grown at 30 C compared to 20 C. Absorption of ^{14}C-fluazifop was 71% at 30 C and 45% at 20 C.

Other research indicates the effect of temperature on weed control with sulfonylurea herbicides appears to be opposite. Control of velvetleaf with thifensulfuron was greater when plants were grown under cool (20 C) rather than warm conditions (30 C) (93). Similarly, sicklepod (*Senna obtusifolia* L.) was more susceptible to chlorimuron when exposed to cooler rather than warmer temperatures (24).

Application of postemergence herbicides in high relative humidity conditions can increase efficacy. Ritter and Coble (62) investigated the effects of temperature and relative humidity on the control of common ragweed and common cocklebur with acifluorfen. Control of common ragweed with acifluorfen was greater at 85% compared to 50% relative humidity conditions and at temperatures of 32 C compared to 26 C. With common cocklebur, temperature was less critical than relative humidity. Absorption of ^{14}C-acifluorfen in treated plants was 42% greater at 85% relative humidity than at 50% relative humidity. Translocation of ^{14}C-acifluorfen in treated plants was also greater under high temperature and high relative humidity conditions. In a field study comparing weed size at application, Lee and Oliver (46) suggested that higher relative humidity conditions (88%) explained greater control of velvetleaf at the 2 leaf stage with acifluorfen than at the 1 leaf stage (54% relative humidity).

Reduced control of prickly sida (*Sida spinosa* L.), pitted morningglory, entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray), and common cocklebur occurred when acifluorfen, fomesafen, or acifluorfen + bentazon was applied at 50% compared to 85% relative humidity (89).

Efficacy of postemergence herbicides is also affected by stage of growth or weed size at application. Generally, smaller weeds are more susceptible to herbicides than larger weeds. Acifluorfen provided greater than 90% control of 4 to 6 leaf common ragweed, while 8 to 10 leaf plants resulted in less than 75% control (64). Lee and Oliver (46) investigated several rates of acifluorfen for control of weeds at the 1, 2, 4, and 8 leaf stages. Control of common cocklebur, entireleaf morningglory, and velvetleaf decreased as leaf stage increased from 1 to 2 to 4 to 8. Zhao et al. (93) found that velvetleaf susceptibility to thifensulfuron decreased as size of treated plants increased from 1 to 3 to 5 leaf. Derr et al. (21) reported excellent control of giant foxtail and large crabgrass (*Digitaria sanguinalis* (L.) Scop.) when fluazifop was applied at the pretillering stage (4 leaf, 10 cm tall). Control was reduced when fluazifop was applied at the tillering (7 leaf, 28 cm) and late tillering (9 leaf, 41 cm) stages in greenhouse and field experiments. Similarly, control with fluazifop on green foxtail, large crabgrass, yellow foxtail (*Setaria glauca* (L.) Beauv.), giant foxtail and Japanese millet (*Echinochloa crus-galli* var. *frumentacea* (Roxb.) W.F. Wright) was reduced as growth stage increased from 3 to 5 to 7 leaf (69). Kells et al. (41) observed significantly greater control of quackgrass with 0.56 kg ai/ha of fluazifop when treatments were applied to 2 to 3 leaf plants compared to 5 to 6 leaf plants. Radioautographs of treated plants suggest greater distribution of the ^{14}C-fluazifop in 2 to 3 leaf stage plants compared to 5to 6 leaf plants.

King and Oliver (42) investigated the effect of timing of application on weed control with aciflourfen, bentazon, chlorimuron, and imazaquin (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid) on eight broadleaf weed species. Based on their data they developed linear or polynomial regression equations which predicted control of the weed species dependent on herbicide rate and weed age. These equations illustrate the common trend that as weeds increase in size or age, susceptibility to a postemergence herbicide application is reduced. Thus the smaller the weed or the earlier an application, the lower the rate of herbicide necessary to provide control.

Control of a larger number of weed species can be achieved using tank mixtures of postemergence herbicides (55). Tank mixing reduces the number of application trips through the field, however, antagonistic interactions between two herbicides can occur, resulting in reduced control in some cases (34, 71, 80, 86, 88).

Acifluorfen antagonized the control of jimsonweed (*Datura stramonium* L.) by bentazon and bentazon antagonized the control of redroot pigweed by acifluorfen when tank mixed (71). Radio labeled herbicide experiments revealed that the uptake of these herbicides was reduced in the presence of the other. Westburg and Coble (87) observed reduced control of common cocklebur and sicklepod when acifluorfen was tank mixed with chlorimuron compared to chlorimuron alone. Absorption and translocation of ^{14}C-chlorimuron by common cocklebur was reduced when chlorimuron was tank mixed with acifluorfen (88).

Environmental conditions can influence the severity of antagonistic tank mixtures. Wesley and Shaw (85) reported no antagonism when chlorimuron was tank mixed with a diphenylether herbicide in 1989 with optimal growing conditions at the time of application. However they did observe antagonistic responses when acifluorfen or fomesafen was tank mixed with chlorimuron in 1990 when temperatures at the time of application were cool. Weed size did not influence the antagonistic effects. Reduced control was experienced when these tank mixtures were applied to either 3 leaf or 8 leaf common cocklebur plants. In contrast to Westburg and Coble (88), the addition of acifluorfen or lactofen to ^{14}C-chlorimuron increased absorption and translocation in common cocklebur (67). However, in this study herbicide was applied only to a localized area on the leaf, not to the entire plant. Thus absorption and translocation of chlorimuron is probably reduced when acifluorfen application causes rapid foliar injury to the entire plant.

Numerous studies have shown reduced control of several grass species when sethoxydim is tank mixed with bentazon (35, 53, 54, 60, 61). Absorption of ^{14}C-sethoxydim was greatly reduced when tank mixed with bentazon (38, 61, 81). Wanamarta et al. (81) provided evidence for explaining the antagonism. Na^+ ions from the sodium salt of bentazon exchanged with the H^+ of the hydroxyl group of sethoxydim when tank mixed, and the sodium salt of sethoxydim was formed. The absorption of the sodium salt of sethoxydim is reduced because it is more polar than sethoxydim (81).

Antagonism with other grass and broadleaf herbicides has also been reported.

Fluazifop can be antagonized by tank mixtures with acifluorfen, chlorimuron, fomesafen, and lactofen (18, 27, 54). Clethodim, quizalofop, and fenoxaprop can also be antagonized by broadleaf herbicides (54, 80). Of the three diphenylether herbicides, fomesafen appears to be least likely to cause an antagonistic response with a grass herbicide (38, 53, 80).

The antagonistic response seen between a graminicide and an ALS inhibiting herbicide is not due to reduced absorption as is the case with bentazon and sethoxydim. Chlorimuron reduced control of sethoxydim on large crabgrass when tank mixed, however chlorimuron did not reduce the uptake of ^{14}C-sethoxydim (38).

The antagonistic response observed when broadleaf herbicides are tank mixed with graminicides can sometimes be overcome by increasing the rate of the graminicide (60). The antagonistic interaction between grass and broadleaf herbicides is species dependent (34) and can be influenced by environmental conditions (38). Antagonism from tank mixing may not reduce control if conditions for plant growth are optimal (27).

Soybean Row Spacing

One factor to consider in a soybean production system which can influence yield is soybean row spacing. Wiggans (90) reported in 1938 that soybean seed yields increased as the spacing between rows was decreased. He remarked, "The nearer the arrangement of plants on a given area approaches a uniform distribution, the greater will be the yield." Many researchers since then have similarly concluded that higher soybean yields can be attained by planting soybeans in narrow row spacings (15 to 50 cm) (16, 17, 25, 48, 84), although this is not always the case (12, 48, 56). The increase in yield from narrow row spacings is dependent on many factors. Increases in yields from narrow row soybeans compared to wide rows are most likely to occur in the northern growing regions of the U.S. (17), with early maturing varieties (16, 17, 25), under optimal growing conditions including high moisture levels (75), or with late planted soybeans (4).

Decreasing the row spacing and spacing of plants within the row can result in increased plant height which can increase lodging of soybeans. This can counteract the yield advantage of narrow rows. Higher populations in narrow rows have resulted in increased lodging and resulted in no difference in soybean yield between row spacings (17, 25, 48). Heatherly (37) reported no yield advantage to planting soybeans in narrow rows under either irrigated or nonirrigated treatments at normal or late planting dates and no lodging.

Narrow row soybeans have the potential to yield higher than wide row soybeans mainly because of increased light interception by the soybean canopy (4, 5, 76). With the same leaf area index in narrow and wide rows, there was greater light interception in narrow rows because of a more uniform leaf distribution, which resulted in higher yield (76).

Prior to the 1980's most soybeans were planted in wide rows (76 to 104 cm) to allow cultivation of weeds. There was no practical advantage of planting soybeans in narrow rows because sufficient weed control could not be obtained without cultivation. The narrow choice of herbicides usually did not control all of the weed species present so one or two cultivations were commonly necessary to control weeds which were not susceptible to a herbicide. However, if weeds can be controlled early in the growing season greater season long weed control can be achieved in narrow rows due to faster canopy closure which can suppress late emerging weeds (19, 57, 82). Wax et al. (83) found that when trifluralin (2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine) was applied alone annual grasses and pigweeds were controlled, but velvetleaf, jimsonweed and ivyleaf morningglory (*Ipomea hederacea* (L.) Jacq.) were not. In this situation, soybeans which were planted in 76 cm rows and were cultivated outyielded soybeans in 18 cm rows by up to 50%. However if trifluralin was applied with metribuzin (4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one) or followed by an application of bentazon to control broadleaf weeds, narrow row soybeans outyielded wide row soybeans by 9%. Similarly, Burnside and Moomaw (11) proved that weeds could adequately be controlled in narrow row soybeans. A variety of treatments using preemergence or preemergence plus postemergence herbicides applied to 38 cm row soybeans provided control of grass and broadleaf weeds similar to the handweeded plots.

Wax and Pendleton (82) compared soybeans planted in 25, 50, 75, and 100 cm row spacings either cultivated or treated with trifluralin. They reported increased grass and broadleaf weed biomass as row spacing increased. Complete soybean canopy was formed at 35, 50, 65, and 80 days after planting in 25, 50, 75, and 100 cm row spacings, respectively. They noted narrow rows provided earlier shading which resulted in better weed control, however, early season weed control is still very important with narrow rows. Soybean yields increased by 10, 18, and 20% in 75, 50, and 25 cm rows, respectively, compared to 100 cm rows.

Peters et al. (57) noted that in soybeans treated with chloramben (3-amino-2,5-dichlorobenzoic acid), weed yields decreased and soybean yields increased as row width decreased. They observed that the soybean canopy of narrow rows provided an earlier and more complete canopy than wide rows, which resulted in a greater shading and weed suppression.

Burnside and Colville (10) compared soybean row spacings of 25, 50, 75, and 100 cm, and found the ground was completely shaded in 36, 47, 58, and 67 days, respectively. They concluded that chemical weed control only needs to be effective for about a month in 25 cm row spacings. Weed control from chloramben treatments was more effective as row spacing was decreased. Chloramben rates could be reduced by 50 to 75% for equivalent weed control in 25 cm rows compared to 100 cm rows. Soybean yields increased as row spacing decreased with soybeans in 25 cm rows yielding 39% higher than soybeans in 100 cm rows.

Patterson et al. (56) compared 15, 30, 45, and 90 cm row spacings grown in competition with common cocklebur and sicklepod under irrigated and nonirrigated conditions. In competition with sicklepod, soybean biomass decreased 14 kg/ha, seed yield decreased 12 kg/ha, and sicklepod biomass increased 12 kg/ha, for each cm increase in soybean row spacing. In competition with common cocklebur soybean biomass decreased 10 kg/ha, seed yield decreased 16 kg/ha, and common cocklebur biomass increased 10 kg/ha for each cm increase in soybean row spacing. Without weed interference soybean biomass and seed yield were similar between row spacings and under irrigated and nonirrigated conditions.

McWhorter and Sciumbato (52) indicated the competitive advantage of narrow row soybeans is not a factor in the early growth stages but becomes apparent later. They reported no difference in the wet weight of sicklepod plants early in the season, however, weight of sicklepod plants were reduced when measured at 72 through 120 days after emergence.

Légère and Shreiber (47) investigated the effects of row spacing on redroot pigweed interference in soybeans. They reported soybean canopy closure was faster in 25 cm rows than in 76 cm rows. Redroot pigweed contributed 24% of the total biomass in narrow rows compared to 43% in wide rows. Total biomass produced by both species in a mixed stand was similar to the biomass produced by soybeans alone in a weed free stand. Narrow row soybeans produced higher yields under weedy and weed free conditions. In dry growing seasons narrow row soybeans proved advantageous over wide rows, especially under weedy conditions.

The data presented by these researchers suggests increased competitiveness of soybeans when grown in narrow rows. Therefore planting soybeans in narrow rows is an option which could increase weed control in a reduced rate postemergence weed control program. A faster canopy enclosure can allow soybeans to outcompete weeds which may be injured but not completely killed from a reduced rate herbicide application or which emerge after herbicide application.

Use of Reduced Rates of Soil Applied Herbicides

Research on the use of reduced rates (less than the recommended rate on the pesticide label) of soil applied herbicides has been conducted in response to growers seeking ways to maximize the profitability of producing soybeans. In the 1970's Burnside and Moomaw (11) applied full and 50% rates of alachlor (2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide), chloramben, or fluorodifen (*p*-nitrophenyl α,α,α-trifluro-2-nitro-*p*-tolyl ether) with a full rate of a broadleaf herbicide to narrow row (38 cm) soybeans. Weed control and soybean yields were similar to full rate treatments.

Banding herbicides over the crop row followed by cultivation can effectively control weeds while reducing herbicide inputs. Preemergence applications of alachlor plus chloramben applied in a 20 cm band over the crop row followed by one or two cultivations resulted in weed control and soybean yield equal to that of a full rate applied broadcast (3).

Adequate rainfall is necessary for soil applied herbicides to be effective, especially at reduced rates. Imazaquin applied preplant incorporated or preemergence at 50% of the recommended rate controlled common cocklebur if adequate rainfall was received (30). Up to 88% control of common cocklebur was achieved at locations where adequate rainfall was received, but as low as 8% control resulted when no rainfall was received. Reduced rates of postemergence applied imazaquin was not as dependent on rainfall in these studies. Control with 50% of the recommended rate applied postemergence ranged from 86% to 97% and control with postemergence applied imazaquin at the lowest rate, 1/6 of the recommended rate, ranged from 70 to 95% at the five locations.

Jones et al. (40) investigated the use of reduced rates of imazaquin (2/3x, 1/3x) plus full rates of alachlor, applied preplant incorporated (PPI) to narrow and wide row soybeans. Acceptable control of common lambsquarters and Pennsylvania smartweed *(Polygonum pensylvanicum* L.) was obtained with 2/3x or 1/3x rates of imazaquin at 5 of 6 locations. At the sixth location, where velvetleaf and ivyleaf morningglory were present, reduced rates of imazaquin did not provide adequate control of these less susceptible species. Planting soybeans in narrow rows resulted in 19% less broadleaf weed biomass and 4% higher soybean yields compared to wide rows.

Buhler et al. (9) investigated the use of reduced rates of broadcast or band applied alachlor plus metribuzin in combination with cultivation. Full or 1/2x rates applied in a band plus one cultivation controlled pigweed species and giant foxtail both years and common lambsquarters one of two years. A second cultivation increased control. A 1/2x rate applied broadcast plus a cultivation also controlled pigweed species and giant foxtail both years and common lambsquarters one of two years. The reduced rate treatments decreased soybean injury compared to full rate treatments applied broadcast. Yield of soybeans treated with 1/2x rate banded plus 1 cultivation was equal to the yield of the handweeded soybeans one of two years. With two cultivations soybean yields were equal both years. A full rate of the herbicides banded plus one or two cultivations resulted in soybean yields equal to yield of the handweeded treatment both years. One-half of the recommended rate applied broadcast produced soybeans which yielded equal to the handweeded treatment one of two years and, with cultivation, was equal both years. A second cultivation often increased weed control but usually did not increase soybean yields.

The University of Wisconsin (23), the University of Missouri (20), and Iowa State University (33) have published extension bulletins which outline guidelines for using reduced rates of herbicides based on their research. Some of the reasons for using reduced rates of soil applied herbicides include: 1) decreased production costs, 2) reduced negative environmental effects from herbicide use, 3) response to government regulations on herbicide use, and 4) lessened risk of herbicide carryover in soil. Soil applied herbicide rates can be reduced by three ways: reducing the rate of a broadcast application, applying a full rate in a band over the row, or by applying a reduced rate in a band. Doll et al. (23) extensively investigated the use of reduced rates of soil applied herbicides in corn and soybeans. Excellent weed control was obtained in one soybean and fourteen corn studies with all three of these methods when followed by a cultivation. They stressed that cultivation must be timely and rotary hoeing may be necessary if no rainfall is received within 7 to 10 days after planting. Reduced rates are not recommended for fields with difficult to control grasses such as shattercane (*Sorghum bicolor* (L.) Moench.), wild proso-millet (*Panicum miliaceum* L.), woolly cupgrass (*Eriochloa villosa* (Thunb.) Kunth.), or quackgrass, and may not be effective on cloddy soils, high organic matter soils, or in a no-tillage system. It is recommended that growers first try reduced rates on a small scale basis.

DeFelice and Kendig (20) found that 50% of the recommended rates of soil applied herbicides did not provide weed control equal to using full rates. They concluded that a cultivation and/or a postemergence herbicide application was almost always necessary for adequate weed control. Cultivation has been an instrumental tool in weed control for decades, however, DeFelice and Kendig warn that there are significant drawbacks with cultivation. One concern which should be considered is the increased risk of soil erosion. Additionally, timeliness, favorable soil conditions, properly adjusted equipment, energy, and labor are all necessary for cultivation to be effective.

Researchers at Iowa State University conducted sixty-four on-farm research trials comparing full rate banded applications followed by cultivation to full rate broadcast applications of soil applied herbicides (33). At 92% of the sites weed control with banded applications equaled that of full rate broadcast applications, and 99% achieved soybean yields equal to yield of soybeans applied with full broadcast rates.

Use of Reduced Rates of Postemergence Herbicides

Numerous studies have examined various aspects of using reduced rates of postemergence herbicides in soybeans (1, 9, 13, 19, 22, 26, 29, 42, 58, 59, 65, 73). These studies have investigated many of the factors which can influence the efficacy of reduced rate postemergence weed control progams. Such factors include: rate of herbicide, timing of application, choice of herbicide or herbicide tank mixtures, soybean row spacing, cultivation, and tillage systems.

DeFelice et al. (19) investigated the use of 1/2x and 1/4x rates of bentazon, acifluorfen, or chlorimuron tank mixed with a 1/2x rate of sethoxydim. Treatments were applied to narrow row soybeans at two locations and to wide rows at a third location. Single appplications of the reduced rates were applied 7 days after planting (DAP) to weeds less than 2 cm tall and full rates were applied 14 DAP to weeds 5 cm tall or less. The sequential application of 1/4x of the full rate of the broadleaf herbicide tank mixed with a 1/2x rate of sethoxydim applied at 7 and 21 DAP gave the most consistent control of grasses and broadleaves, providing control of giant foxtail, velvetleaf, and common cocklebur equal to that of full rate treatments. In most cases single applications of reduced rates did not provide control equal to full rate treatments and soybean yields were not equal to sequential or full rate treatments. One location in 1987 experienced hot and dry conditions at the time of application. Because of these conditions none of the reduced rate or full rate treatments adequately controlled velvetleaf or common cocklebur, illustrating that reduced rates of postemergence herbicides should not be applied when plants are moisture stressed. Antagonism of sethoxydim was observed when tank mixed with bentazon. Control of crabgrass with the 1/2x bentazon + 1/2x sethoxydim treatment was less than the 1/4x bentazon + 1/2x sethoxydim treatment. Decreased weed control including late season germination and weed growth and lower soybean yields were observed at the wide row soybean site.

Steckel et al. (73) investigated the effect of a cultivation in combination with using reduced rates of postemergence herbicides. Twenty-five percent of the recommended rates of bentazon, chlorimuron, and imazaquin, and 50% of the recommended rates of imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid) were applied at 10 DAP, sequential 25% use rates were applied 10 and 21 DAP, and full rates were applied 21 DAP. All treatments were cultivated. Sequential applications of 25% of the recommended rate of these herbicides controlled common cocklebur and velvetleaf as well as the full rate applications. Single applications of 25% of the recommended rate did not control these weeds as well as full or sequential rates. Soybean yield with sequential or single reduced rate treatments were equal to yield of soybeans treated with full rates of the herbicides. Even though weed control with single reduced rate treatments was lower, yield was not reduced.

Devlin et al. (22) reported 1/2x rates of bentazon, acifluorfen, a tank mixture of bentazon + acifluorfen, or chlorimuron applied 14 DAP controlled common cocklebur, common sunflower (*Helianthus annuus* L.), smooth pigweed (*Amaranthus hybridus* L.), and velvetleaf as well as full rates of these herbicides applied 28 DAP, except at one location. At this location cool damp weather conditions delayed soybean and weed emergence and as a result many weeds germinated after the 14 DAP application. Applications of 1/4x rates of these herbicides at 14 DAP were less consistent in controlling weeds. Cultivation at 28 DAP appeared to improve weed control but was not statistically significant when averaged over all treatments. Cultivation improved weed control with 1/4x treatments to equal to that of full rate treatments with no cultivation. Soybean yield of 1/2x and 1/4x treatments was similar to soybean yield in the full rate treatments.

Prostko and Meade (58) found that applying a sequential 1/4x rate treatment of fomesafen + sethoxydim, chlorimuron + sethoxydim, or bentazon + acifluorfen + sethoxydim to wide row soybeans controlled common ragweed and common lambsquarters as well as full rate applications. Single applications of 1/2x rates of these herbicides applied at an early timing generally did not control broadleaf weeds as well as using full rates. Control of stinkgrass (*Eragrostis cilianensis* (All.) Lutati.) with 1/2x or 1/4x sequential applications was equal or better than a single application at a full rate. Yield of soybean treated with 1/4x sequential applications was equal to yield of soybean treated with full rates. Yield of soybean treated with 1/2x rates also was not different than yield from full rate treatments even though weed control was not equal.

Rathjen and Martin (59) compared weed control with reduced rates of postemergence herbicides applied to soybeans planted in 25 cm or 76 cm row spacings. The 76 cm rows were cultivated. Imazethapyr, chlorimuron, and bentazon + acifluorfen applied at 1/2x rates 20 DAP were compared to full rates of these herbicides applied 25 DAP for control of velvetleaf and common sunflower. Rotary hoeing did not increase weed control in either row spacing. In general the reduced rate treatments provided weed control similar to the standard rates. Weed control in narrow rows was similar to weed control in wide rows with a cultivation.

Results of research conducted in no-till soybeans with the use of reduced rates of postemergence herbicides is similar to the research conducted in conventionally tilled soybeans. Single and sequential applications of reduced rates of postemergence herbicides can adequately control weeds, however, sequential applications are more consistent in providing weed control (36, 65). The reduction in annual weed pressure in long term no-till fields, may provide greater opportunity for the use of reduced rates of postemergence herbicides.

Recommendations for applying reduced rates of postemergence herbicides in soybeans have been published by the University of Missouri (20) and by Iowa State University (33). DeFelice and Kendig (20) recommend early applications for broadleaf weed control. Herbicide rates of 1/4x should be applied 8 to 10 DAP, which usually coincides with 4 to 6 days after weed emergence (DAWE) and weeds 0.6 to 1.3 cm in height. Growers should make a second application of 1/4x rate or cultivate if necessary due to late weed germination. Rates of 1/2x should be applied 11 to 16 DAP (7 to 12 DAWE or 1.3 to 2.5 cm weeds). A second herbicide application or cultivation is less likely to be necessary with 1/2x rates. Reduced rates of postemergence grass herbicides are not recommended by the University of Missouri.

DeFelice and Kendig (20) commented that results of research indicating that less than label rates can successfully control weeds, does not imply that the labeled rates are too high. Herbicide rates recommended on product labels are set high enough to ensure control of a range of weeds that vary in susceptibility and are applied under a range of environmental conditions. Herbicide manufacturers can not afford to risk labeling a herbicide rate which will not consistently provide effective weed control over a wide range of conditions.

One concern with using reduced rates, is that the manufacturer is not liable for herbicide performance if applied at less than the labeled rate, therefore the grower assumes all risk. However, DeFelice and Kendig (20) stated there are ways to apply less herbicide and still comply with the manufacturers label. Many weeds are present only in patches in a field. By scouting fields for these patches, application can be made at a labeled rate to only these areas rather than the entire field. Also, some herbicide labels recommend different application rates depending on the species and weed size. If indicated on the label, some herbicides can be applied at a lower rate if it is a highly susceptible species or small in size.

Economics of Reduced Rate Herbicide Programs

The critical factor determining whether or not reduced rate herbicide programs are effective is the resulting gross margin. Some researchers have judged the profitability of reduced rate herbicide programs by comparing the gross margins of the treatments. Gross margins for each treatment can be estimated by subtracting the variable input costs (input costs which vary between treatments) from the gross income (yield multiplied by the assumed market price). Others have economically justified reduced rate treatments simply by comparing input costs if there are no differences in soybean yields between full and reduced rates.

Bicki et al. (3) reported that using reduced rate band applications plus cultivation can produce weed control and soybean yield equal to using full rate broadcast applications. Under this system herbicide use was decreased by 73% and weed control costs were reduced by 51 and 29% with one or two cultivations. Other research has shown that the highest input treatments do not always result in the highest gross margin (8, 44). Woods (91) compared preemergence and postemergence herbicide treatments applied at full and reduced rates in a band with cultivation. In one of two years, higher gross margins were achieved with banded applications of preemergence and postemergence herbicide treatments compared to full rates applied broadcast. Vencill et al. (79) conducted experiments to compare the gross margins from soybean systems using different weed control methods. Treatments included broadcast preemergence, banded preemergence, postemergence, and postemergence directed herbicide applications, and cultivation. Dry weather in 1990 resulted in low soybean yields and low gross margins. Under these conditions low input treatments gave the highest gross margins but all treatments were unacceptable. Better growing conditions in 1991 resulted in higher yields and higher gross margins. The best weed control treatments resulted in the highest yielding soybeans and also the highest gross margins. Metribuzin treatments applied broadcast preemergence resulted in gross margins that were higher than banded metribuzin treatments. In 1992 gross margins of banded or broadcast applied metribuzin treatments were not different. Thus, reducing herbicide input costs in this study did not increase gross margins.

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RATE RESPONSE OF GIANT FOXTAIL, BARNYARDGRASS, REDROOT PIGWEED, COMMON RAGWEED, AND VELVETLEAF TO POSTEMERGENCE HERBICIDES

Abstract. Greenhouse experiments were conducted to compare the efficacy of postemergence soybean herbicides applied at reduced rates to five weed species in the greenhouse. The results of these experiments indicate that the ranking for control of giant foxtail based on the relative reduced rates applied was: clethodim > quizalofop > fluazifop-P&fenoxaprop; and the ranking for barnyardgrass was: clethodim > fluazifop-P&fenoxaprop > quizalofop. Thifensulfuron, fomesafen, lactofen, and acifluorfen controlled redroot pigweed similarly. Chlorimuron was less effective. The relative ranking for control of common ragweed based on the rates applied was: fomesafen = lactofen > acifluorfen > bentazon = chlorimuron > thifensulfuron; and for velvetleaf was: fomesafen = chlorimuron = thifensulfuron > lactofen > bentazon > acifluorfen.

INTRODUCTION

The use of postemergence herbicides is a common and effective strategy to control weeds in Michigan soybean fields. The efficacy of a postemergence herbicide application is highly influenced by the application rate. Rates recommended on herbicide labels must consistently control a range of weed species that vary in susceptibility and size at application, and which are applied under an array of environmental conditions. Herbicide manufacturers are hesitant to label a herbicide at a rate which will control only a few weed species or a rate that may lack consistency over a wide range of conditions.

The application rate of a postemergence herbicide necessary to kill a susceptible plant species is dependent on many factors including weed size and environmental conditions at the time of application. Smaller weeds are generally more susceptible to a postemergence herbicide application than large weeds (3, 7) and therefore less herbicide may be necessary to control small weeds (9). Plant moisture stress due to hot dry weather can cause thickening of the epicuticular waxes on plant leaves resulting in reduced herbicide absorption (1, 6). Greater weed control can be achieved with postemergence herbicides when environmental conditions at application are ideal. Adequate soil moisture, high relative humidity, high air temperature, and high light intensity can increase the absorption and translocation of herbicides resulting in greater weed control (8, 7, 12). Therefore, when postemergence herbicides are applied to small weeds under ideal environmental conditions, herbicide rates could potentially be reduced.

Weed control equal to using full rates has been achieved using 25 and 50% of the recommended rates of postemergence herbicides (2, 4, 13). However, when applying reduced rates of postemergence herbicides, it is important to carefully consider the choice of herbicide or herbicide tank mixture. In some cases, this choice can make the difference between adequate weed control and weed control failure when using reduced rates (11). The susceptibility of a given weed species to two herbicides can vary greatly. Even if both herbicides will control the weed at a labeled rate, one herbicide may be more active. At a reduced rate this more active herbicide may provide good control while the less active herbicide will fail.

The objective of these experiments was to compare the efficacy of postemergence soybean herbicides applied at reduced rates on five weed species in the greenhouse to determine if there were differences in the relative effectiveness of these herbicides as application rates were reduced.

MATERIALS AND METHODS

Giant foxtail and barnyardgrass seeds were planted into potting soil (60% sphagnum peat, 20% perlite, and 20% rock wool) in 945 ml plastic pots in the greenhouse. Prior to herbicide application, pots were fertilized with 0.1 g of soluble fertilizer (20% N, 20% P_2O_5, 20% K_2O) and thinned to 10 plants per pot. Environmental conditions were maintained at 27 C $\pm$ 5 C with a 16 hour photoperiod of natural lighting supplemented with sodium vapor lighting giving a cloudless midday photosynthetic photon flux density of 500 $\mu E/m^2/s$.

Herbicides were applied to three leaf (7 to 10 cm) giant foxtail and barnyardgrass plants using a moving nozzle sprayer equipped with an 8002E even flat fan nozzle, traveling 4.8 km/hr, and delivering 234 L/ha at a pressure of 193 kPa.

The experiments were designed as randomized complete blocks with a factorial arrangement of treatments and repeated in time. Clethodim, the formulated premix of fluazifop-P&fenoxaprop, and quizalofop were applied to giant foxtail and barnyardgrass plants at five rates. These herbicides have similar labeled field use rates of 584 ml/ha of formulated product for control of barnyardgrass. Preliminary experiments showed 100% control of barnyardgrass and giant foxtail with application rates of as little as 146 ml/ha (1/4x). Therefore, rates used for these experiments started at one eighth of the labeled field use rate (1/8x) and subsequent rates decreased in half (1/16x, 1/32x, 1/64x, 1/128x). The 1/8x rates were: clethodim at 17 g ai/ha, the premix of fluazifop-P&fenoxaprop at 23 g/ha (17 g + 6 g), and quizalofop at 8 g/ha. All treatments included nonionic surfactant at 0.125% v/v and 28% urea ammonium nitrate at 2.3 L/ha.

Redroot pigweed, common ragweed, and velvetleaf seeds were planted into Baccto[1] greenhouse potting soil in 945 ml plastic pots. Prior to herbicide application, pots were fertilized with 0.1 g of soluble fertilizer (20% N, 20% P_2O_5, 20% K_2O) and thinned to one plant per pot. Environmental conditions were maintained at 29 C $\pm$ 5 C

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[1]Baccto is a product of Michigan Peat Co. Houston, TX 77098.

with a 16 hour photoperiod of natural lighting supplemented with metal halide lighting giving a midday photosynthetic photon flux density of 1000 $\mu E/m^2/s$.

Herbicides were applied to 6 leaf redroot pigweed, 3 leaf velvetleaf, and 6 leaf common ragweed using a continuous link belt sprayer equipped with an 8001E even flat fan nozzle, traveling 1.5 km/hr, and delivering 234 L/ha at a pressure of 221 kPa.

The experiments were designed as randomized complete blocks with a factorial arrangement of treatments and repeated in time. Herbicide rates used in these greenhouse studies were based on recommended field use rates. Lactofen, fomesafen, acifluorfen, thifensulfuron, and chlorimuron were applied at five rates (1/4x, 1/8x, 1/16x, 1/32x, 1/64x) to redroot pigweed. These herbicides were also applied at five rates (1/2x, 1/4x, 1/8x, 1/16x, 1/32x) and bentazon at four rates (1/2x, 1/4x, 1/8x, 1/16x) to common ragweed and velvetleaf. Acifluorfen and bentazon, which are commonly applied as a formulated premix in the field, were applied separately in the greenhouse to examine the effects of each herbicide. Therefore the rates of acifluorfen and bentazon are not considered true full rates, because the recommended field rate of either herbicide would be higher when applied alone. This should be considered when comparing acifluorfen or bentazon to other herbicides. The 1/2x rates of the herbicides used in these studies were: lactofen at 53 g/ha + nonionic surfactant (NIS) at 0.125% v/v, fomesafen at 140 g/ha + NIS at 0.125% v/v + 28% urea ammonium nitrate (UAN) at 2.3 L/ha, acifluorfen at 93 g/ha + crop oil concentrate (COC) at 2.3 L/ha, bentazon at 421 g/ha + COC at 2.3 L/ha, thifensulfuron at 2.2 g/ha + NIS at 0.125% v/v + UAN at 4.6 L/ha, and chlorimuron at 2.9 g/ha + NIS at 0.125% v/v +UAN at

4.6 L/ha. The adjuvants included were always applied at the full rate listed regardless of the herbicide rate.

Injury to each species was evaluated visually at 7 and 14 days after treatment (DAT). Plant dry weight was measured by harvesting, oven drying and weighing all above ground portions of giant foxtail, barnyardgrass, redroot pigweed, and velvetleaf at 14 DAT. Common ragweed growth in the greenhouse was slower than other species. Dry weight measurement was delayed to 21 DAT in order to attain sufficient regrowth similar to the other broadleaf experiments.

Data were combined over experiment repetitions and analysis of variance revealed significant herbicide by rate interactions. Means were separated using Duncan's Multiple Range Test. Results and discussion are based on dry weight data which was converted to a percent reduction in dry weight, based on the untreated control in each replication of each experiment for each weed species using the equation 100 - ((plant dry weight/untreated plant dry weight) $\times$ 100).

RESULTS AND DISCUSSION

Giant foxtail. All three herbicides provided excellent control (91 to 92% dry weight reduction) of giant foxtail when applied at the 1/8x rate (Figure 1). However, as the rate was further reduced, clethodim provided greater control than quizalofop, and fluazifop-P&fenoxaprop provided the least control.

Barnyardgrass. Control of barnyardgrass at the 1/8x rate was excellent with clethodim and fluazifop-P&fenoxaprop (93 and 95% dry weight reduction), while control with quizalofop was less (83%) (Figure 2). As rates were further reduced, clethodim provided the greatest control, followed by fluazifop-P&fenoxaprop. Quizalofop provided the least control.

Redroot pigweed. There was no difference in redroot pigweed dry weight reduction between lactofen, fomesafen, acifluorfen, or thifensulfuron at any rate (data not presented). Chlorimuron provided similar control to other herbicides at the 1/4x rate, however control with chlorimuron was less than other herbicides at rates lower than 1/4x. Green (5) reported that redroot pigweed was less susceptible to chlorimuron than thifensulfuron. The amount of active ingredient necessary for chlorimuron to provide 90% control of redroot pigweed was 4 times that of thifensulfuron.

Common ragweed. All herbicides applied at 1/2x provided greater than 80% reduction in common ragweed dry weight (Figure 3). At rates less than 1/2x, fomesafen and lactofen provided the greatest control. Acifluorfen provided greater control than bentazon or chlorimuron, and thifensulfuron provided the least control of common ragweed.

Velvetleaf. All herbicides applied at 1/2x resulted in 86% or greater reduction in velvetleaf dry weight, except for acifluorfen (42%) (Figure 4). At rates less than 1/2x, fomesafen, thifensulfuron, and chlorimuron provided the greatest control of velvetleaf, followed by lactofen. Bentazon and aciflourfen provided the least control.

Comparisons between herbicides based on rate responses are dependent on the rate chosen as a "full rate". In most cases a herbicide label does not list a single rate at which it is to be applied. The labeled recommended application rate can be dependent on weed species, crop species, weed size, environmental conditions, soil characteristics, location, tank mixtures, adjuvants, or governmental regulations. Therefore, choosing the "full rate" of a particular herbicide is a subjective decision and can influence the results. However, at the rates applied in these studies, results indicate there were differences between the effectiveness of these herbicides as rates were reduced. Clethodim appeared to be the best choice for control of giant foxtail or barnyardgrass when applied at reduced rates. Fomesafen, lactofen, acifluorfen, and thifensulfuron were equally effective in controlling redroot pigweed at reduced rates. Fomesafen and lactofen were the most effective herbicides for common ragweed control, while fomesafen, thifensulfuron, and chlorimuron were the most effective for control of velvetleaf in the greenhouse.

Results from these experiments suggest which herbicides may be more likely to provide adequate weed control in the field when applied at reduced rates. However, plants can respond differently to postemergence herbicides in the greenhouse compared to the field (10), due to differences in the environment or due to root uptake in the field. It is also likely that differences in plant response between greenhouse and field environments will vary with herbicide class. Field research is needed to confirm which herbicides are most effective when applied at reduced rates.

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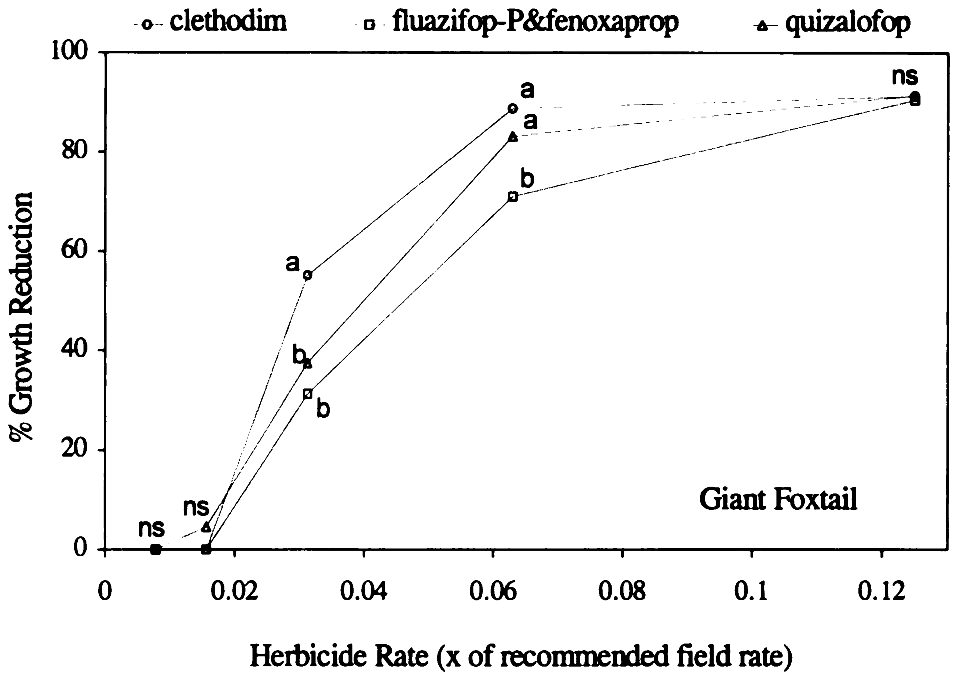

Figure 1. Reduction in giant foxtail dry weight 14 days after postemergence herbicide application. Means denoted by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within a herbicide rate.

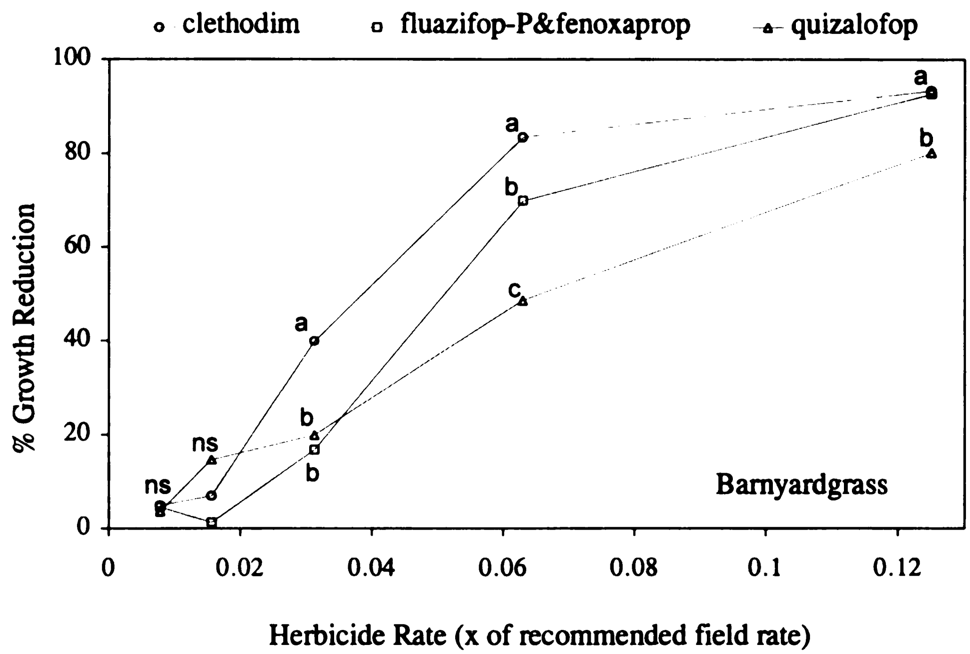

Figure 2. Reduction in barnyardgrass dry weight 14 days after postemergence herbicide application. Means denoted by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within a herbicide rate.

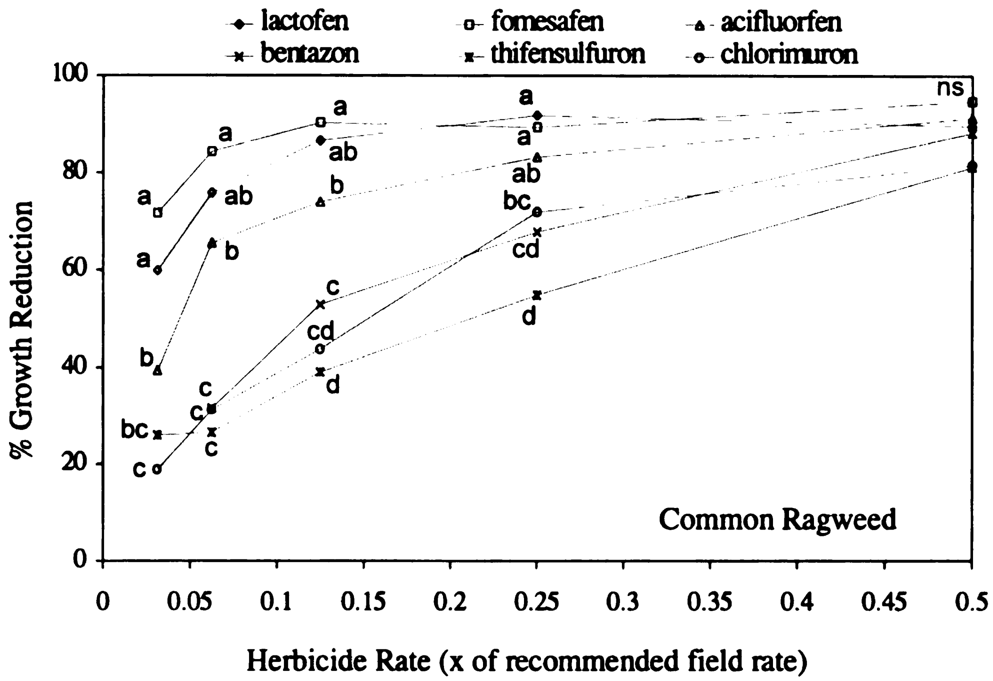

Figure 3. Reduction in common ragweed dry weight 21 days after postemergence herbicide application. Means denoted by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within a herbicide rate.

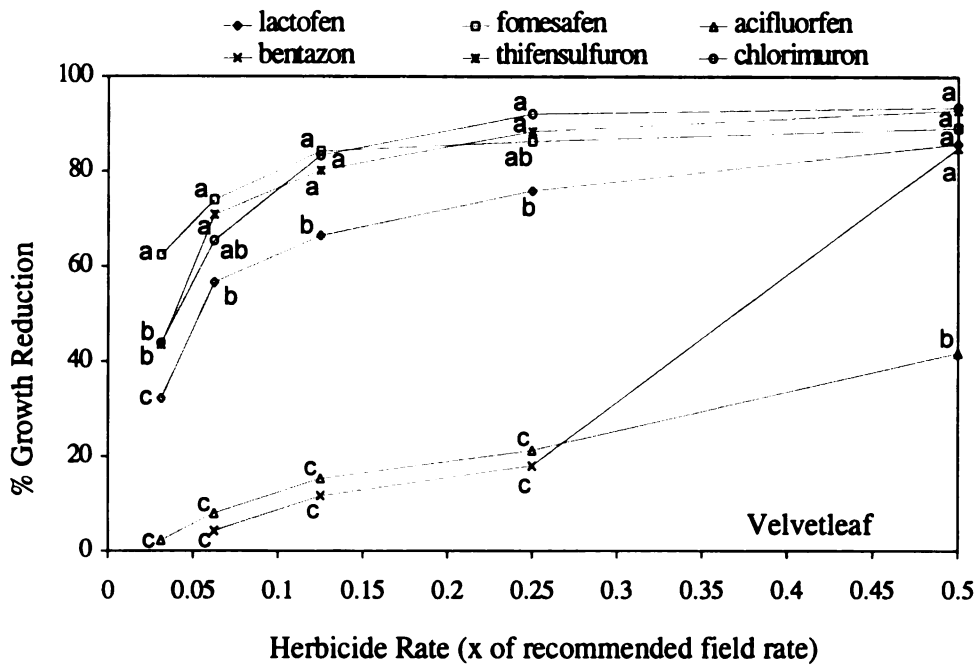

Figure 4. Reduction in velvetleaf dry weight 14 days after postemergence herbicide application. Means denoted by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within a herbicide rate.

WEED CONTROL USING REDUCED RATES OF POSTEMERGENCE HERBICIDES IN NARROW AND WIDE ROW SOYBEANS

Abstract. Field studies were conducted in 1994 and 1995 to examine the effects of soybean row spacing and application rate and timing of four postemergence herbicide tank mixtures on weed control and soybean yield. Weed control and soybean yield were greater in narrow rows (19 cm) than wide rows (76 cm). Herbicide tank mixtures applied at one quarter of the full recommended rate at an early postemergence timing followed by a second application of one quarter of the full rate applied at a standard postemergence timing (1/4x E Post + 1/4x Post) resulted in weed control and soybean yield equal to that of herbicide tank mixtures applied at the full recommended rate at a standard postemergence timing (1x Post). Three of four tank mixtures in 1994 and two of four in 1995, applied at one half of the full rate applied at a standard postemergence timing (1/2x Post) resulted in weed control and soybean yield equal to that of 1x Post applications. All tank mixtures applied at one half of the full rate applied at an early postemergence timing (1/2x E Post) resulted in poor weed control and low soybean yield. In most cases it was more profitable to plant soybeans in narrow rows than wide rows regardless of application rate or timing, based on economic gross margin calculations. Gross margins of tank mixtures applied at 1/4x E Post + 1/4x Post were similar to or greater than the gross margin of the same tank mixture applied at the full rate in thirteen of sixteen cases. Gross margins of tank mixtures applied at 1/2x Post were similar to or greater than the gross margin of the same tank mixture applied at the full rate in eight of sixteen cases.

INTRODUCTION

Weed competition can greatly reduce soybean (*Glycine max* (L.) Merr.) yield (8, 15, 19, 28, 30, 34). To attain maximum yields weeds must be controlled. Cultural, mechanical, and chemical means used to control weeds can make up a significant portion of the input costs associated with producing soybeans. Low profit margins associated with producing soybeans have prompted growers to look for ways to decrease their input costs, while maintaining high yields in order to maximize profitability. The use of herbicides as the principle method of weed control has contributed to increased input costs associated with producing soybeans. It has also resulted in increased concerns of the environmental impacts of herbicide use. Weed control programs that use reduced rates of postemergence herbicides can potentially lower producer input costs while maintaining adequate weed control. However, growers must be willing to spend more time and management efforts towards weed control and be willing to accept the risk of using below label rates.

The efficacy of postemergence herbicides is affected by many factors including environmental conditions and weed size. Soil moisture, air temperature, relative humidity and light intensity are some of the environmental conditions which can vary greatly and influence the efficacy of postemergence herbicides (6, 14, 18, 20, 26, 41). Poor weed control may result if reduced rates are applied under non-ideal growing conditions. DeFelice et al. (10) reported unacceptable weed control with full and reduced rates of postemergence herbicides when conditions at the time of herbicide application were hot and dry.

Tank mixing postemergence herbicides allows growers to minimize the number of trips through the field, however, antagonistic interactions between two herbicides can occur, resulting in reduced weed control in some cases (16, 29, 35, 40). Few studies have evaluated weed response to tank mixtures of herbicides applied at reduced rates.

Weed control equal to using full rates has been achieved using 25 and 50% of the recommended rates of postemergence herbicides in conventionally tilled soybeans (10, 11, 24, 25, 31). Only three of the fifteen locations were planted to soybeans in narrow row spacings. Most research has been conducted in wide rows, often in combination with cultivation. Planting soybeans in narrow rows can result in greater season long weed control than wide row soybeans due to a faster closure of the soybean canopy which results in greater shading and weed suppression (7, 21, 23, 36). Also, planting soybeans in narrow rows can result in higher soybean yields due to increased light interception by the soybean canopy (4, 5, 33). Therefore, planting soybeans in narrow rows is an option which could increase weed control in a reduced rate postemergence herbicide program and maintain or increase soybean yields.

Information on reduced rate herbicide programs for soybean growers in the northern production region of the U.S. is lacking. This research was initiated to assess the potential of reduced rates of postemergence herbicides for weed control in this region. Two aspects studied in this research have not been previously reported; applying reduced rates of herbicide tank mixtures containing a grass and two broadleaf herbicides in order to control a broad spectrum of weed species, and the efficacy of reduced rate treatments is directly compared between narrow and wide row soybeans.

The objectives of this research were to: 1) evaluate differences in weed control between narrow and wide row soybeans using full and reduced postemergence herbicide rates, 2) determine the effects of row spacing on soybean yield, and 3) determine if planting soybeans in narrow rows can increase the effectiveness of reduced rate postemergence herbicide programs.

MATERIALS AND METHODS

Field experiments were conducted in 1994 and 1995 at Michigan State University, in East Lansing, MI. The soil was a Capac sandy clay loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) with 3.1% organic matter and pH of 7.1 in 1994. In 1995, the soil was a Capac loam with 3.2% organic matter and pH of 6.6. The 1994 site was chisel plowed the previous fall, and disked and field cultivated in the spring. The 1995 site was moldboard plowed, disked, cultimulched, and field cultivated in the spring.

'Conrad' soybeans were planted on May 13, 1994 and May 11, 1995. Soybeans were planted in 19 cm row spacings with a Great Plains Solid Stand 10[1] grain drill at a seeding rate of 470,000 seeds/ha, and in 76 cm row spacings with a John Deere 7200

[1]Great Plains Manufacturing Inc., P.O. Box 218, Assaria, KS 67416.

Max-Emerge®2 planter[2] at a seeding rate of 358,000 seeds/ha. Preemergence herbicides were applied with a tractor mounted compressed air plot sprayer using 8003 flat fan nozzles calibrated to deliver 206 L/ha at a pressure of 207 kPa. Postemergence herbicides were applied using 8002 flat fan nozzles calibrated to deliver 140 L/ha at a pressure of 207 kPa.

Plots were 3 m wide by 12 m long in 1994 and 3 m wide by 10.7 m long in 1995. The experimental design was a split plot with four replications. Main plots were narrow or wide rows. Subplots were a factorial arrangement of four herbicide tank mixtures applied at four application rate/timing combinations. Additional treatments included a weedy control, weedfree control, standard preemergence herbicide treatment, and mechanical control only. The preemergence treatment contained metolachlor applied at 2240 g ai/ha + linuron at 560 g ai/ha + metribuzin at 280 g ai/ha. The mechanical treatment consisted of two rotary hoes in narrow row soybeans, and two rotary hoes followed by two cultivations in wide rows.

Weeds were counted the day before early postemergence herbicide application. Weed densities were: 125 and 527 giant foxtail plants/m^2, 274 and 40 common lambsquarters plants/m^2, 152 and 17 redroot pigweed plants/m^2, 182 and 7 common ragweed plants/m^2, and 0 and 17 velvetleaf plants/m^2 in 1994 and 1995, respectively. SOYHERB (27) and WEEDSIM (32) computer modeling programs were used to select four tank mixtures based on weed densities and herbicide cost. The four herbicide tank mixtures and full recommend rates selected were: 1) clethodim at 105 g ai/ha +

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[2]Deere and Co., Moline, IL 61265-1304.

thifensulfuron at 4.4 g ai/ha + lactofen at 105 g ai/ha + nonionic surfactant[3] (NIS) at 0.125% v/v, 2) the formulated premix of fluazifop-P&fenoxaprop at 186 g ai/ha (140 g + 46 g) + thifensulfuron at 4.4 g/ha + fomesafen at 280 g ai/ha + 28% urea ammonium nitrate (UAN) at 2.3 L/ha + NIS at 0.125% v/v, 3) quizalofop at 49 g ai/ha + a formulated premix of bentazon&acifluorfen at 1032 g ai/ha (841 g + 191 g) + crop oil concentrate[4] at 2.3 L/ha, and 4) quizalofop at 49 g/ha + thifensulfuron at 4.4 g/ha + chlorimuron at 5.8 g ai/ha + UAN at 4.6 L/ha + NIS at 0.125% v/v. Each herbicide tank mixture was applied at four rate/timing combinations: 1) one quarter of the full recommended rate applied at an early postemergence timing followed by a second application of one quarter of the full rate applied at a standard postemergence timing (1/4x E Post + 1/4x Post), 2) one half of the full rate applied at an early postemergence timing (1/2x E Post), 3) one half of the full rate applied at a standard postemergence timing (1/2x Post), and 4) the full recommended rate applied at a standard postemergence timing (1x Post). The early postemergence application timing was targeted when weeds were 2.5 cm tall. The standard postemergence timing was targeted when weeds were 10 cm tall.

Early postemergence treatments were applied on May 28, 1994 and May 26, 1995 (15 days after planting). Air temperature was 20 C with 48% relative humidity in 1994, and 18 C with 64% relative humidity in 1995. Rainfall in the 10 days prior to

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[3]Activator-90, a mixture of alkyl polyoxyethylene ether and free fatty acids. Loveland Industries, Inc., P.O. Box 1289, Greeley, CO 80632.

[4]Herbimax, 83% petroleum oil, 17% surfactant, Loveland Industries, Inc., P.O. Box 1289, Greeley, CO 80632.

application was 0.6 cm in 1994 and 3.4 cm in 1995. Standard postemergence treatments were applied on June 9 in 1994 and 1995 (27 and 29 days after planting). Air temperature was 24 C with 37% relative humidity in 1994 and 22 C with 65% relative humidity in 1995. Rainfall in the 10 days prior to application was 1.0 cm in 1994 and 0.8 cm in 1995. Soybeans were at the cotyledon to unifoliate stage at the early postemergence application and 1 to 2 trifoliate stage at the standard postemergence application. Weed heights at herbicide application are presented in Table 1.

Injury to giant foxtail, common lambsquarters, redroot pigweed, common ragweed, and velvetleaf was evaluated visually at 10, 24, 38, and 52 days after postemergence application. The rating scale ranged from 0 (no visual injury) to 100% (complete plant death). Crop response was evaluated visually at 3, 10, 24, and 38 days after postemergence application. Injury ratings were based on plant stunting, chlorosis, and necrosis. Weed biomass was sampled on July 27, 1994 and July 31, 1995 by harvesting all aboveground portions of each weed species from a 25 by 91 cm rectangular area arranged perpendicular to the soybean row. Weeds were harvested and counted by species from two areas per plot, oven dried, and weighed. *Sclerotinia* stem rot, or white mold, (*Sclerotinia sclerotiorum* var. *sojae*) was measured September 9, 1994 by scoring 30 plants per plot on a 0 to 3 rating scale where 0 equals no symptoms and 3 equals lesions on the main stem resulting in plant death and poor pod fill. Soybeans were harvested for seed from the center 1.5 m strip of each plot on October

22, 1994 and October 13, 1995 with a Massey 10[5] plot harvesting combine. Seed yields were adjusted to 13.0% moisture. In 1994 disease severity index (DSI)[6] for *Sclerotinia* stem rot was calculated and analysis of covariance was used, with DSI as the covariate, to adjust soybean yield. An economic analysis determined the gross margin of each treatment by subtracting the variable input costs from the gross income. Gross income was calculated by multiplying the soybean seed yield by an assumed market price of $0.20/kg. Variable input costs[7] assumed were: $12.36/ha per herbicide application; $21.15/ha for seeding soybeans in wide rows; $27.72/ha for seeding soybeans in narrow rows; $60.39/ha for the 1x rate of clethodim+ thifensulfuron+ lactofen; $70.79/ha for the 1x rate of fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen; $57.25/ha for the 1x rate of quizalofop+ bentazon&acifluorfen; $57.43 for the 1x rate of quizalofop+ thifensulfuron+ chlorimuron; $90.44/ha for metolachlor+ linuron+ metribuzin, $8.60/ha for a cultivation, and $3.61/ha for a rotary hoe operation.

Analysis of variance revealed significant year by treatment interactions for visual weed injury ratings, soybean injury ratings, weed biomass, and soybean yield, so data is presented separately for 1994 and 1995. Means were separated using Duncan's Multiple Range Test at the 5% level of significance. Results and discussion of visual weed injury are based on the rating taken 38 days after standard

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[5]Kincaid Equipment Manufacturing, P.O. Box 400, Haven, KS 67543.

[6]DSI was calculated by summing the scoring values for each of the 30 plants and dividing by 90, the highest possible total score.

[7]Herbicide prices according to SOYHERB and cultivation and rotary hoe costs according to Doane's Agricultural Reports, 1995. v. 58. No.15-5.

postemergence application (52 days after early postemergence application). Results and discussion of soybean injury are based on the rating taken 10 days after early postemergence application for 1/4x E Post + 1/4x Post and 1/2x E Post, and 10 days after standard postemergence application for 1/2x Post and 1x Post.

RESULTS AND DISCUSSION

Annual grass. In 1994 the row spacing by herbicide tank mixture interaction was significant ($P<0.05$). Control of annual grass (predominantly giant foxtail) was similar with all herbicide tank mixtures in narrow row soybeans, when averaged over rate/timing combinations (Table 2). In wide rows, control of annual grass with quizalofop+ bentazon&acifluorfen was greater than with clethodim+ thifensulfuron+ lactofen or with fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen. Crop oil concentrate was included in the quizalofop+ bentazon&acifluorfen tank mixture, while nonionic surfactant was included in other tank mixtures. Crop oil concentrate has been reported to be a more effective adjuvant than nonionic surfactant for grass control with postemergence soybean herbicides (3).

In 1994 and 1995 the herbicide tank mixture by rate/timing interaction was significant ($P<0.05$). In 1994, all herbicide tank mixtures applied at the full recommended rate (1x Post) provided 92% or greater control of annual grass, averaged over row spacing (Table 3). Grass control with all four herbicide tank mixtures applied at 1/2x Post and with three of the four herbicide tank mixtures applied at 1/4x E Post

+1/4x Post was equal to 1x Post applications. Grass control with the quizalofop+ thifensulfuron+ chlorimuron tank mixture applied at 1/4x E Post + 1/4x Post was not equal to 1x Post applications, but was similar to other tank mixtures applied at 1/4x E Post + 1/4x Post. Barnyardgrass was present in small patches throughout the field and may be the reason for poor grass control with this treatment. Quizalofop was less effective on barnyardgrass than other grass herbicides in greenhouse experiments. In 1995, three of the four tank mixtures applied at 1/4x E Post + 1/4x Post, 1/2x Post, or 1x Post provided 90% or greater control of annual grass (Table 3). Grass control with clethodim+ thifensulfuron+ lactofen applied at 1x Post only reached 71% control. Reduced control with this tank mixture may have been caused by an antagonistic interaction between clethodim and lactofen. Vidrine et al. (35) reported an antagonistic response in barnyardgrass and johnsongrass when lactofen was tank mixed with clethodim.

Annual grass was not controlled by any herbicide tank mixture applied at 1/2x E Post in 1994 or 1995. Many grass plants emerged after the early postemergence herbicide application (personal observation). Because the postemergence herbicides applied have minimal soil activity, late emerging grasses were not controlled and resulted in poor season long weed control. DeFelice et al. (10) also reported reduced control of giant foxtail with 1/4x or 1/2x rates applied at an early application timing (7 days after planting) compared to sequential or full rate applications at a later application timing.

Common lambsquarters. Row spacing by herbicide tank mixture, row spacing by rate/timing, and herbicide tank mixture by rate/timing interactions were significant in both 1994 and 1995.

Control of common lambsquarters from clethodim+ thifensulfuron+ lactofen and fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen applied in wide row soybeans was less than in narrow row soybeans in 1994 (Table 4). In 1995, common lambsquarters control with clethodim+ thifensulfuron+ lactofen was similar between row spacings, yet control in wide row soybeans was less than in narrow row soybeans with the other three tank mixtures, when averaged over all rate/timing combinations.

In 1994, all four rate/timing combinations when averaged over herbicide tank mixtures provided equal control of common lambsquarters when applied to narrow row soybeans (Table 5). Control with herbicide tank mixtures applied at 1/2x E Post was similar in wide and narrow rows (93 and 95%), but applications of 1/4x E Post + 1/4x Post, 1/2x Post, and 1x Post to wide rows resulted in reduced control compared to narrow rows. In 1995, herbicides applied at 1/2x Post or 1x Post resulted in reduced control in wide rows compared to narrow rows. Very few common lambsquarters emerged after the E Post application (personal observation). Therefore control was greater when herbicides were applied at E Post because common lambsquarters were smaller.

Averaged over row spacings in 1994, all rate/timing combinations of quizalofop+ bentazon&acifluorfen or quizalofop+ thifensulfuron+ chlorimuron provided 93% or greater control of common lambsquarters (Table 6). Less control occurred with clethodim+ thifensulfuron+ lactofen at 1/4x E Post + 1/4x Post or fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen at 1/2x Post or 1x Post. In 1995, three of four tank mixtures applied at 1/4x E Post + 1/4x Post or 1/2x E Post provided 92% or greater control of common lambsquarters, averaged over row spacing. Control of common lambsquarters with 1/2x Post or 1x Post applications ranged from 61% to 87%.

Common lambsquarters is very susceptible to thifensulfuron (2), which was a component in three of the four tank mixtures. In most cases these tank mixtures adequately controlled common lambsquarters, however in some cases when thifensulfuron was tank mixed with lactofen or fomesafen control was less than when tank mixed with chlorimuron. This may be evidence of antagonism which can occur when a diphenylether herbicide is tank mixed with a sulfonylurea herbicide (38, 39, 40). The tank mixture containing bentazon and acifluorfen also controlled common lambsquarters at reduced rates in most cases. Bentazon and acifluorfen both have activity on common lambsquarters. Very few common lambsquarters emerged after the early postemergence herbicide application (personal observation), therefore control with herbicides applied at 1/4x E Post + 1/4x Post or 1/2x E Post was equal to or greater than herbicides applied at 1/2x Post or 1x Post.

Redroot Pigweed. In 1994 the row spacing by herbicide tank mixture by rate/timing interaction was significant. Redroot pigweed was controlled by all rate/timing combinations in narrow and wide rows except with quizalofop+ bentazon&acifluorfen (Table 7). Control with 1/2x Post or 1x Post applications of this tank mixture were greater in narrow rows, 84% and 87%, respectively, than in wide rows, 76% and

54%, respectively. In 1995, quizalofop+ bentazon&acifluorfen also provided less control in wide rows compared to narrow rows (Table 8). Applications of quizalofop+ bentazon&acifluorfen at 1/4x E Post + 1/4x Post or 1/2x E Post resulted in 82 and 81% control and applications at 1/2x Post or 1x Post resulted in 61% control (Table 9).

When herbicide tank mixtures contained two broadleaf herbicides in which both have activity on redroot pigweed (thifensulfuron plus lactofen, fomesafen, or chlorimuron) control was excellent, regardless of row spacing or rate/timing. The tank mixture containing bentazon and acifluorfen did not control redroot pigweed. Bentazon does not control redroot pigweed (1), and apparently the rate of acifluorfen contained in the formulated premix (191 g/ha) did not provide adequate control.

Common ragweed. In 1994 the row spacing main effect and herbicide tank mixture by rate/timing interaction were significant. Common ragweed control was 82% in narrow rows and 67% in wide rows, averaged over herbicide tank mixtures and rate/timing combinations. Fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen and quizalofop+ thifensulfuron+ chlorimuron applied at 1/4x E Post + 1/4x Post and 1x Post provided greater than 90% control, averaged over row spacings (Table 10). With all four herbicide tank mixtures, applications at 1/4x E Post + 1/4x Post were equal to or greater than 1x Post applications and were greater than 1/2x E Post or 1/2x Post applications. Prostko and Meade (24) also reported greater control of common ragweed with 1/4x + 1/4x sequential applications than with single 1/2x applications. Control with 1/2x E Post applications was less than 1/2x Post applications with three of four tank mixtures, due to later emerging common ragweed, and not due to regrowth (personal observation).

In 1995, control of common ragweed with three of the four herbicide tank mixtures applied at 1/4x E Post + 1/4x Post, 1/2x Post, or 1x Post was similar between row spacings, and ranged from 71% to 98% (Table 13). Control with quizalofop+ thifensulfuron+ chlorimuron was similar between row spacings when applied at 1/2x Post or 1x Post but was reduced in wide rows when applied at 1/4x E Post + 1/4x Post.

Differences in common ragweed control between years may be due to the difference in common ragweed densities. Common ragweed pressure was very high in 1994 (182 plants/m^2), however, in 1995 the common ragweed population was low (7 plants/m^2). When common ragweed was dense, narrow row soybeans improved control, regardless of herbicide tank mixture, and a split application (1/4x E Post + 1/4x Post) was most effective. The most effective herbicide tank mixtures were fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen and quizalofop+ thifensulfuron+ chlorimuron. Greenhouse rate response studies indicated fomesafen was one of the most effective herbicides applied at reduced rates for common ragweed control.

Velvetleaf. Fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen and quizalofop+ thifensulfuron+ chlorimuron, provided greater velvetleaf control in narrow rows compared to wide rows, when averaged over rate/timing combinations (Table 12). Quizalofop+ bentazon&acifluorfen and quizalofop+ thifensulfuron+ chlorimuron, applied at 1x Post controlled velvetleaf, 89% and 97%, respectively, averaged over row spacing (Table 13). Applications of quizalofop+ thifensulfuron+ chlorimuron at 1/4x E Post + 1/4x Post or 1/2x Post were the only reduced rate treatments which provided greater than 80% control of velvetleaf, when averaged over row spacing. Thifensulfuron and chlorimuron were two of the most effective herbicides at reduced rates in greenhouse experiments. Control with 1/2x E Post applications was less than 1/4x E Post + 1/4x Post or 1/2x Post applications with all tank mixtures, due to late emerging velvetleaf. Other researchers have reported reduced control of velvetleaf with early postemergence applications of reduced rates (10, 31).

Weed Biomass. Data analysis revealed no interactions with row spacing. Planting soybeans in narrow rows resulted in 30% less total weed biomass (all species combined) compared to soybeans planted in wide rows. Complete canopy closure occurred much earlier in narrow row soybeans, approximately 50 days after planting, compared to 95 days after planting for wide rows. Researchers in Nebraska and Illinois have reported canopy closure of soybeans planted in 25 cm rows by 35 to 36 days after planting and in 76 cm rows by 58 to 65 days after planting (7, 36). Slower canopy closure in Michigan regardless of row spacing, can probably be attributed to differences in geography, environmental conditions, and soybean cultivars.

In 1994, no differences in weed biomass could be detected between tank mixtures applied at 1x Post (Table 14). In 1995, fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen, and quizalofop+ thifensulfuron+ chlorimuron applied at 1x Post resulted in less weed biomass than clethodim+ thifensulfuron+ lactofen applied at 1x Post. In 1994 and 1995, no difference in weed biomass could be detected between tank mixtures applied at 1/4x E Post +1/4x Post or 1/2x Post and the same tank mixture applied at 1x Post, except for clethodim+ thifensulfuron+ lactofen applied at 1/2x Post in 1995, due to poor annual grass control. All tank mixures applied at 1/2x E Post resulted in greater weed biomass than at 1x Post, due mainly to late emerging annual grass, common ragweed, and velvetleaf.

Soybean Injury. Clethodim+ thifensulfuron+ lactofen caused the greatest soybean injury of the four herbicide tank mixtures 10 days after herbicide application (Table 15). When this tank mixture or quizalofop+ bentazon&acifluorfen, were applied at the early postemergence timing (1/4x E Post + 1/4x Post and 1/2x E Post), in most cases, greater soybean injury occurred than when applied at the standard postemergence timing (1/2x Post and 1x Post). Smaller, younger weeds are more susceptible to postememergence herbicides than larger, more mature weeds (20, 26). Soybeans which were in the cotyledon to unifoliate stage at the early postemergence application may have been more susceptible to injury than soybeans in the 1 to 2 trifoliate stage at the standard postemergence application. Soybeans treated with fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen responded similarly regardless of application rate/timing except at 1/2x Post in 1995 which was greater than other application rate/timing combinations. Quizalofop+ thifensulfuron+ chlorimuron applied at the standard postmergence timing resulted in greater soybean injury than at the early postemergence timing. By 38 days after herbicide application treatments ranged from 0 to 5% injury in 1994 and 0 to 3% injury in 1995 (data not presented).

***Sclerotinia* Stem Rot.** There was no difference in *Sclerotinia* stem rot infection of soybeans between row spacings or herbicide tank mixtures. All postemergence herbicide treatments resulted in greater infection (50 to 75%) than the untreated control (24%). Soybeans applied with a herbicide tank mixture at 1/4x E Post + 1/4x Post resulted in greater infection (71%) than soybeans applied with herbicides at 1/2x Post (58%) or 1x Post (57%), averaged over row spacing and rate/timing combinations. All yield data for 1994 has been adjusted using analysis of covariance, with DSI as the covariate. Yield adjustments ranged from 0 to 256 kg/ha.

Soybean Yield. Planting soybeans in narrow rows resulted in 14% greater soybean yield than soybeans planted in wide rows, averaged over the sixteen postemergence herbicide treatments and two years. There was no difference in soybean yield between row spacings in the weed free control. This suggests the yield advantage in narrow row soybeans was due mainly to improved weed control in narrow rows. Soybean lodging occurred in 1994 and 1995 (personal observation) and may be the reason no yield advantage was seen in narrow row soybeans in the weed free control. Lehman and Lambert (22) reported greater yield in a weed free environment in narrow rows with a short growing cultivar, but no difference in soybean yield between row spacing with a tall growing cultivar which lodged. Soybeans planted in narrow rows at high populations can result in increased plant height which can increase lodging of soybeans (13, 37). This can counteract the yield advantage of narrow rows.

The year by herbicide tank mixture by rate/timing interaction was significant. Therefore, treatment data is presented separately for each year and each of the sixteen postemergence herbicide treatments, but averaged over row spacing. In 1994, no significant difference in soybean yield could be detected between tank mixtures applied at 1x Post (Table 16). In 1995 the highest soybean yield, 4433 kg/ha, was achieved by applying quizalofop+ thifensulfuron+ chlorimuron at 1x Post. Soybeans applied with 1x Post rates of quizalofop+ bentazon&acifluorfen or fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen yielded less (3940 and 3922 kg/ha). Soybeans applied with clethodim+ thifensulfuron+ lactofen yielded the lowest (3450 kg/ha) of all tank mixtures applied at 1x Post. Soybean yield was related to weed biomass.

In 1994 and 1995, all four tank mixtures applied at 1/4x E Post + 1/4x Post resulted in soybean yield similar to the same tank mixture applied at 1x Post. In 1994 three of four tank mixtures applied at 1/2x Post resulted in soybean yield similar to the same tank mixture applied at 1x Post. Soybeans applied with clethodim+ thifensulfuron+ lactofen at 1/2x Post yielded less than when applied at 1x Post. Low soybean yield was a result of high weed biomass. In 1995 two of four tank mixtures, quizalofop+ thifensulfuron+ chlorimuron and fluazifop-P&fenoxaprop+ thifensulfuron+ fomesafen, applied at 1/2x Post resulted in soybean yield similar to soybeans applied with these tank mixtures at 1x Post.

High weed biomass levels present in plots applied at 1/2x E Post resulted in low soybean yields with all four herbicide tank mixtures in both years. Weed control was poor due to weeds which emerged after herbicide application and resulted in severe weed competition.

Economic Analysis. Twelve of the sixteen postemergence herbicide treatments in 1994 and 14 of 16 treatments in 1995 had higher gross margins (≥5% higher) in narrow row soybeans than wide rows (Table 17). All tank mixtures applied at 1/2x E Post resulted in low gross margins. Of the 16 reduced rate treatments which were applied at either 1/4x E Post + 1/4x Post or 1/2x Post in wide row soybeans in 1994 and 1995, 3 treatments resulted in higher gross margins (greater than 5%), 8 treatments resulted in similar gross margins (within 5%), and 5 treatments resulted in lower gross margins (less than 5%) than the gross margin from the full rate treatment (1x Post) of the same tank mixture. Of the 16 reduced rate treatments applied at either 1/4x E Post + 1/4x Post or 1/2x Post in narrow row soybeans in 1994 and 1995, 3 treatments resulted in higher gross margins, 7 treatments resulted in similar gross margins, and 6 treatments resulted in lower gross margins than the gross margin from the full rate treatment of the same tank mixture. Gross margins from full rate treatments varied with herbicide tank mixture.

The results of this study show that adequate weed control can be achieved using reduced rates of postemergence herbicide tank mixtures in Michigan. Generally, herbicides applied at 1/4x E Post + 1/4x Post provided more consistent weed control than single applications of 1/2x rates, as was previously reported by other researchers (11, 24, 31). Herbicides applied at 1/2x E Post did not provide season long control of annual grass, common ragweed, or velvetleaf, because of weed emergence after the herbicide application. Other researchers have reported reduced weed control when herbicides were applied at an early application timing (10, 31) or if cool damp soil conditions delayed weed emergence (11). However some studies have shown that applying a reduced rate at an early application timing provided weed control equal to a full rate application at a standard timing (11).

Greater weed control was achieved in narrow rows compared to wide rows with full and reduced rate treatments. The soybean canopy closed much earlier in the season with narrow rows. This improved weed control by suppressing late emerging weeds and weeds which were not completely killed by a postemergence herbicide application. DeFelice et al. (10) commented that better weed control was observed with reduced rates in drilled soybean studies than in wide row studies. Research has shown that a timely cultivation can improve weed control with reduced rates (12, 31). A cultivation probably would have improved weed control in wide row soybeans, however by planting soybeans in narrow rows, improved weed control was achieved without requiring the added time and expense of a cultivation. Results from this study also indicate that a total postemergence herbicide program, using tank mixtures of grass and broadleaf herbicides, can be used at reduced rates to control a broadspectrum of weeds. However, careful selection of herbicides must be exercised, in order to avoid antagonistic interactions between herbicides. The yield advantage observed in narrow row soybeans can probably be attributed mainly to improved weed control, because no difference in soybean yield was observed between row spacings in the weed free control. Even though the potential for higher yields in narrow row soybeans exists (4, 5, 33), often yield enhancement in narrow row soybeans does not occurr in weed free environments (9, 13, 17, 22). Soybeans treated with a split herbicide application (1/4x E Post + 1/4x Post) consistently resulted in soybean yields equal to that of full rate treatments. Other researchers report similar results (10, 11). Applying herbicides in a split application can allow growers to reduce their herbicide input costs and consistently maintain soybean yield, however the additional time required for the second application is a drawback.

Calculation of gross margins showed that when using full or reduce rates, in most cases it was more profitable to plant soybeans in narrow rows. In some cases it was more profitable to use a reduced rate of a herbicide tank mixture compared to a full rate of the same tank mixture, justifying the added risk involved. In other cases gross margins with reduced rates were similar or less than using full rates, indicating the added risk may not be justified. However it is difficult to confidently judge profitability based on a direct comparison of gross margins because the gross margins were highly influenced by soybean yield and do not account for the experimental error associated with the soybean yield data, and because soybean prices and input costs can vary greatly. Perhaps the best assessment of profitability is to simply compare input costs of full and reduced rate treatments if soybean yields do not significantly differ.

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Table 1. Height of weed species at the time of herbicide application.

Weed species	Weed height			
	Early Post[a]		Post	
	1994	1995	1994	1995
	cm			
Giant foxtail	3	2	10-15	10-15
Common lambsquarters	3	2	5-10	4-6
Redroot pigweed	3	2	5-10	4-6
Common ragweed	3	2	7-10	4-8
Velvetleaf	-	2	-	3-6

[a]Early Post = early postemergence herbicide application, applied May 28, 1994 and May 26, 1995. Post = standard postemergence herbicide application, applied June 9, 1994 and 1995.

Table 2. Influence of herbicide tank mixture and soybean row spacing on annual grass control in 1994[1].

Herbicide tank mixture	Annual grass control[2,3]	
	Wide	Narrow
	---------------------%---------------------	
Clethodim + thifensulfuron + lactofen + NIS	66 c	73 abc
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	68 bc	77 ab
Quizalofop + bentazon & acifluorfen + COC	78 a	69 abc
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	70 abc	76 ab

[1]Means averaged over rate/timing combinations. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid within and across columns.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

[3]Wide = soybeans planted in 76 cm rows, Narrow = soybeans planted in 19 cm rows.

Table 3. Control of annual grass in soybeans with reduced rates of postemergence herbicides in 1994 and 1995[1].

Herbicide tank mixture	Rate/timing	Annual grass control[2]	
		1994	1995
		%	
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	88 ab	70 b
	1/2x E Post	3 d	11 d
	1/2x Post	95 a	39 c
	1x Post	92 a	71 b
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	91 ab	93 a
	1/2x E Post	19 c	32 c
	1/2x Post	87 ab	95 a
	1x Post	95 a	94 a
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	86 ab	95 a
	1/2x E Post	24 c	20 d
	1/2x Post	92 a	97 a
	1x Post	93 a	99 a
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	78 b	96 a
	1/2x E Post	28 c	10 d
	1/2x Post	91 a	90 a
	1x Post	94 a	96 a

[1]Means averaged over row spacing. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within years.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

Table 4. Influence of herbicide tank mixture and soybean row spacing on common lambsquarters control in 1994 and 1995[1].

Herbicide tank mixture	Common lambsquarters control[2,3]			
	1994		1995	
	Wide	Narrow	Wide	Narrow
	---------------------- % ----------------------			
Clethodim + thifensulfuron + lactofen + NIS	86 b	95 a	81 cde	80 cde
Fluazifop-P&fenoxaprop + thifensulfuron +fomesafen + UAN +NIS	85 b	94 a	78 de	89 ab
Quizalofop + bentazon & acifluorfen + COC	94 a	95 a	73 e	87 bc
Quizalofop + thifensulfuron + chlorimuron +UAN + NIS	95 a	95 a	83 bcd	96 a

[1]Means averaged over rate/timing combinations. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid within and across columns within a year. Comparisons are not valid between years.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

[3]Wide = soybeans planted in 76 cm rows, Narrow = soybeans planted in 19 cm rows.

Table 5. Influence of application rate and timing, and soybean row spacing on common lambsquarters control in 1994 and 1995[1].

Rate/timing	Common lambsquarters control[2,3]			
	1994		1995	
	Wide	Narrow	Wide	Narrow
	-------------------------------%-------------------------------------			
1/4x + 1/4x	90 b	95 a	88 ab	94 a
1/2x E Post	93 a	95 a	89 a	90 a
1/2x Post	89 b	95 a	68 c	81 b
1x Post	86 c	94 a	70 c	87 ab

[1]Means averaged over herbicide tank mixtures. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid within and across columns within a year. Comparisons are not valid between years.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

[3]Wide = soybeans planted in 76 cm rows, Narrow = soybeans planted in 19 cm rows.

Table 6. Control of common lambsquarters in soybeans with reduced rates of postemergence herbicides in 1994 and 1995[1].

Herbicide tank mixture	Rate/timing	Common lambsquarters control[2]	
		1994	1995
		--------------------%--------------------	
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	88 cd	83 abc
	1/2x E Post	94 ab	78 bcd
	1/2x Post	91 abc	77 bcd
	1x Post	90 bc	83 abc
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	93 ab	94 a
	1/2x E Post	93 ab	94 a
	1/2x Post	88 cd	77 bcd
	1x Post	84 d	68 de
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	95 a	93 a
	1/2x E Post	95 a	92 a
	1/2x Post	95 a	61 e
	1x Post	93 ab	75 cd
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	95 a	92 a
	1/2x E Post	95 a	94 a
	1/2x Post	94 a	84 abc
	1x Post	95 a	87 ab

[1]Means averaged over row spacings. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within years.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

Table 7. Control of redroot pigweed in soybeans with reduced rates of postemergence herbicides in 1994[1].

Herbicide tank mixture	Rate/timing	Redroot pigweed control[2,3]	
		Wide	Narrow
		%	
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	99 a	99 a
	1/2x E Post	99 a	99 a
	1/2x Post	99 a	99 a
	1x Post	99 a	99 a
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	99 a	99 a
	1/2x E Post	84 ab	84 ab
	1/2x Post	96 a	98 a
	1x Post	98 a	98 a
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	40 d	49 d
	1/2x E Post	67 c	44 d
	1/2x Post	76 bc	84 ab
	1x Post	54 d	87 ab
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	99 a	99 a
	1/2x E Post	99 a	99 a
	1/2x Post	99 a	99 a
	1x Post	99 a	99 a

[1]Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid within and across columns.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

[3]Wide = soybeans planted in 76 cm rows, Narrow = soybeans planted in 19 cm rows.

Table 8. Influence of herbicide tank mixture and soybean row spacing on redroot pigweed control in 1995[1].

Herbicide tank mixture	Redroot pigweed control[2,3]	
	Wide	Narrow
	%	
Clethodim + thifensulfuron + lactofen + NIS	98 a	97 a
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	95 a	98 a
Quizalofop + bentazon & acifluorfen + COC	57 c	85 b
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	96 a	99 a

[1]Means averaged over rate/timing combinations. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid within and across columns.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

[3]Wide = soybeans planted in 76 cm rows, Narrow = soybeans planted in 19 cm rows.

Table 9. Control of redroot pigweed in soybeans with reduced rates of postemergence herbicides in 1995[1].

Herbicide tank mixture	Rate/timing	Redroot pigweed control[2]
		----------%----------
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	99 a
	1/2x E Post	93 a
	1/2x Post	99 a
	1x Post	99 a
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	98 a
	1/2x E Post	98 a
	1/2x Post	94 a
	1x Post	96 a
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	82 b
	1/2x E Post	81 b
	1/2x Post	61 c
	1x Post	61 c
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	99 a
	1/2x E Post	97 a
	1/2x Post	96 a
	1x Post	99 a

[1]Means averaged over row spacing. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

Table 10. Control of common ragweed in soybeans with reduced rates of postemergence herbicides in 1994[1].

Herbicide tank mixture	Rate/timing	Common ragweed control[2]
		-----------%----------
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	80 cd
	1/2x E Post	66 ef
	1/2x Post	54 fg
	1x Post	85 abc
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	99 a
	1/2x E Post	58 efg
	1/2x Post	81 cd
	1x Post	97 ab
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	84 bc
	1/2x E Post	34 h
	1/2x Post	51 g
	1x Post	69 de
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	95 ab
	1/2x E Post	69 de
	1/2x Post	81 cd
	1x Post	91 abc

[1]Means averaged over row spacing. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

Table 11. Control of common ragweed in soybeans with reduced rates of postemergence herbicides in 1995[1].

Herbicide tank mixture	Rate/timing	Common ragweed control[2,3]	
		Wide	Narrow
		---------%---------	
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	93 abc	94 abc
	1/2x E Post	68 ef	92 abc
	1/2x Post	86 abcde	88 abcd
	1x Post	95 abc	96 ab
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	97 a	98 a
	1/2x E Post	92 abc	92 abc
	1/2x Post	71 def	81 abcde
	1x Post	91 abc	97 a
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	84 abcde	92 abc
	1/2x E Post	91 abc	76 cdef
	1/2x Post	71 def	78 bcdef
	1x Post	79 abcde	83 abcde
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	61 f	98 a
	1/2x E Post	68 ef	60 f
	1/2x Post	81 abcde	89 abcd
	1x Post	80 abcde	98 a

[1]Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid within and across columns.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

[3]Wide = soybeans planted in 76 cm rows, Narrow = soybeans planted in 19 cm rows.

Table 12. Influence of herbicide tank mixture and soybean row spacing on velvetleaf control in 1995[1].

Herbicide tank mixture	Velvetleaf control[2,3]	
	Wide	Narrow
	--------------------%--------------------	
Clethodim + thifensulfuron + lactofen + NIS	58 c	63 bc
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	41 d	71 b
Quizalofop + bentazon & acifluorfen + COC	56 c	56 c
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	70 b	84 a

[1]Means averaged over rate/timing combinations. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid within and across columns.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

[3]Wide = soybeans planted in 76 cm rows, Narrow = soybeans planted in 19 cm rows.

Table 13. Control of velvetleaf in soybeans with reduced rates of postemergence herbicides in 1995[1].

Herbicide tank mixture	Rate/timing	Velvetleaf control[2]
		-----------%----------
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	72 bcd
	1/2x E Post	25 f
	1/2x Post	67 cde
	1x Post	78 bc
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	75 bcd
	1/2x E Post	30 f
	1/2x Post	60 de
	1x Post	60 de
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	51 e
	1/2x E Post	24 f
	1/2x Post	59 de
	1x Post	89 ab
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	81 abc
	1/2x E Post	34 f
	1/2x Post	96 a
	1x Post	97 a

[1]Means averaged over row spacing. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test.

[2]Visual injury ratings were made 38 days after the standard postemergence herbicide application timing.

Table 14. Influence of various rates of postemergence herbicides on weed biomass in 1994 and 1995[1].

Herbicide tank mixture	Rate/timing	Weed biomass	
		1994	1995
		------------------g/m^2------------------	
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	43 e	84 bcd
	1/2x E Post	379 a	212 a
	1/2x Post	102 cde	236 a
	1x Post	40 e	125 b
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	30 e	35 d
	1/2x E Post	193 b	203 a
	1/2x Post	53 de	62 cd
	1x Post	27 e	48 cd
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	74 de	52 cd
	1/2x E Post	195 b	242 a
	1/2x Post	133 bcd	93 bc
	1x Post	85 de	92 bc
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	127 bcd	53 cd
	1/2x E Post	178 bc	223 a
	1/2x Post	37 e	57 cd
	1x Post	53 de	35 d
Untreated		338	461
Weedfree		0	0
Preemergence standard		363	139
Mechanical control only		286	289

[1]Means averaged over row spacing. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within years.

Table 15. Injury to soybean from postemergence herbicides in 1994 and 1995[1].

Herbicide tank mixture	Rate/timing	Soybean visual injury[2] 1994	1995
		--------------------%--------------------	
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	16 b	22 ab
	1/2x E Post	22 a	24 a
	1/2x Post	12 c	14 def
	1x Post	11 c	18 bc
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	6 d	9 hi
	1/2x E Post	7 d	13 efg
	1/2x Post	6 d	8 hi
	1x Post	5 d	8 hi
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	7 d	15 cde
	1/2x E Post	13 bc	17 cd
	1/2x Post	8 d	11 fgh
	1x Post	11 c	9 ghi
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	0 e	3 jk
	1/2x E Post	0 e	2 k
	1/2x Post	5 d	6 ij
	1x Post	8 d	14 cdef

[1]Means averaged over row spacing. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within years.

[2]Visual injury ratings presented are taken 10 days after the early postemergence herbicide application for 1/4x E Post + 1/4x Post and 1/2x E Post timings, and 10 days after standard postemergence herbicide application for 1/2x Post and 1x Post timings.

Table 16. Influence of various rates of postemergence herbicides on soybean yield in 1994 and 1995[1].

Herbicide tank mixture	Rate/timing	Yield[2]	
		1994	1995
		------------------kg/ha------------------	
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	2255 abcd	3469 d
	1/2x E Post	1318 e	2485 e
	1/2x Post	1755 de	2555 e
	1x Post	2413 ab	3450 d
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	2357 abc	4260 ab
	1/2x E Post	1747 de	2679 e
	1/2x Post	2403 ab	3740 cd
	1x Post	2634 a	3922 bc
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	2430 ab	4163 abc
	1/2x E Post	1938 bcd	2412 e
	1/2x Post	1929 bcd	3470 d
	1x Post	2340 abc	3940 bc
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	2510 a	4140 abc
	1/2x E Post	1828 cde	2549 e
	1/2x Post	2372 abc	4126 abc
	1x Post	2326 abc	4433 a
Untreated		1050	1030
Weedfree		2867	4611
Preemergence standard		1219	4097
Mechanical control only		1651	2562

[1]Means averaged over row spacing. Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test. Mean comparisons are valid only within years.

[2]1994 data presented is the adjusted yield. Soybean yields were adjusted using analysis of covariance, with *Sclerotinia* stem rot disease severity index rating as the covariate.

Table 17. Gross margin of soybean treatments in 1994 and 1995.

Herbicide tank mixture	Rate/timing	Gross margins[1]			
		1994		1995	
		Wide	Narrow	Wide	Narrow
		-----------------$/ha-----------------			
Clethodim + thifensulfuron + lactofen + NIS	1/4x+1/4x	320^{-}	433^{+}	596^{+}	636$^{=}$
	1/2x E Post	139^{-}	257^{-}	399^{-}	468^{-}
	1/2x Post	262^{-}	309^{-}	417^{-}	474^{-}
	1x Post	379	397	531	660
Fluazifop-P&fenoxaprop + thifensulfuron + fomesafen + UAN +NIS	1/4x+ 1/4x	339^{-}	437$^{=}$	711^{+}	827^{+}
	1/2x E Post	275^{-}	283^{-}	468^{-}	467^{-}
	1/2x Post	391$^{=}$	428$^{=}$	656$^{=}$	698$^{=}$
	1x Post	397	447	637	721
Quizalofop + bentazon & acifluorfen + COC	1/4x+ 1/4x	398$^{=}$	421^{+}	724^{+}	788$^{=}$
	1/2x E Post	285^{-}	365$^{=}$	366^{-}	475^{-}
	1/2x Post	322^{-}	322^{-}	637$^{=}$	623^{-}
	1x Post	378	375	624	769
Quizalofop + thifensulfuron + chlorimuron + UAN + NIS	1/4x+ 1/4x	440^{+}	410$^{=}$	698$^{=}$	804^{-}
	1/2x E Post	230^{-}	377^{-}	401^{-}	498^{-}
	1/2x Post	408^{+}	412$^{=}$	717$^{=}$	804^{-}
	1x Post	317	424	715	875
Preemergence standard		104	189	711	742
Mechanical control only		349	266	656	327

[1](+) indicates the gross margin of the reduced rate treatment was greater than (5% or more) the gross margin of the same tank mixture applied at a full rate; (=) indicates the gross margin of the reduced rate treatment was within 5% of the gross margin of the same tank mixture applied at a full rate; (-) indicates the gross margin of the reduced rate treatment was lower than (5% or more) the gross margin of the same tank mixture applied at a full rate. Comparisons of gross margins using these symbols are valid only within a tank mixture, row spacing, and year.