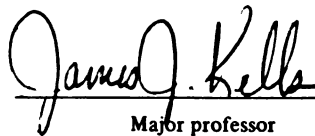




This is to certify that the
thesis entitled
Horseweed [Conyza canadensis (L.) Cronq.] Management
in No-Tillage Soybean Production

presented by
Joseph Alan Bruce

has been accepted towards fulfillment
of the requirements for
M.S. degree in Crop and Soil Sciences


Major professor

Date 8/7/89

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.

DATE DUE DATE DUE DATE DUE		
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

MSU Is An Affirmative Action/Equal Opportunity Institution

**HORSEWEED [*Coryza canadensis* (L.) Cronq.] MANAGEMENT
IN NO-TILLAGE SOYBEAN PRODUCTION**

By

Joseph A. Bruce

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

1989

6001464

ABSTRACT

HORSEWEED [*Coryza canadensis* (L.) Cronq.] MANAGEMENT IN NO-TILLAGE SOYBEAN PRODUCTION

By

Joseph A. Bruce

Research was conducted in Michigan in 1986, 1987 and 1988 to identify consistent and effective herbicide programs for control of horseweed in no-tillage soybean production. Horseweed densities as low as 13 plants/m² significantly reduced soybean yield by 29% as compared to a weed-free environment. Preemergence application of paraquat (0.56 kg/ha) plus metolachlor (2.24 kg/ha) plus linuron (0.84 kg/ha) plus non-ionic surfactant (0.25% v/v) provided less than 60% horseweed control. Early pre-plant applications of glyphosate (0.84 kg/ha), 2,4-D ester (0.56 kg/ha), HOE-39866 (0.84 kg/ha) or BAS-514 (0.07 kg/ha) provided greater than 95% horseweed control when followed by the preemergence application of paraquat plus linuron plus metolachlor plus surfactant. The substitution of glyphosate or HOE-39866 for paraquat in the above preemergence treatment significantly improved horseweed control. Horseweed control improved significantly when metribuzin, metribuzin plus chlorimuron (10:1) or linuron plus chlorimuron (16:1) was substituted for linuron in the preemergence treatment containing paraquat. Postemergence application of selective foliar herbicides and ropewick application of glyphosate did not provide consistent and effective horseweed control. Nomenclature: glyphosate, *N*-(phosphonomethyl)glycine; 2,4-D, (2,4-dichlorophenoxy)acetic acid; HOE-39866, ammonium-(3-amino-3-carboxypropyl)-methyl-phosphinate; BAS-514, 3,7-dichloro-8-quinoline carboxylic acid; paraquat, 1-

1'-dimethyl-4,4'-bipyridinium ion; linuron, *N*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea; metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide; metribuzin, 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one; chlorimuron, 2-[[[[[4-chloro-6-methoxy-2-pyrimidinyl]amino]carbonyl]amino]sulfonyl] benzoic acid; horseweed, *Conyza canadensis* (L.) Cronq.; soybean, *Glycine max* (L.) Merr.

ACKNOWLEDGEMENTS

I would like to thank my graduate committee, Dr. Jim Kells, Dr. Don Penner, Dr. Alan Putnam and Dr. Stephen Stephenson for their contributions to this research. I wish to sincerely thank my major advisor, Jim Kells, for his valuable ideas and assistance during this project. A very special thanks to Geoff List for his valuable assistance in the field. Without his help, this project would not have been nearly as successful. Thanks to Jim, Rich Zollinger and especially Geoff and Jay Schmidt for their friendship and ability to make the long days a little shorter.

A very special thank you goes to my wife, Kathy, for her assistance, patience and love which made life more enjoyable.

TABLE OF CONTENTS

	PAGE
LIST OF TABLES	vii
 CHAPTER 1: REVIEW OF LITERATURE	
NO-TILLAGE SOYBEAN PRODUCTION	1
Introduction	1
Adaptions for No-tillage Soybeans	3
Weed Control in No-tillage Soybean Production	5
HORSEWEED BIOLOGY	9
Introduction	9
Life Cycle	10
Allelopathy	12
Ecology and Competition	12
Horseweed in No-tillage Production	14
CHEMICAL CONTROL OF HORSEWEED IN NO-TILLAGE SOYBEANS	15
Introduction	15
Early Preplant Herbicide Applications	16
Preemergence Herbicide Applications	18
Postemergence Horseweed Control	19
BIBLIOGRAPHY	20
 CHAPTER 2: HORSEWEED [<i>Conyza canadensis</i> (L.) Cronq.]	
INTERFERENCE IN NO-TILLAGE SOYBEAN PRODUCTION	
ABSTRACT	25
INTRODUCTION	27
MATERIALS AND METHODS	28
RESULTS AND DISCUSSION	32
BIBLIOGRAPHY	39

TABLE OF CONTENTS (cont'd)

	PAGE
CHAPTER 3: EARLY PREPLANT AND PREEMERGENCE CONTROL OF HORSEWEED [<i>Coryza canadensis</i> (L.) Cronq.] IN NO-TILLAGE SOYBEANS	
ABSTRACT	41
INTRODUCTION	43
MATERIALS AND METHODS	44
RESULTS AND DISCUSSION	47
Early Preplant Applications	47
Preemergence Applications	52
Sequential Applications	56
BIBLIOGRAPHY	59
CHAPTER 4: HORSEWEED [<i>Coryza canadensis</i> (L.) Cronq.] CONTROL WITH FOLIAR APPLIED HERBICIDES	
ABSTRACT	61
INTRODUCTION	63
MATERIALS AND METHODS	64
Nonselective Herbicide Applications	64
Selective Herbicide Applications	65
Ropewick Application of Glyphosate	68
RESULTS AND DISCUSSION	69
Nonselective Herbicide Applications	69
Selective Herbicide Application	71
Ropewick Application of Glyphosate	77
BIBLIOGRAPHY	80

LIST OF TABLES

TABLE	PAGE
CHAPTER 2:	
1. Soybean plant populations for each of three soybean row spacings	29
2. Herbicide programs and corresponding herbicide rates	31
3. Total and average monthly rainfall for Cass County, Michigan for 1986, 1987 and 1988	33
4. Results from 1987 horseweed interference research conducted in Cass County, Michigan	34
5. Results from 1988 horseweed interference research conducted in Cass County, Michigan	35
CHAPTER 3:	
1. Environmental conditions for early preplant and preemergence application of herbicides	46
2. Total and average monthly rainfall in Cass County, Michigan for 1986, 1987 and 1988.	48
3. Early season horseweed control, horseweed density, soybean injury and late season horseweed control as affected by early preplant herbicide application	49
4. Early season horseweed control, horseweed density, soybean injury and late season horseweed control as affected by preemergence herbicide application	53
5. Early season horseweed control, horseweed density, soybean injury and late season horseweed control as affected by preemergence application of soil active herbicides	55
6. Comparison of single preemergence and sequential application of soil active herbicides for control of horseweed	58

LIST OF TABLES (cont'd)

TABLE	PAGE
CHAPTER 4:	
1. Environmental conditions for nonselective foliar herbicide applications in 1987 and 1988	66
2. Environmental conditions for selective foliar herbicide applications in 1987 and 1988	67
3. Horseweed control provided by nonselective foliar applied herbicides as affected by horseweed height at application	70
4. Total and average monthly rainfall for the nonselective herbicide research conducted in 1987 and 1988	72
5. Total and average monthly rainfall for selective foliar herbicide research conducted in 1987 and 1988, Shiawassee County	73
6. Horseweed control provided by selective foliar applied herbicides as affected by horseweed height at application	74
7. Ropewick application of glyphosate for controlling horseweed and reducing flower production in 1987	78

CHAPTER 1

REVIEW OF LITERATURE

NO-TILLAGE SOYBEAN PRODUCTION

Soil tillage has played an important role in crop production. The primary reason for its use has been weed control. Spring tillage will destroy existing vegetation and create an even-start condition for both crop and weed seeds (Staniforth and Wiese, 1985). Tillage has also been important for incorporation of herbicides, fertilizers and previous crop residue, control of insects and diseases, as well as soil aeration and removal of previous crop residue (Phillips, 1984). Crop producers generally believe that a well prepared seedbed is necessary to promote rapid crop seed germination.

No-tillage crop production, often called no-till or zero-till, is the production of crops without the use of tillage prior to planting. This production method has become increasing popular during the past decade. Michigan full season no-tillage soybean production increased from 405 hectares in 1978 to 27,900 hectares in 1988 according to Quisenberry (1988a). National no-tillage soybean production was 4.6×10^6 hectares in 1988, a 16.9% increase since 1987 (Conservation Technology Information Center, 1988).

No-tillage crop production has many advantages and disadvantages as compared to conventional tillage systems. Phillips and Phillips (1984) noted these advantages:

1. Reduced soil erosion
2. Ability to crop erosive soils
3. Decreased labor requirements (up to 50%)

4. Decreased fuel consumption

5. Decreased equipment costs

Reducing both soil erosion and crop production inputs have become increasingly important to soybean producers. The United States government recently passed a farm bill, effective 1990, which will require producers to reduce erosion of highly erodible soils to acceptable levels in order to qualify for governmental financial assistance (Quisenberry, 1988b). Producers are also faced with lower commodity prices which have forced them to decrease production inputs to maintain profit levels. These factors are a few of the many reasons for the increase in no-tillage soybean production.

There are several disadvantages to no-tillage soybean production (Phillips and Phillips, 1984). No-tillage planting operations are sometimes delayed due to higher soil moisture content and lower soil temperatures than experienced in conventional tillage systems. Delayed planting dates can often result in decreased soybean yields. In Michigan, soybean yields decline approximately 63 kg/ha per day if planted after May 10 according to Hesterman *et al.* (1987). Incidence of disease, insect and rodent damage are also more prevalent in no-tillage crop production (Phillips and Phillips, 1984). The large quantity of crop residue remaining on the soil surface in no-tillage production favors the incidence of insects and diseases which overwinter in these residues. The use of tillage will bury residues thus reducing the incidence of insect and disease problems. According to Crosson (1981), the incidence of soybean insects is not influenced by tillage, however, soybean disease incidence increases as the amount of tillage is reduced. Weed control is the most important disadvantage in no-tillage systems. Sanford *et al.* (1973) has reported weed control as being the most common deterrent to successful no-tillage soybean production. In the absence of tillage, producers generally rely entirely upon herbicides to control all weeds. Should herbicides fail, mechanical row cultivation often provides ineffective weed control due to the

firm soil conditions (Richey *et al.*, 1977). Advances in agriculture are helping to solve these problems. Changes in cultural practices and crop management combined with an increasing number of herbicides available to the producer are making no-tillage soybean production a good alternative to conventional tillage production.

Adaptations for No-Tillage Soybeans

No-tillage soybean production has become possible through modification of planting and cultural practices to overcome previous crop residue and soil conditions. According to Sprague and Triplett (1986), conventional tillage systems may have only 2-5% soil surface coverage by crop residue the spring following soybeans or corn. In no-tillage, however, crop residues may cover 60-80% of the soil surface the following spring. The absence of tillage also increases the soil water content (Thomas, 1986; Phillips and Phillips, 1984; Unger and McCalla, 1980). This is attributed in part to increased water infiltration due to improved soil structure and increased soil porosity (Triplett *et al.* 1968). Thomas (1986) reported that increased plant residue acts as a barrier which prevents diffusion of water vapor from the soil. This residue also reflects more incoming light than bare soil, resulting in decreased soil temperatures and reduced evaporation of water. Through different planting and cultural methods, several of these obstacles have been overcome.

Planting equipment has been modified by adding coulters which effectively cut through crop residue. The coulters slice through residue and at the same time loosen the soil. The planting unit follows in the same path and places the soybean seed in the loosened soil. The seeds are then covered and packed firmly by specially designed press wheels to obtain good seed to soil contact.

The incidence of disease damage is more prevalent in no-tillage soybean production. The use of crop rotation combined with disease resistant soybean varieties can help overcome these problems. In a 20 year comparison of no-tillage and conventional till soybeans, Dick and Van Doren (1977) found a higher incidence of phytophthora root rot and lower grain yields in no-tillage soybeans than in conventional till. The use of resistant soybean varieties combined with crop rotation resulted in equivalent soybean grain yields for the two tillage systems.

A common adaptation in no-tillage soybean production is the shift to narrower soybean row spacings. Research has proven that reducing row spacing from 102 cm to 51 cm or less will improve soybean grain yields (Wax and Pendleton, 1968; Lehman and Lambert, 1960; Peters *et al.*, 1965; Burnside and Colville, 1963). When compared to 102 cm rows, Burnside and Colville (1963) found a 39, 17 and 5% increase in soybean grain yield for 25, 51 and 76-cm row spacings, respectively. Wax and Pendleton (1968) reported a similar soybean yield trend. Wax and Pendleton (1968) as well as Peters *et al.* (1965) observed greater weed control when soybeans were planted in narrow row spacing. Increased soybean grain yield and weed control provides very strong incentives for no-tillage soybean producers to switch to narrow row soybean production.

Yield potential is a very important factor influencing the adoption of no-tillage soybean production. Producers will not utilize no-tillage production if soybean yields are inferior to those obtained in conventional tillage systems. Current research has shown that no-tillage soybean production will produce equivalent or greater soybean yields under certain conditions. Soil type appears to be very critical. According to Dick and Van Doren (1985) and Unger and McCalla (1980), no-tillage soybean generally have lower yields than conventional tillage soybeans when planted in soils with high water holding capacity. No-tillage has produced equal or greater soybean yield than conventional till in soils with low

to moderate water holding capacity and during years of low rainfall (Unger and McCalla, 1980; Dick and Van Doren, 1985; Tyler and Overton, 1982; Edwards *et al.*, 1988). Tyler and Overton (1982) also reported greater soybean seed quality from no-tillage than conventional tillage systems during a hot dry year.

The most common deterrent to successful no-tillage soybean production is weed control (Sanford *et al.* 1973). Kapusta (1979) found that in two out of three years, method of tillage did not influence soybean yields. However, this was only true when similar acceptable weed control was obtained.

Weed Control in No-tillage Soybean Production

Weed control is an essential component of any production system. Conventional tillage utilizes soil disturbance to control existing spring vegetation prior to crop planting. After crop emergence, row cultivation is often used to remove weeds not effectively controlled by herbicides. In no-tillage production, producers must rely upon a combination of cultural methods and herbicides to effectively control weeds.

According to Triplett *et al.* (1964), an effective no-tillage herbicide program must incorporate the following concepts or elements:

1. Obtain complete control of all existing vegetation prior to soybean planting
2. Exhibit growth suppression of annual and perennial weed seedings
3. Induce no injury to the present crop
4. Induce no injury to the succeeding crop
5. Be competitive in cost with alternative weed control techniques

Through the use of cultural and chemical weed control, no-tillage soybean weed control has become increasingly successful.

Cultural weed control in no-tillage consists of planting optimum soybean populations and utilizing narrow row spacings to maximize soybean competition with weeds. McWhorter and Barrentine (1975) observed increased weed control as soybean populations increased from 80,000 to 350,000 plants/ha. Reducing soybean row spacing reduces weed dry weight. Burnside and Colville (1963) reported average total weed dry weights of 190, 190, 314 and 347 kg/ha in 25, 51, 76 and 102-cm soybean row spacings. The time period for canopy closure was 36, 47, 58 and 67 days after planting for 'Ford' soybeans in 25, 51, 76 and 102-cm rows, respectively. Wax and Pendleton (1968) reported canopy closure for 'Wayne' soybeans in 35, 50, 65 and 80 days when planted in 25, 51, 76 and 102-cm row spacings, respectively. Rapid canopy development shades the soil surface and thus inhibits weed germination and growth of established weed seedlings. The use of these cultural practices can further enhance herbicidal effectiveness.

Effective season-long weed control in no-tillage soybean production requires the use of several herbicide types. Fawcett (1983) and Fawcett *et al.* (1983) stated that control of all established vegetation prior to soybean emergence is essential. A nonselective foliar active herbicide such as glyphosate [*N*-(phosphonomethyl) glycine] or paraquat [1-1'-dimethyl-4-4'-bipyridinium ion] is most commonly used. Nonselective herbicides are usually applied after planting but prior to soybean emergence. This preemergence (PRE) approach generally utilizes soil active herbicides in combination with the nonselective herbicide. Soil active herbicides are used to provide control of germinating weed seedlings for an extended time period. The PRE herbicide program provides effective season-long weed control. Since the soil active herbicides are applied to the soil surface, rainfall is required for moving the herbicide into the soil for effective weed control (Fawcett, 1983; Fawcett *et al.*, 1983). Despite the risk of inadequate rainfall, PRE herbicide programs are the standard weed control programs used by no-tillage crop producers (Kapusta, 1979).

The early preplant (EPP) herbicide program was developed to overcome the disadvantages of preemergence applications (Fawcett, 1983; Fawcett *et al.*, 1983). In this program (EPP), soil active herbicides are applied prior to weed seed germination. Early applications reduce the risk of herbicide failure due to dry weather since there is a greater probability of rain prior to weed seed germination. This approach usually eliminates the need for a nonselective postemergence herbicide. Possible causes of reduced weed control in this approach are: (1) herbicide degradation prior to crop planting, and (2) disruption of the herbicide layer by planting operations. To overcome these shortcomings, sequential or split herbicide applications were used. In this approach a portion of the total herbicide rate is applied EPP followed by a PRE application of the remaining portion of herbicide after crop planting (Fawcett, 1983; Fawcett *et al.*, 1983).

Postemergence herbicide programs are also utilized to provide effective season-long weed control. A total postemergence weed control program utilizes a nonselective herbicide to destroy all existing vegetation prior to planting. Approximately four to six weeks after planting, selective postemergence herbicides are applied for control of existing broadleaf and grassy weed species. Selective postemergence herbicides are commonly used to control weeds when soil active herbicides fail to provide effective weed control.

Following several years of no-tillage production, researchers have seen changes in the weed species composition of a field. Conventional tillage systems contain predominately annual grasses and broadleaves. However, in the absence of tillage, populations of annual grasses and perennial weeds often increase (Phillips and Phillips, 1984; Buhler and Oplinger, 1989; Staniforth and Wiese, 1985; Triplett and Lytle, 1972). No-tillage soybean production has its own unique shift in weed composition. Horseweed [*Conyza canadensis* (L.) Cronq.] has become a serious problem in no-tillage soybean production. Kapusta (1979) reported horseweed in no-tillage soybeans at populations of 24,000, 12,000 and 96,000 plants/ha over

a three-year period compared to no horseweed in areas receiving tillage. He also observed a high density of horseweed in a first year no-tillage field following 20 consecutive years of conventional tillage cropping. Brown and Whitwell (1988) and Elmore and Heatherly (1983) have also reported horseweed populations in the absence of tillage but a shallow disking eliminated the weed.

HORSEWEED BIOLOGY

Horseweed [*Conyza canadensis* (L.) Cronq.] is commonly referred to as marestail. This species, originally identified by Linnaeus as *Erigeron canadensis* (L.), is referred to by both names in the literature. This species has been identified as having three different varieties, 'canadensis' (most common), 'pusilla' and 'glabrata' according to Cronquist (1947).

This annual composite normally has a stout unbranched erect stem reaching heights of 0.3-1.8 m. The stem is also covered with bristly hairs. Horseweed plants have linear leaves which lack petioles. The leaves have toothed or entire margins with coarse white bristly hair on the leaf surface. The plant produces numerous small greenish or pinkish white flowers in axillary panicles with a narrow pointed bract at the base of each head. Flowers produce very small (1.5 mm) seeds which are attached to a pappus (Anonymous, 1981). Horseweed is commonly found in pastures, roadsides, waste areas and undisturbed or abandoned agricultural fields (Regehr and Bazzaz, 1979; Hopkins and Wilson, 1974; Anonymous, 1981; Cronquist, 1980; Brown and Whitwell, 1988; Kapusta, 1979). The horseweed variety 'canadensis' has a hairy stem and green involucre bracts (Gleason and Cronquist, 1963). This common variety is found in all portions of the United States according to Cronquist (1980). The variety 'pusilla' is found along the eastern coastal area from Connecticut to tropical America. The variety has a nearly glabrous stem and purple-tipped involucre bracts (Gleason and Cronquist, 1963).

Life Cycle

The horseweed life cycle is that of a winter and summer annual. Keever (1950) reported fall germination of horseweed rosettes. These rosettes overwintered and then "bolted" the following spring as temperatures and daylength increased. This life cycle made horseweed very competitive since rosettes would bolt prior to the establishment of other weeds.

Regehr and Bazzaz (1979) observed horseweed germination from August to October in Illinois. In Massachusetts, Bekech (1988) reported horseweed germination from August to September beneath crop canopies. Shontz and Oosting (1970) reported no difference in fall germination with horseweed in sandy, heavy or peat soils. In North Carolina, he found horseweed most prevalent in fields with a low sand content. Hanf, (unknown) however, reported horseweed that prefer stony, sandy or loamy soils.

Apparently, newly produced seed are viable at the time of dissemination (Shontz and Oosting, 1970). Germination rates are higher after periods with high soil moisture (Regehr and Bazzaz, 1979). Seed placement in the soil profile also greatly effects germination. Tremmel and Peterson (1983) saw a 94% decline in germination from seeds planted at a 1 cm depth compared to surface planting. Shontz and Oosting (1979) reported similar results. Eighty percent of the horseweed seeds that can germinate were located in the top 2 cm of the soil profile according to Bekech (1988). Field plots fumigated in the spring to destroy all seed reserves had significantly fewer horseweed rosettes in December than non-fumigated plots (Regehr and Bazzaz, 1979). Since the soil seed reserve is a major contributor to a horseweed population, a stand of horseweed could be established in an area despite the absence of horseweed for several years.

Horseweed rosettes have a very low mortality rate (1%) prior to frost according to Regehr and Bazzaz (1979). Regehr and Bazzaz (1976) observed rosettes accumulating energy reserves by photosynthesis in cool temperatures which enable rapid spring growth. Rosette winter mortality rates are quite variable (14 to 84%). The primary cause of mortality is frost heaving. Mortality is higher among smaller rosette sizes. Plants which survive the winter experience very low mortality (2.4 to 5.5%) due to partial uprooting from the winter or competition from other plant species (Regehr and Bazzaz, 1979).

Spring germination of horseweed has also been reported. Regehr and Bazzaz (1979) observed an average population of 10 plants/m² germinating in April and May. Of these, only 36% reached maturity and produced seed without passing through the rosette stage. Bekech (1988) also noted spring germination; however, residue cover delayed this germination by four weeks and reduced germination to only 20% of that in bare soil.

Horseweed flowering and seed production occur between July and October, depending upon location (Hanf, unknown; Shontz and Oosting, 1970). A single horseweed plant may produce as many as 200,000 seeds according to Bekech (1988). Regehr and Bazzaz (1979) also examined seed production. They found total seed production was proportional to mature plant height. Reproductive effort, however, was inversely proportional to plant height. They suggested that maximum plant height is more important than maximum energy allocation to seed production. Horseweed height is very important for seed dissemination. The small, light seed and pappus allow it to utilize the wind to move large distances. Regehr and Bazzaz (1979) reported densities of 126 seeds/m² at a distance 122 m downwind of the source.

Allelopathy

Allelopathic substances have been identified in horseweed. Kobayashi et al. (1980) discovered three C₁₀-polyacetylene compounds in horseweed. Concentrations of trans- and cis-matricaria esters and cis-lachnophyllum ester were found in horseweed roots and shoots. Crude extracts from horseweed showed strong growth inhibitory effects on common ragweed *Ambrosia artemisiifolia* (L.). Raynal and Bazzaz (1975) observed insignificant suppression of *A. artemisiifolia* growth in the presence of horseweed leachates. Keever (1950) and Shontz and Oosting (1970) reported reduced horseweed germination or growth in soil with horseweed residue present. Shontz and Oosting (1970) suspect horseweed allelopathy to cause reduced seed germination of *Haplopappus divaricatus* (Nutt.). In a field crop situation, horseweed residue could potentially reduce crop germination, growth and yield due to the presence of these allelopathic substances.

Ecology and Competition

Horseweed has a specific light requirement for germination and growth. Horseweed seed germination is minimal in the absence of light (Shontz and Oosting, 1970). Gorski et al. (1977) observed that light quality or intensity did not affect horseweed seed germination, therefore shading does not account for seasonal variations in germination rate. Full horseweed germination in the growth chamber was obtained by either continuous light exposure or ten minute irradiation one to two days after the onset of dark incubation (Zinzolker et al. 1985). Four to six days after onset of dark incubation, horseweed seeds were unresponsive to the short irradiation but full germination was obtained by continuous irradiation.

Little information is available on the cause of stem elongation or flowering. Zinzolker *et al.* (1985) reported earlier stem elongation and flowering of horseweed rosettes exposed to long day (16 hr) compared to short day (8 hr) irradiation.

Bekech (1988) examined the effect of light intensity on horseweed growth and seed production. She found total dry weight ($\text{wt} \cdot \text{m}^{-2}$) increased significantly from 0.44 to 3.53 kg as light intensity increased from 25% to 100% of full sunlight. Increasing light intensity also increased horseweed plant height from 92 to 192 cm. Seed production at 25% of full sunlight was only 4% of the 19×10^6 seeds/ m^2 produced by plants grown in full sunlight.

The effects of competition on horseweed growth and development have been addressed. Keever (1950) reported horseweed as a poor fall competitor. Plant residue combined with germination of other winter annuals decreased horseweed germination and competitiveness. In an intraspecific environment, Palmblad (1967) reported delayed flowering and decreased seed production as horseweed densities increased. Horseweed also exhibited "controlled germination" where germination is inhibited as seed density increased. This phenomenon appears to be an adaptive mechanism to regulate horseweed density. Similar results were observed by Bekech (1988). As horseweed density increased, total seed production per plant decreased significantly from a maximum total seed production of 19×10^6 seeds/ m^2 . She also found that inflorescence dry weight decreased from 27% to 12% and dry weight allocation to stems increased from 51% to 58% as horseweed density increased from 100 to 400 plants/ m^2 respectively. Plant density did not affect plant height.

Density dependant mortality has also been examined by Bekech (1988). In naturally occurring populations, a peak horseweed density of 5960 plants/ m^2 declined to an average of 587 plants/ m^2 at flowering. Mortality was greater in more fertile areas.

Horseweed in No-Tillage Production

Bekech (1988) summarized several reasons for the increased frequency of horseweed population in no-tillage crop production. The natural environment to which horseweed is adapted closely resembles the conditions created by no-tillage crop production. Horseweed germinates in the fall under a crop canopy since germination is not effected by light intensity. Without tillage, overwintering rosettes are not destroyed. These plants are then able to compete successfully with spring weeds and crops.

Horseweed is seldom a problem with the use of tillage for two reasons according to Bekech (1988). First, tillage effectively destroys overwintering rosettes. Secondly, spring germination of horseweed still occurs, however the low light conditions generated by crop canopy and weeds effectively reduces horseweed growth reducing its competitiveness.

Horseweed will persist as a no-tillage crop production problem. No-tillage provides undisturbed bare soil surfaces which remain plant-free throughout the entire growing season. These soil conditions provide a non-competitive environment which is the ideal growth environment for horseweed. Continued regeneration of these conditions will lead to the persistence of horseweed in no-tillage crop production.

CHEMICAL CONTROL OF HORSEWEED IN NO-TILLAGE SOYBEANS

In no-tillage crop production, herbicides are utilized to provide effective weed control. Horseweed has become a severe weed control problem in no-tillage soybeans. This is due, in part, to ineffective horseweed control from commonly used soybean herbicide programs. This theory is reinforced by observations that horseweed is not reported as a serious weed control problem in no-tillage corn production. The commonly used herbicides in corn, atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine], cyanazine [2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile], simazine [6-chloro-*N,N'*-diethyl-1,3,5-triazine-2,4-diamine], 2,4-D [2,4-dichlorophenoxy]acetic acid] and dicamba [3,6-dichloro-2-methoxybenzoic acid] are each reported to effectively control horseweed (Wilson *et al.*, 1985; Triplett and Lytle, 1972; Keeling and Abernathy, 1988; Kaufman and Ritter, 1986).

Herbicide resistant biotypes of horseweed have been reported. Atrazine resistant horseweed were found in Switzerland (Lebaron and Gressel, 1982) and in Hungarian vineyards (Hartman, 1981; Mikulas and Polos, 1983). Paraquat resistant horseweed has been reported in Japan by Watanabe *et al.* (1982) and Kato and Okuda (1983). In all cases, the herbicides had been applied for several consecutive years.

Early Preplant Herbicide Applications

Early preplant (EPP) herbicide applications are made prior to crop planting. This approach is designed to control existing vegetation for soil water conservation. EPP applications reduce the risk of soil active herbicide failure from insufficient rainfall by greater likelihood of early season rainfall. Generally, an EPP approach will utilize a nonselective herbicide alone or in combination with soil active herbicides.

Hagood and Davis (1986) obtained excellent horseweed control from EPP applications of cyanazine in Virginia. Combinations of cyanazine with 2,4-D or paraquat applied two weeks prior to planting provided greater than 90% horseweed control without soybean injury in studies conducted by Kaufman and Ritter (1986). Stougaard et al. (1984) applied cyanazine at 2.2 kg/ha or greater, four weeks prior to planting and observed greater than 95% midseason horseweed control without soybean injury in southern Illinois.

Kells (1985) observed significant soybean injury in Michigan when cyanazine (2.2 kg/ha) was applied up to four weeks prior to planting. In Michigan, Kells and List (1986) examined the use of 2,4-D ester for horseweed control. Rates as low as 0.28 kg/ha when followed by a preemergence application of paraquat in combination with soil active herbicides provided greater than 90% control. A similar treatment by McCutchen and Hayes (1983) obtained excellent horseweed control with 2,4-D ester at 1.1 kg/ha. In Texas, Henniger *et al.* (1989) obtained greater than 80% control of horseweed rosettes with 2,4-D ester (0.6 kg/ha) and 2,4-D amine (1.12 kg/ha). Effective control of 10-cm tall horseweed required 1.1 and 2.2 kg/ha of the ester and amine formulations of 2,4-D, respectively. At heights of 30 cm, 2,4-D did not provide effective horseweed control.

Henniger *et al.* (1989) also examined several nonselective foliar herbicides. Paraquat did not provide adequate horseweed control. Glyphosate (0.4 kg/ha) or

glyphosate (0.3 kg/ha) plus 2,4-D (0.5 kg/ha) provided greater than 80% control of horseweed rosettes. HOE-39866 [ammonium-(3-amino-3-carboxypropyl)-methyl-phosinate] (1.1 kg/ha) was the only herbicide to provide effective control from rosette to 30-cm tall horseweed.

Based on the observations of Hagood and Davis (1986), horseweed control from paraquat, glyphosate, HOE-39866 and SC-0224 [trimethylsulfoniumcarboxymethylamino methylphosphonate] ranged from good to excellent. Kells and List (1986) obtained greater than 90% midseason horseweed control from glyphosate (0.42 kg/ha) when followed by a preemergence application of paraquat in combination with metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide], linuron [*N'*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea] and surfactant.

In southern Illinois, Kapusta and Krausz (1988) observed pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] in combination with either imazaquin [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid] or imazethapyr [(±)2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] provide some early season control, however by mid-June no horseweed control was observed. The addition of glyphosate to these combination provided 99% horseweed control. Kapusta (1981) obtained 32% control of 38 to 64 cm tall horseweed from alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide] plus metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] (0.42 kg/ha). By combining this mixture with either paraquat (0.28 kg/ha), glyphosate (0.86 kg/ha), HOE-39866 (0.56 kg/ha) horseweed control was at least 96%.

Excellent horseweed control (100%) was obtained from BAS 514 [3,7-dichloro linecarboxylic acid] (0.28 kg/ha) applied EPP followed by a tank-mix combination of paraquat, metolachlor, linuron and surfactant applied preemergence (Kells and List, 1986).

Preemergence Herbicide Applications

Preemergence (PRE) herbicide applications are soil applied after planting but prior to crop emergence. A PRE herbicide program most generally consists of a nonselective foliar herbicide in combination with soil active herbicides. A herbicide program such as this is designed to control all weeds in one herbicide application.

Considerable research has been on the use of nonselective herbicides for control of horseweed. Wilson *et al.* (1985) found HOE-39866 (0.6 kg/ha) or glyphosate (1.7 kg/ha) provided significantly greater control of 20 to 35-cm and 35 to 90-cm horseweed than paraquat (0.6 kg/ha). Considerable horseweed regrowth was observed in the paraquat treatment. Greater horseweed control was observed from HOE-39866 when applied to taller plants. Application of SC-0224 (0.6 kg/ha) provided greater horseweed control than 0.6 kg/ha of glyphosate. Bellinder and Wilson (1983) observed that HOE-39866 provided horseweed control superior to that obtained from glyphosate or SC-0224. Horseweed control decreased with time in plots treated with paraquat or HOE-39866.

Glyphosate (1.1 kg/ha) provided significantly greater control (94%) of 15-46 cm horseweed than paraquat (58%) at the 0.6 kg/ha rate (Wilson and Worsham, 1988). According to Kaufman and Ritter (1988), a glyphosate application rate of 1.1 or 1.7 kg/ha was required to provide horseweed control equivalent to 0.84 kg/ha of HOE-39866.

Kaufman and Ritter (1988) obtained effective control of horseweed with paraquat when a sequential application of 0.28 kg/ha applied EPP was followed by another 0.28 kg/ha applied PRE in combination with linuron.

According to Kells and List (1986), the substitution of HOE-39866 (0.84 kg/ha) for paraquat (0.56 kg/ha) as part of a PRE combination with metolachlor and linuron provided significantly greater horseweed control (84%) than paraquat (38%). When metribuzin

replaced linuron in combination with paraquat horseweed control improved to 83%. Kapusta (1979) observed similar results. Kells and List (1986) also reported significantly less horseweed control from imazaquin or imazethapyr (0.14 kg/ha) as compared to metribuzin. Slack *et al.* (1988) observed less than 40% horseweed control from imazaquin or imazethapyr in combination with paraquat; however, substitution of glyphosate for paraquat resulted in at least 90% control. Combinations of chlorimuron [2-[[[[[4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid] ethyl ester with glyphosate or paraquat provided greater than 90% horseweed control.

Postemergence Horseweed Control

Information on herbicides for postemergence horseweed control in soybeans is very limited. Hagood and Davis (1986) report unsatisfactory control from bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] or acifluorfen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid]. Kells and List (1986) also found inadequate control with acifluorfen (0.56 kg/ha), however, bentazon (1.1 kg/ha) plus crop oil concentrate (2.3 L/ha) provided 95% control of 3 to 30-cm horseweed. Postemergence applications of metribuzin in carrots [*Daucus carota* (L.)] provided 98% control of 2.5 to 5 cm tall horseweed at the 0.56 kg/ha rate (Henne, 1978).

BIBLIOGRAPHY

- Anonymous. 1981. Weeds of the North Central States. North Central Region Research Publication No. 281, Bulletin 772. University of Illinois at Urbana-Champaign.
- Bekech, M. M. 1988. The biology of horseweed [*Coryza canadensis* (L.) Cronq.]. University of Massachusetts, Amherst. Thesis for the degree of M. S. p. 18-70.
- Bellinder, R. R. and H. P. Wilson. 1983. Comparison of several nonselective herbicides in reduced tillage systems. Proc. Northeast Weed Sci. Soc. 36:51.
- Brown, S. M. and T. Whitwell. 1988. Influence of tillage on horseweed, *Coryza canadensis*. Weed Tech. 2:269-270.
- Buhler, D. D. and E. S. Oplinger. 1989. Influence of tillage systems on weed populations and control in soybean production. Abst. Weed Sci. Soc. Am. 29:17.
- Burnside, O. C. and W. L. Colville. 1963. Soybean and weed yield as affected by irrigation, row spacing, tillage and amiben. Weeds 12:109-112.
- Conservation Technology Information Center. 1988. 1988 National Survey Conservation Tillage Practices. Conserv. Tech. Info. Ctr., W. Lafayette, IN.
- Cronquist, A. 1947. Notes on the compositae of northeastern United States. Bull. Torrey Bot. Club 74:142-150.
- Cronquist, A. 1980. Vascular Flora of the Southeastern United States. University of North Carolina Press, Chapel Hill, NC. p. 166.
- Crosson, Pierre R. 1981. Conservation Tillage and Conventional Tillage: A comparative assessment. Soil Conservation Society of America, Ankey, IA. p. 10-12.
- Dick, W. A. and D. M. Van Doren Jr. 1985. Continuous tillage and rotation combinations effects on corn, soybean and oat yields. Agron. J. 77:459-465.
- Duffy, M. 1983. Pesticide use and practices. 1982. Agricultural Information Bull. No. 462, Economic Res. Service. 14pp.
- Edwards, J. H., D. L. Thurlow and J. T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybeans and wheat. Agron. J. 80:76-80.
- Elmore, C. D. and L. G. Heatherly. 1983. Preplant tillage effects on the weed flora in soybeans. Abst. Weed Sci. Soc. Am. 23:66-67.

- Fawcett, R. S. 1983. Weed control in conservation tillage systems. Proc. North Central Weed Control Conf. 38:67.
- Fawcett, R. S., M. D. K. Owen and P. C. Kassel. 1983. Early preplant treatments for weed control in no-till corn and soybeans. Proc. North Central Weed Control Conf. 38:112-117.
- Gleason, H. A. and A. Cronquist. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. Willard Grant Press, Boston, MA. 1963. p.734-735.
- Gorski, T., K. Gorska and J. Rybicki. 1977. Studies on the germination of seeds under leaf canopy. Flora 166:249-259.
- Hagood, E. S. Jr. and P. H. Davis. 1986. Horseweed control in no-till corn and soybeans. Proc. Northeast Weed Sci. Soc. 40:25.
- Hanf, M. (year unknown). Weeds and their Seedlings. BASF United Kingdom Limited, Agricultural Division Ipswich, England. p. 237.
- Hartman, F. 1981. Resistance of *Erigeron canadensis* L. against atrazine and spread of the weed in department Komarom. Novenyvedelem 17:133-137.
- Henne, R. C. 1978. Control of horseweed, nutsedge, and other weeds in carrots. Proc. Northeast Weed Sci. Soc. 32D:234-238.
- Henniger, C. G., J. W. Keeling and J. R. Abernathy. 1989. Horseweed [*Conyza canadensis* (L.) Cronq.] control in conservation tillage systems. Abst. Weed Sci. Soc. Am. 19:12.
- Hesterman, O.B., J.J. Kells and M.L. Vitosh. 1987. Producing soybeans in narrow rows. Cooperative Extension Service, Bulletin E-2080. Michigan State University, East Lansing, MI.
- Hopkins, W. E. and R. E. Wilson. 1974. Early oldfield succession on bottomlands of southeastern Indiana. Castanea 39:57-71.
- Kapusta, G. 1979. Seedbed tillage and herbicide influence on soybean (*Glycine max*) weed control and yield. Weed Sci. 27:520-526.
- Kapusta, G. 1981. Evaluation of HOE 661 for no-till corn and soybean weed control. Res. Rept. North Central Weed Control Conf. 38:76-77.
- Kapusta, G. and R. F. Krausz. 1987. Soybean pendimethalin plus imazaquin or imazethapyr no-till EPP. Res. Rept. North Central Weed Control Conf. 44:355-357.
- Kato, A. and Y. Okuda. 1983. Paraquat resistance in *Erigeron canadensis*. Weed Res. (Japan) 28:54-56.
- Kaufman, L. M. and R. L. Ritter. 1986. Early preplant applications of cyanazine in full season no-tillage soybeans. Proc. Northeast Weed Sci. Soc. 40:25.

- Kaufman, L. M. and R. L. Ritter. 1988. Use of HOE-039866 in no-till soybeans. Abst. Weed Sci. Soc. Am. 28:19.
- Keeling J. W. and J. R. Abernathy. 1988. Weed control systems for conservation tillage cotton production on sandy soils. Abst. Weed Sci. Soc. Am. 28:21.
- Keever, C. 1950. Causes of succession on old fields of the Piedmont, North Carolina. Ecol. Monographs 20:229-250.
- Kells, J. J. 1985. Weed control strategies for no-tillage corn and soybean production. Proc. British Crop Protection Conf.-Weeds 3:865-872.
- Kells, J. J. and G. A. List. 1986. Horseweed [*Conyza canadensis* (L.) Cronq.] control in no-tillage soybeans. Proc. North Central Weed Control Conf. 41:44.
- Kobayashi, A., S. Morimoto, Y. Shibata, K. Yamashita, and M. Numata. 1980. 10 Carbon polyacetylenes as allelopathic substances in dominants in early stages of secondary succession. J. Chem. Ecol. 6:119-132.
- Lebaron, H. M. and J. Gressel. 1982. Herbicide Resistance in Plants. John Wiley and Sons, New York. p. 46.
- Lehman, W. F. and J. W. Lambert. 1960. Effects of spacing of soybean plants between and within rows on yield and its components. Agron. J. 52:84-86.
- McCutchen, T. C. and R. M. Hayes. 1983. Control of horseweed, cocklebur, and smartweed in no-till soybeans. Proc. So. Weed Sci. Soc. 37:20-26.
- McWhorter, C. G. and W. L. Barrentine. 1975. Cocklebur control in soybeans as affected by cultivars, seeding rates, and methods of weed control. Weed Sci. 23:386-390.
- Mikulas, J. and E. Polos. 1983. The spreading of *Erigeron canadensis* L. in grapevine plantations and means of control. Novenyvedelem 19:149-153.
- Palmblad, I. G. 1967. Competition in experimental populations of weeds with emphasis on the regulation of population size. Ecol. 49:26-34.
- Peters, E.J., M.R. Gebhardt and J.F. Stritzke. 1965. Interrelations of row spacings, cultivations and herbicides for weed control. Weed Sci. 23:386-390.
- Phillips, R. E. and S. H. Phillips. 1984. No-tillage Agriculture Principles and Practices. Van Nostrand and Reinhold Co., New York. p. 3-9.
- Quisenberry, D. 1988a. Michigan no-till survey 1988. United States Department of Agriculture, Soil Conservation Service, East Lansing, MI. Dec. 1988.
- Quisenberry, D. 1988b. Personal communication.
- Raynal, D. J. and F. A. Bazzaz. 1975. Interference of winter annuals with *Ambrosia artemisiifolia* in early successional fields. Ecol. 56:35-49.

- Regehr, D. L. and F. A. Bazzaz. 1976. Low temperature photosynthesis in successional winter annuals. *Ecol.* 57:1297-1303.
- Regehr, D. L. and F. A. Bazzaz. 1979. The population dynamics of *Erigeron canadensis*, a successional winter annual. *J. Ecol.* 67:923-933.
- Richey, C. B., D. R. Griffith and S. D. Parsons. 1976. Yields and cultural energy requirements for corn and soybeans with various tillage-planting systems. *Adv. Agron.* 29:141-182.
- Sanford, J. O., D. L. Myhre and N. C. Mervine. 1973. Double cropping systems involving no-tillage and conventional tillage. *Agron. J.* 65:978-982.
- Shontz, J. P. and H. J. Oosting. 1970. Factors affecting interaction and distribution of *Haplopappus divaricatus* and *Conyza canadensis* in North Carolina old fields. *Ecol.* 51:780-793.
- Slack, L. H., R. B. Wells and W. W. Witt. 1988. Chlorimuron, imazaquin, and imazethapyr performance in no-tillage, full season soybeans. *Abst. Weed Sci. Soc. Am.* 28:82-83.
- Sprague, M. A. and G. B. Triplett, ed. No-Tillage and Surface-Tillage Agriculture. John Wiley and Sons, Inc. 1986. p.12-15.
- Staniforth, D. W. and A. F. Wiese. 1985. Weed Biology and Its Relationship to Weed Control in Limited-Tillage Systems. p. 16-22. In Weed Control in Limited-Tillage Systems. A. F. Wiese, ed. Weed Sci. Soc. Am., Champaign, Illinois.
- Stougaard, R. N., G. Kapusta and G. Roskamp. 1984. Early preplant herbicide applications for no-till soybeans weed control. *Weed Sci.* 32:293-298.
- Thomas, G. W. 1986. Mineral Nutrition and Fertilizer Placement. p. 94-99. In No-Tillage and Surface-Tillage Agriculture. M. A. Sprague and G. B. Triplett, eds. John Wiley and Sons, Inc.
- Tremmel, D. C. and K. M. Peterson. 1983. Competitive subordination of a piedmont old field successional dominant by an introduced species. *Amer. J. Bot.* 70:1125-1132.
- Triplett, G. B., Jr., and G. D. Lytle. 1972. Control and ecology of weeds in continuous corn grown without tillage. *Weed Sci.* 20:453-457.
- Triplett, G. B., Jr., D. M. Van Doren, Jr. and W. H. Johnson. 1964. Non-plowed strip tilled corn culture. *Trans. Am. Soc. Agric. Eng.* 7:105-107.
- Triplett, G. B., Jr., D. M. Van Doren, Jr. and B. L. Schmidt. 1968. Effect of corn stover mulch on no-tillage corn yield and water infiltration. *Agron. J.* 60:236-239.
- Tyler, D. D. and J. R. Overton. 1982. No-tillage advantages for soybean seed quality during drought stress. *Agron. J.* 74:344-347.
- Unger, P. W. and T. M. McCalla. 1980. Conservation tillage systems. *Adv. Agron.* 33:1-58.

- Watanabe, Y., T. Honma, K. Itoh and M. Miyahara. 1982. Paraquat resistance in *Erigeron philadelphicus* L. Weed Res. (Japan) 27:49-54.
- Wax, L. M. and J. W. Pendleton. 1968. Effect of row spacing on weed control in soybeans. Weed Sci. 25:462-464.
- Wilson, H. P., T. E. Hines, R. R. Bellinder and J. A. Grande. 1985. Comparisons of HOE-39866, SC-0224, paraquat, and glyphosate in no-till corn (*Zea mays*). Weed Science 33:531-536.
- Zinzolker, A., J. Kigel and B. Rubin. 1985. Effects of environmental factors on the germination and flowering of *Conyza albida*, *C. bonariensis* and *C. canadensis*. Phytoparasitica 13(3/4):229-230.

CHAPTER 2

HORSEWEED [*Coryza canadensis* (L.) Cronq.] INTERFERENCE IN NO-TILLAGE SOYBEAN PRODUCTION

ABSTRACT

Research was conducted in 1987 and 1988 to: 1) study the impact of horseweed populations on soybean yield and 2) examine the effect of soybean row spacing on soybean competition with horseweed. The herbicides glyphosate, paraquat and linuron were applied to horseweed to provide a range of horseweed population densities.

Horseweed densities of 0, 13, 16 and 165 plants/m² resulted in soybean yields of 1837, 1065, 1289 and 170 kg/ha, respectively when averaged over row spacing in 1987. Horseweed densities of 16, 13 and 165 plants/m² significantly reduced soybean yield 29, 42 and 91%, respectively as compared to the weed-free environment. Soybean yields averaged 541 kg/ha in the weed-free areas during the extremely dry 1988 growing season. Significant soybean yield reductions of 87 to 94% were observed in horseweed densities of 79, 94 and 208 plants/m². Increasing horseweed density significantly reduced soybean plant height in 1987 as well as the number of soybean pods per plant and seed weight in 1987 and 1988.

Soybean yields were significantly greater in soybean rows spaced 18 and 36 cm than 71 cm in 1987. Due to the low yields and drought related variability in 1988, this yield advantage was not observed for narrow row spacing. No significant differences in

horseweed population were observed with soybean row spacing averaged over herbicide program in either year. Nomenclature: glyphosate, *N*-(phosphonomethyl) glycine; paraquat, 1-1'-dimethyl-4-4'-bipyridinium ion; linuron, *N*'-(3,4-dichlorophenyl)-*N*-methoxy-*M*-methylurea; horseweed, *Conyza canadensis* (L.) Cronq. #¹ ERICA; soybean, *Glycine max* (L.) Merr. # GLXMA.

¹Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

INTRODUCTION

Horseweed is a winter or summer annual plant commonly found in pastures, roadsides and fallow areas (Anonymous, 1981). Kapusta (1979), Elmore and Heatherly (1983) and Brown and Whitwell (1988) have reported horseweed populations in the absence of tillage but a shallow disking eliminated the weed. Horseweed has become a severe weed control problem in no-tillage soybean production due to lack of tillage and inadequate horseweed control provided by commonly used herbicides.

Only limited studies have examined the impact of horseweed control on soybean yield due to the recent severity of the weed. McCutchen and Hayes (1983) reported soybean yields of 2345 and 1512 kg/ha when horseweed control ratings were 91 and 68%, respectively. Wilson and Worsham (1988) also reported soybean yields, however, their results were affected by other annual weed species as well as horseweed. No results examining the effect of horseweed population on soybean yield have been reported at this time.

Narrow soybean row spacing is commonly used in no-tillage soybean production. Burnside and Colville (1963) reported decreased total weed dry weight/unit area, reduced time for soybean canopy closure and increased soybean grain yields as row spacings were reduced from 102 to 25-cm. By reducing soybean row spacing, the crop becomes a stronger competitor with weeds.

Horseweed has been reported as a poor competitor in sub-optimal conditions. Fall germinating horseweed fared poorly in severe winter annual competition according to

Keever (1950). Bekech (1988) reported significant decreases in total horseweed dry weight/m² and plant height as light intensity decreased from full sunlight. Soybeans may compete more effectively with horseweed when planted in narrow rows compared to wide rows.

The objectives of this study were to: 1) examine the impact of several horseweed populations on soybean yield, and 2) study the effect of soybean row spacing on soybean competition with horseweed.

MATERIALS AND METHODS

Research was conducted in adjacent experimental areas during 1987 and 1988 in Cass County MI. The soil type for each location was a Kalamazoo loam (Fine-loamy, mixed, mesic Typic Hapludalfs). The soils contained 1.9 and 1.2% organic matter with soil surface pH of 6.0 and 6.6 for 1987 and 1988, respectively.

The study was conducted in a split plot design with four and three replications in 1987 and 1988, respectively. Main plots were row spacings of 16, 38, and 72 cm row spacings. Sub-plots consisted of four herbicide programs designed to provide a range of horseweed population densities. Plots were 3.4 meters wide and 11 meters in length.

The soybean variety 'Corsoy 79' was planted without tillage into soybean residue on May 15, 1987 and into corn residue on May 17, 1988. A no-tillage drill was used to plant soybeans into the desired row spacings by preventing seed flow to specific planting units. The drill was calibrated to deliver 40,470 seeds/ha. Actual soybean plant populations for each row spacing are shown in Table 1.

Table 1. Soybean plant populations for each of three soybean row spacings.

Row spacing	Soybean population	
	1987	1988
(cm)	----- (Plants/ha) -----	
18	43,215	37,020
36	52,420	42,297
71	36,846	29,314

Herbicides were applied preemergence with a tractor mounted compressed air sprayer. Applications utilized 80015 or 8003 flat fan nozzles³ which delivered 98 and 207 L/ha respectively at a spray pressure of 207 kPa. Glyphosate treatments were applied with a spray volume of 98 L/ha spray volume. All other treatments were applied at 207 L/ha. At the time of application, horseweed height averaged 7.5 cm and 6 cm with populations of 139 and 166 plants/m² for 1987 and 1988, respectively.

Four herbicide programs were selected to provide a range of horseweed control. These programs are summarized in Table 2. The glyphosate plus linuron program was designed to provide complete horseweed control. The two paraquat treatments, with and without linuron, were applied to provide intermediate horseweed control and population densities. The untreated program is included to examine the effect of a natural horseweed population on soybeans. All herbicide plots received a postemergence application of sethoxydim plus crop oil concentrate at the rates of 0.17 kg/ha and 2.3 L/ha, respectively for control of grassy weed species. Weed species other than horseweed were removed by handweeding.

The horseweed populations were estimated bi-weekly beginning four weeks after soybean planting through mid-July. Horseweed population in low density plots was estimated by counting horseweed plants in an area 0.5 by 11 m from the center of each plot. In high density plots, horseweed populations was estimated by counting horseweed plants in three randomly selected 0.09-m² areas within each plot. Evaluation of horseweed control was taken every bi-weekly throughout the growing season beginning 4 weeks after soybean planting. Visual horseweed control evaluations were based on a scale of 0 to 100 where 0 was no visible horseweed injury and 100 represented complete horseweed control.

At harvest, 10 soybean plants were randomly selected from each plot for determination of soybean height, number of pods per plant and weight of 100 seeds.

³Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.

Table 2. Herbicide programs and corresponding herbicide rates.

Herbicide program	Herbicide component and rate
	------(kg/ha)-----
1	Glyphosate (1.7) + linuron (0.8) + surfactant ² (0.5% v/v)
2	Paraquat (0.6) + linuron (0.8) + surfactant (0.25% v/v)
3	Paraquat (0.6) + surfactant (0.25% v/v)
4	Untreated

²X-77, Valent U.S.A. Corp., 1333 N California Blvd., Walnut Creek, CA 94596.

Soybeans were harvested with a mechanical harvester and soybean yields were corrected to 13% moisture. All data were subjected to analysis of variance and means separated by least significant difference at either the 0.1 or 0.05 level of significance.

RESULTS AND DISCUSSION

The environmental conditions experienced in 1987 were relatively normal. However, the growing season in 1988 was very dry with below-normal rainfall occurring between mid-May and mid-July as well as above normal temperatures (Table 3). The horseweed control and soybean yields reflect these conditions.

The analysis of variance indicated a significant treatment effect from herbicide program but no row spacing by herbicide program interaction. Therefore data for the herbicide program are averaged over soybean row spacing and data for soybean row spacing are averaged over the herbicide program.

An increase in horseweed population decreased soybean grain yields in 1987 (Table 4). The weed-free environment of herbicide program 1 (glyphosate plus linuron) resulted in soybean yield of 1837 kg/ha when averaged over soybean row spacing. Herbicide programs 2 and 3 which utilized paraquat with and without linuron, respectively, resulted in horseweed populations of 16 and 13 plants/m². These populations significantly reduced soybean yields by 29% and 42% as compared to the weed-free environment. The untreated horseweed population had 165 plants/m² and a soybean grain yield of 170 kg/ha or 9% of the weed-free yield.

The weed-free areas produced an average soybean yield of 541 kg/ha during the extremely dry 1988 growing season (Table 5). These weed-free yields were considerably less than the 1987 weed-free yields. Herbicide programs 2 and 3 had horseweed densities of 79

Table 3. Total and average monthly rainfall for Cass County, Michigan for 1986, 1987 and 1988.

Year	Total monthly rainfall			
	April	May	June	July
	----- (cm) -----			
1987	7.2	8.8	5.8	7.1
1988	9.3	4.6	1.3	5.4
30 year ave	9.5	7.9	10.1	9.4

Table 4. Results from 1987 horseweed interference research conducted in Cass County, Michigan.

Row spacing	Herbicide program	Horseweed			Soybean yield parameters			
		Density	Control		Average	Pod	Seed	Yield
(cm)		4 WAT ^a	4 WAT	10 WAT	height	number	weight	
		(plts/m ²)	-----(%)-----		(cm)	(#/plant)	(g/100)	(kg/ha)
18	1	0	100	100	32	58	10.9	2099
	2	12	69	38	31	42	11.2	1483
	3	12	70	28	28	28	10.9	1088
	4	180	0	0	13	3	9.1	138
36	1	0	100	100	32	32	10.6	1738
	2	8	74	51	31	26	11.9	1442
	3	11	69	38	28	25	12.3	1172
	4	135	0	0	17	6	11.5	273
71	1	0	100	100	34	49	11.2	1673
	2	29	66	21	32	34	11.6	968
	3	15	74	34	30	28	11.9	933
	4	179	0	0	14	5	10.3	100
LSD _(0.05) ^b		57	7	20	4	10	1.6	408
Herbicide program averaged over soybean row spacing								
	1	0	100	100	33	46	10.9	1837
	2	16	70	37	31	34	11.5	1298
	3	13	71	33	29	27	11.7	1065
	4	165	0	0	15	5	10.3	170
LSD _(0.05) ^b		33	4	12	2	6	1.0	235
Soybean row spacing averaged over herbicide program								
18		60	41	51	26	33	10.5	1202
36		61	47	39	27	22	11.6	1156
71		60	39	56	27	29	11.2	918
LSD _(0.05) ^b		4	8	30	2	6	0.9	203 ^c

^aWeeks after treatment.^bComparisons valid within columns.^cLeast significant difference at the 0.1 level.

Table 5. Results from 1988 horseweed interference research conducted in Cass County, Michigan.

Row spacing	Herbicide program	Horseweed			Soybean yield parameters			
		Density	Control		Average	Pod	Seed	Yield
(cm)		4 WAT ^a	4 WAT	10 WAT	height	number	weight	
		(plts/m ²)	------(%)-----		(cm)	(#/plant)	(g/100)	(kg/ha)
18	1	0	100	100	18	43	12.5	332
	2	60	37	32	12	14	8.7	41
	3	47	30	25	11	10	10.7	57
	4	277	0	0	2	3	3.7	4
36	1	0	100	100	21	45	13.4	712
	2	86	27	18	12	9	8.0	50
	3	107	25	0	9	8	9.0	37
	4	178	0	0	8	1	5.4	7
71	1	0	100	100	19	45	13.3	577
	2	92	27	13	10	4	6.7	114
	3	130	17	7	9	3	7.1	11
	4	167	0	0	9	4	8.0	20
LSD _(0.05) ^b		95	11	30	3	9	3.5	186
<u>Herbicide program averaged over soybean row spacing</u>								
	1	0	100	100	--	45	13.1	541
	2	79	30	21	--	9	7.8	68
	3	94	24	11	--	7	8.9	35
	4	1208	0	0	--	3	5.7	10
LSD _(0.05) ^b		55	6	13	--	5	2.0	107
<u>Soybean row spacing averaged over herbicide program</u>								
18		42	39	96	--	18	8.9	108
36		38	30	93	--	16	9.0	201
71		36	30	97	--	14	8.8	180
LSD _(0.05) ^b		8	12	78	--	5	3.2	58 ^c

^aWeeks after treatment.^bComparisons valid within columns.^cLeast significant difference at the 0.1 level.

and 94 plants/m², respectively. Soybean yields for these densities were 68 and 35 kg/ha which represent 13% and 6% of the yield potential in a weed-free culture.

Horseweed is a very competitive weed in no-tillage soybean production. Populations as low as 13 plants/m² significantly reduced soybean yield by 29% as compared to a weed-free environment. The horseweed population obtained from application of paraquat and linuron, two commonly used no-tillage soybean herbicides, significantly reduced soybean yield as compared to a weed-free environment.

The lower weed control ratings and higher horseweed densities experienced in 1988 may be due in part to the very dry growing conditions. These conditions prevented the incorporation of soil active herbicides and possibly reduced the foliar absorption of foliar active nonselective herbicides compared to 1987. Ahmadi *et al.* (1980) observed reduced barnyardgrass (*Echinochloa crus-galli*) phytotoxicity from foliar applications of glyphosate and paraquat plus terbutryn as soil water potential decreased from 1/8 to 37 bar tension. Further examination revealed decreased absorption and translocation of ¹⁴C-glyphosate as soil moisture decreased. Sherrick *et al.* (1986) observed significantly greater deposition of epicuticular wax on plants grown in a high light, low humidity environment than plants grown in a low light, high humidity. They speculate that differential cuticle development may be responsible for reduced glyphosate absorption in drought stressed plants.

The effect of horseweed density on soybean yield parameters is also reported in Tables 4 and 5. As horseweed density increased, soybean height at harvest decreased. Soybean heights could not be averaged over row spacing in 1988 (Table 5) due to a significant row spacing by herbicide interaction for this variable. However, soybean heights decreased as horseweed density increased in the 18 and 36 cm row spacings. The number of soybean pods per plant averaged over row spacing decreased significantly in the presence of 13 to 16 horseweed plants/m² in 1987. A soybean plant in the weed-free environment

averaged 46 pods compared to 27 and 34 pods in the 13 and 16 horseweed densities, respectively. The combined effects of dry conditions and greater weed densities in 1988 caused pod number reductions of even greater magnitude than in 1987. Soybean plants grown among 79 horseweed plants/m² averaged only 9 pods per plant compared to 45 pods per plant on soybeans grown weed-free.

Soybean seed weights were not significantly different when horseweed populations were 16 plants/m² or less in 1987. Soybean seed produced under weed-free conditions in 1988 had significantly greater weight than seed produced in the presence of 79 or 94 horseweed plants/m².

Soybean yield data from 1987 indicate that soybeans planted in narrow row spacings have a yield advantage compared to wide row spacings. Soybean yields, averaged over herbicide program in 1987, were 1202 and 1156 kg/ha in 18 and 36 cm row spacings, respectively. These yields were significantly greater at the 0.1 level than soybean yields from 71 cm row spacings. This observation is consistent with data reported by Lehman and Lambert (1960), Burnside and Colville (1963), Peters *et al.* (1965) and Wax and Pendleton (1968) who observed soybean yields improved when row spacings were reduced from 102 to 52 cm or less. Soybean yields averaged over row spacing in 1988 were only 17% of yields obtained in 1987 due to the droughty conditions. These yields are not representative of typical Michigan no-tillage soybean production. Due the low yields and variability caused by the drought, the effect of soybean row spacing on yield will not be addressed.

The effects of soybean row spacing on horseweed control is reported in Tables 4 and 5 for 1987 and 1988, respectively. No significant differences were observed with soybean row spacings averaged over herbicide programs. Horseweed densities for 18, 36 and 71-cm soybean row spacings were 51, 39 and 56 plants/m² respectively in 1987 and 96, 93 and 97 plants/m² in 1988. Soybean inability to effectively compete with horseweed, regardless

of row spacing, may be due in part to the rapid rate of horseweed recovery following herbicide application. Horseweed regrowth initiated from apical and axillary meristems near the top of the plant within 2 weeks after herbicide application. At the time of application, horseweed plants averaged 6 to 8 cm in height. Horseweed regrowth initiating from these heights was taller than newly emerged soybean plants, thus giving the horseweed a competitive advantage over the soybean.

BIBLIOGRAPHY

- Ahmadi, M. S., L. C. Haderlie and G. A. Wicks. 1980. Effect of growth stage and water stress on barnyardgrass (*Echinochloa crus-galli*) control and on glyphosate absorption and translocation. *Weed Sci.* 28:277-282.
- Anonymous. 1981. Weeds of the North Central States. North Central Region Research Publication 286, Bulletin 772. Univ. of Illinois at Urbana-Champaign. p.204.
- Bekech, M. M. 1988. The biology of horseweed [*Coryza canadensis* (L.) Cronq.]. University of Massachusetts, Amherst, Thesis for the degree of M. S. p. 18-70.
- Brown, S. M. and T. Whitwell. 1988. Influence of tillage on horseweed, *Coryza canadensis*. *Weed Tech.* 2:269-270.
- Burnside, O. C. and W. L. Colville. 1963. Soybean and weed yield as affected by irrigation, row spacing, tillage and amiben. *Weeds* 12:109-112.
- Elmore, C. D. and L. G. Heatherly. 1983. Preplant tillage effects on the weed flora in soybeans. *Abst. Weed Sci. Soc. Am.* 23:66-67.
- Kapusta, G. 1979. Seedbed tillage and herbicide influence on soybean (*Glycine max*) weed control and yield. *Weed Sci.* 27:520-526.
- Keever, C. 1950. Causes of succession on old fields of the Piedmont, North Carolina. *Ecol. Monographs* 20:229-250.
- Lehman, W. F. and J. W. Lambert. 1960. Effects of spacing of soybean plants between and within rows on yield and its components. *Agron. J.* 52:84-86.
- McCutchen, T. C. and R. M. Hayes. 1983. Control of horseweed, cocklebur, and smartweed in no-till soybeans. *Proc. So. Weed Sci. Soc.* 37:20-26.
- Peters, E. J., M. R. Gebhardt and J. F. Stritzke. 1965. Interrelations of row spacings, cultivations and herbicides for weed control. *Weed Sci.* 23:386-390.
- Sherrick, S. L., H. A. Holt and F. D. Hess. 1986. Effects of adjuvants and environment during plant development on glyphosate absorption and translocation in field bindweed (*Convolvulus arvensis*). *Weed Sci.* 34:811-816.
- Wax, L. M. and J. W. Pendleton. 1968. Effect of row spacing on weed control in soybeans. *Weed Sci.* 25:462-464.

- Wilson, J. S. and A. D. Worsham. 1988. Combinations of nonselective herbicides for difficult to control weeds in no-till corn (*Zea mays*), and soybeans (*Glycine max*). Weed Sci. 36:648-652.

CHAPTER 3

EARLY PREPLANT AND PREEMERGENCE CONTROL OF HORSEWEED

[*Coryza canadensis* (L.) Cronq.] IN NO-TILLAGE SOYBEANS

ABSTRACT

A three year study was initiated in 1986 to identify effective and consistent horseweed control strategies in no-tillage soybean production. Preemergence (PRE) applications of paraquat (0.56 kg/ha) plus metolachlor (2.2 kg/ha) plus linuron (0.84 kg/ha) plus non-ionic surfactant (0.25% v/v) provided less than 60% horseweed control. Early preplant (EPP) applications of either glyphosate (0.84 kg/ha), 2,4-D ester (0.56 kg/ha), HOE-39866 (0.84 kg/ha) or BAS-514 (0.07 kg/ha) provided greater than 95% horseweed control when followed by the above preemergence treatment. Horseweed control and soybean yield from these EPP treatments were significantly greater than the PRE application alone.

The substitution of either glyphosate (0.84 kg/ha) or HOE-39866 (0.84 kg/ha) for paraquat in the above PRE treatment significantly improved horseweed control. The addition of BAS-514 (0.07 kg/ha) to the above PRE treatment containing paraquat significantly improved horseweed control in all years and soybean yield in 1987, however, soybean injury was observed at all rates tested. Horseweed control improved when either metribuzin or linuron plus chlorimuron (16:1) were substituted for linuron in the PRE treatment containing paraquat. The substitution of metribuzin plus chlorimuron (10:1) for

linuron in the paraquat containing PRE treatment significantly improved horseweed control. The herbicides imazaquin or imazethapyr did not provide adequate horseweed control ($\leq 65\%$) when applied PRE with paraquat plus metolachlor plus surfactant.

Sequential application of soil active herbicides provided equal or greater horseweed control in 1987 than a single preemergence application of the same total rate. In the dry 1988 growing season, the soil active herbicides linuron, linuron plus chlorimuron (16:1) and metribuzin plus chlorimuron (10:1) provided significantly greater horseweed control than the same total herbicide rate applied PRE. Nomenclature: glyphosate, *N*-(phosphonomethyl)glycine; 2,4-D, (2,4-dichlorophenoxy)acetic acid; HOE-39866, ammonium-(3-amino-3-carboxypropyl)-methyl-phosphinate; BAS-514, 3,7-dichloro-8-quinolinecarboxylic acid; paraquat, 1-1'-dimethyl-4-4'-bipyridinium ion; linuron, *N*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea; metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methyl ethyl)acetamide; chlorimuron, 2-[[[[[4-chloro-6-methoxy-2-pyrimidinyl]amino]carbonyl] amino]sulfonyl]benzoic acid; metribuzin, 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one; imazaquin, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid; imazethapyr, ($\pm$)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid; horseweed, *Conyza canadensis* (L.) Cronq. #¹ ERICA; soybean, *Glycine max* (L.) Merr. # GLXMA.

¹Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

INTRODUCTION

Successful no-tillage weed control requires complete control of existing vegetation prior to crop emergence as well as control of emerging weeds after planting. Early preplant (EPP) and preemergence (PRE) herbicide applications provide effective weed control in no-tillage crop production (Stougaard *et al.*, 1984; Fawcett *et al.*, 1983). In an EPP herbicide program, soil active herbicides are applied prior to weed emergence to control weeds through the entire growing season. PRE applications are made following crop planting but prior to crop emergence. An effective PRE herbicide program consists of a nonselective foliar active herbicide, to control existing vegetation, in combination with soil active herbicides. A combination of both systems is referred to as sequential herbicide application. In this system, a portion of soil active herbicide is applied EPP followed by an additional application PRE (Fawcett *et al.*, 1983). The PRE application program is most commonly used in no-tillage crop production according to Kapusta (1979).

The presence of horseweed is frequently observed in the absence of tillage. The use of shallow tillage eliminated this weed according to Kapusta (1979), Elmore and Heatherly (1983) and Brown and Whitwell (1988). Horseweed is a serious weed control problem in no-tillage soybean production. The commonly used herbicides, paraquat and linuron, fail to provide effective horseweed control in no-tillage soybeans (McCutchen and Hayes 1983; Wilson *et al.*, 1985; Wilson and Worsham, 1988). Researchers have observed significantly greater horseweed control when paraquat was substituted with either glyphosate (Wilson *et al.*, 1985; Wilson and Worsham, 1988) or HOE-39866 (Wilson *et al.*, 1985). The substitution

of metribuzin for linuron improved horseweed control (Kapusta, 1979).

Presently, only limited research has been conducted to specifically address horseweed control strategies in no-tillage soybeans. In 1986, a three year study was initiated to identify consistent and effective herbicide programs for the control of horseweed in no-tillage soybean production.

MATERIAL AND METHODS

Research was conducted in Cass county Michigan. The location of the study was rotated yearly between two adjacent fields. Soil at all experimental locations was a Kalamazoo loam soil (Fine-loamy, mixed, mesic Typic Hapludalfs) with naturally high horseweed populations. Soybeans were planted without tillage into corn (1986 and 1988) and soybean (1987) residue, two weeks after EPP applications. Herbicide treatments were arranged as a randomized complete block with three replications. All herbicide applications were made in plots at least 3 m wide by 11 m long with a tractor mounted compressed air sprayer. The sprayer was calibrated to deliver 98 L/ha and 206 L/ha at 207 kPa. In all years, glyphosate treatments, which included non-ionic surfactant² (0.5% v/v), were applied with a spray volume of 98 L/ha. All other herbicide applications were applied in a spray volume of 206 L/ha.

Visual evaluations of horseweed control and soybean injury were conducted bi-weekly throughout the growing season. Evaluations were based on a scale with zero being no visible injury and 100 representing complete plant death. Horseweed density was estimated bi-weekly beginning four weeks after soybean planting and continued through mid-July. The horseweed population in low density plots was estimated by counting horseweed plants

²X-77. Valent U.S.A. Corp., 1333 N. California Blvd., Walnut Creek, CA 94596.

in an area 0.5 m wide by 11 m long from the center of each plot. In high density plots, population was estimated by counting horseweed plants in three randomly selected 0.09-m² areas from each plot. Soybeans were harvested with a mechanical harvester. Soybean yields were corrected to 13% moisture. All data were subjected to analysis of variance with means separated by least significant difference at the 0.05 level of significance.

The first year of research was conducted on a sandy loam soil containing 1.2% organic matter with soil surface (0 to 5 cm) pH of 6.6. The site had a uniform 'horseweed' population averaging 94 plants/m². EPP herbicide applications were made to horseweed averaging 8 cm in height on May 13, 1986. Table 1 shows the environmental conditions at the time of herbicide application. Approximately two weeks later, the soybean variety 'Northrup King 2596' was planted into corn residue in 48-cm row spacings. Herbicides were applied preemergence on May 29, the same day as planting, to horseweed at an average height of 18 cm.

The 1987 and 1988 studies were located in adjacent fields with the 1988 study conducted in the same location as the 1986 study. These soils had surface pH of 6.0 and 6.6 and contained 1.9 and 1.5% organic matter in 1987 and 1988, respectively. Horseweed populations averaged 139 plants/m² in 1987 and 166 plants/m² in 1988. In both years, very few weed species other than horseweed were observed. The soybean variety 'Corsoy 79' was planted in 18-cm row spacings in both years. EPP herbicide applications were made to horseweed at average heights of 1 and 6 cm on May 1, 1987 and April 29, 1988, respectively. Herbicides were applied PRE on May 15, 1987 and May 17, 1988, the same day as soybean planting to horseweed at average heights of 8 and 6 cm, respectively. Table 1 summarizes the environmental conditions at the time of all herbicide applications.

Table 1. Environmental conditions for early preplant and preemergence application of herbicides.

	<u>1986</u>	<u>1987</u>	<u>1988</u>
Planting date	5/29	5/15	5/17
Horseweed density (plants/m ²)	94	139	166
EPP application			
Date	5/13	5/1	4/29
Cloud cover (%)	10	95	Clear
Air temperature (°F)	65	48	52
Relative humidity (%)	43	50	39
Soil temperature (°F)	63	50	46
Leaf surface moisture (1 = wet, 5 = dry)	4	3	5
Horseweed height (cm) ave (range)	8(3-13)	5(0.5-9)	1(0.5-3)
PRE application			
Date	5/29	5/15	5/17
Cloud cover (%)	100	5	Clear
Air temperature (°F)	63	62	65
Relative humidity (%)	80	50	45
Soil temperature (°F)	60	78	71
Leaf surface moisture (1 = wet, 5 = dry)	3	3	5
Horseweed height (cm) ave (range)	18(5-23)	8(1-15)	6(2-13)

RESULTS AND DISCUSSION

Early preplant applications. Above average, normal and below average rainfall occurred in 1986, 1987 and 1988, respectively (Table 2). Despite the very different environmental conditions, horseweed control from the EPP herbicide applications remained consistent between years (Table 3). Fawcett *et al.* (1983) reported that EPP herbicide programs reduce the risk of herbicide failure due to inadequate rainfall.

Early season horseweed control and early season horseweed densities for the herbicide treatments are correlated negatively as indicated by the data presented in Tables 3, 4 and 5. Horseweed control ratings declined as the growing season progressed. This decrease in weed control is probably due, in part, to (1) increased number of horseweed axillary shoots per plant late in the season, and (2) greater visibility of existing horseweed plants became more apparent as they grew above the soybean canopy. Since horseweed control decreased with time, only late season control will be discussed.

All herbicides applied EPP were followed by a PRE application of paraquat (0.56 kg/ha) plus linuron (0.84 kg/ha) plus metolachlor (2.2 kg/ha) plus non-ionic surfactant (0.25% v/v). This commonly used PRE herbicide program provided less than 56% late season horseweed control in any of the three years. For simplicity, this PRE herbicide program shall be referred to as the standard PRE.

EPP application of glyphosate at 0.86 kg/ha with low carrier volume (98 L/ha) when followed by the standard PRE, provided significantly greater horseweed control (>96%) and soybean yield than the standard PRE alone (Table 3). The addition of ammonium sulfate

Table 2. Total and average monthly rainfall in Cass County, Michigan for 1986, 1987 and 1988.

Year	Total monthly rainfall			
	April	May	June	July
	----- (cm) -----			
1986	5.8	12.6	14.8	12.6
1987	7.2	8.8	5.8	7.1
1988	9.3	4.6	1.3	5.4
30 year ave	9.5	7.9	10.1	9.4

Table 3. Early season horseweed control, horseweed density, soybean injury and late season horseweed control as affected by early pre-plant herbicide application.

Herbicide ^a	Rate (kg/ha)	1986				1987				1988						
		Soybean injury 4 WAP (%)	Horseweed		Soybean yield (kg/ha)	Soybean injury 4 WAP (%)	Horseweed		Soybean yield (kg/ha)	Soybean injury 4 WAP (%)	Horseweed		Soybean yield (kg/ha)			
			Control	Density 7 WAP (plants/m ²)			Control	Density 7 WAP (plants/m ²)			Control	Density 7 WAP (plants/m ²)				
		7 WAP	12 WAP	7 WAP	7 WAP	12 WAP	7 WAP	7 WAP	12 WAP	7 WAP	12 WAP	7 WAP	12 WAP			
		-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----			
		(%)	(%)	(plants/m ²)	(kg/ha)	(%)	(plants/m ²)	(kg/ha)	(%)	(plants/m ²)	(kg/ha)	(%)	(plants/m ²)			
Glyphosate ^b	0.21	0	79	70	15	1717	0	65	52	17	1467	0	88	85	2	1278
Glyphosate ^b	0.42	0	94	88	1	2009	0	87	81	4	2232	0	93	96	1	1751
Glyphosate ^b	0.84	0	99	97	0	2081	0	98	97	0	2491	0	100	100	0	1406
Glyphosate ^b + ammonium sulfate	0.21 + 20.4 g/L	--	--	--	--	--	0	70	59	8	1857	0	83	83	7	1238
Glyphosate ^b + ammonium sulfate	0.42 + 20.4 g/L	--	--	--	--	--	0	88	90	1	2410	0	98	96	0	1578
Glyphosate ^b + 2,4-D ester	0.21 + 0.56	--	--	--	--	--	0	99	98	0	2540	0	100	99	0	1598
Glyphosate ^b + 2,4-D amine	0.21 + 0.56	--	--	--	--	--	0	100	98	0	2462	0	99	100	0	1449
Glyphosate ^c	0.21	--	--	--	--	--	0	58	60	11	1770	0	88	87	3	1271
Glyphosate ^c	0.42	--	--	--	--	--	0	84	80	4	2149	0	99	95	0	1595
Glyphosate ^c	0.84	--	--	--	--	--	--	--	--	--	--	0	100	99	0	1450
2,4-D ester	0.56	0	96	96	0	1939	0	97	98	0	2450	0	100	100	0	1317
2,4-D ester	1.12	0	100	100	0	2123	0	100	99	0	2581	0	100	100	0	1370
HOE-39866	0.56	--	--	--	--	--	0	98	96	0	2626	0	98	98	0	1556
HOE-39866	0.84	--	--	--	--	--	0	97	98	0	2692	0	100	99	0	1423
HOE-39866	1.68	--	--	--	--	--	0	99	100	0	2726	3	100	100	0	1494
Paraquat ^d	0.56	--	--	--	--	--	--	--	--	--	--	0	98	97	13	984

(continued next page)

Table 3. (continued)

Herbicide ^a	Rate (kg/ha)	1986				1987				1988			
		Soybean		Horseweed		Soybean		Horseweed		Soybean		Horseweed	
		injury 4 WAP (%)	yield 7 WAP (kg/ha)	Density 7 WAP (plants/m ²)	yield 7 WAP (kg/ha)	injury 4 WAP (%)	yield 7 WAP (kg/ha)	Density 7 WAP (plants/m ²)	yield 7 WAP (kg/ha)	injury 4 WAP (%)	yield 7 WAP (kg/ha)	Density 7 WAP (plants/m ²)	yield 7 WAP (kg/ha)
BAS-514 ^d	0.07	--	--	--	--	0	98	98	0	0	100	100	0
BAS-514 ^d	0.14	--	--	--	--	7	100	99	0	0	100	100	0
BAS-514 ^d	0.25	0	100	100	0	3	100	100	0	15	100	100	0
Standard PRE ^a		0	38	17	31	0	60	55	15	0	15	18	27
Untreated		0	0	0	93	0	0	0	211	0	0	100	43
LSD(0.05) ^e		n.s.	12	19	20	9	17	22	27	6	19	20	32

^aAll EPP treatments received a PRE (Standard PRE) application of paraquat (0.56 kg/ha) plus linuron (0.84 kg/ha) plus metolachlor (2.2 kg/ha).

^bIncludes surfactant (0.5% v/v) applied with 98 L/ha carrier volume.

^cIncludes surfactant (0.5% v/v) applied with 206 L/ha carrier volume.

^dIncludes surfactant (0.25% v/v).

^eComparisons valid within columns of the same year.

(20.4 g/L spray volume) to glyphosate did not improve horseweed control. O'Sullivan *et al.* (1981) and Suwunnamek and Parker (1975) observed increased glyphosate activity with the addition of ammonium sulfate. Glyphosate when applied either in 98 or 206 L/ha carrier volumes, obtained similar horseweed control. Downs (1981) reported similar findings, however Jordan (1981), O'Sullivan *et al.* (1981), Buhler and Burnside (1983) and Carlson and Burnside (1984) observed increased glyphosate phytotoxicity with reduced carrier volumes.

The lowest rate of 2,4-D ester (0.56 kg/ha) applied EPP provided greater than 95% horseweed control. When applied two weeks prior to soybean planting, no soybean injury or crop yield reduction was observed with 2,4-D at rates up to 1.1 kg/ha. The addition of 2,4-D ester (0.56 kg/ha) to glyphosate (0.2 kg/ha) provided horseweed control equivalent to 2,4-D ester applied alone.

The experimental herbicides HOE-39866 and BAS-514 provided excellent control of horseweed when applied EPP. HOE-39866 obtained greater than 95% control of horseweed at the lowest rate tested (0.56 kg/ha). HOE-39866 applied EPP significantly improved soybean yield as compared to the standard PRE herbicide program. Application of BAS-514 (0.07 kg/ha) provided greater than 98% horseweed control in 1987 and 1988. Soybean injury was observed with BAS-514 at rates greater than 0.14 kg/ha in 1987. During the dry 1988 growing season, crop injury was significant at the 0.25 kg/ha herbicide rate. Soybean yields, however were not significantly reduced by this injury (Table 3).

In 1988, paraquat was applied early preplant at 0.56 kg/ha followed by the standard PRE. This treatment provided excellent (97%) horseweed control. The horseweed density in this treatment consisted of 13 severely stunted plants/m². This herbicide program did not significantly improve soybean yield as compared to the standard PRE alone. Paraquat applied in this manner may suppress horseweed, however with normal rainfall these plants

may recover.

The herbicides glyphosate, 2,4-D ester, HOE-39866 or BAS-514 provided excellent control of horseweed when applied EPP. The use of EPP herbicide applications demonstrated outstanding weed control consistency in the environmentally diverse three year study. Fawcett *et al.* (1983) reported similar consistency among EPP applications.

Preemergence applications. The PRE application of paraquat (0.56 kg/ha) plus linuron (0.84 kg/ha) plus metolachlor (2.2 kg/ha) plus non-ionic surfactant (0.25% v/v) is commonly used by Michigan no-tillage soybean producers. The paraquat treatment desiccates horseweed plants, however the plants recover by generating new growth from axillary meristems within two to four weeks after treatment. The addition of BAS-514 to this standard PRE combination significantly improved horseweed control over the standard PRE combination alone (Table 4). In 1987, BAS-514 (0.07 kg/ha) added to the standard PRE provided 94% horseweed control. Soybean injury at this rate was slight, however as BAS-514 rates increased, soybean injury increased significantly. In 1988, BAS-514 caused significant crop injury at all rates and provided only fair to good horseweed control. These results may be due to inadequate rainfall for proper herbicide placement in the soil profile.

Greater horseweed control was obtained when glyphosate was substituted for paraquat in the standard PRE herbicide program. At the 0.84 kg/ha rate, glyphosate provided between 78% and 89% horseweed control in the three year study. The 0.84 kg/ha rate of glyphosate resulted in significantly greater soybean yield than paraquat in the 1986 and 1988 growing seasons. Glyphosate provided more consistent horseweed control than paraquat or HOE-39866 in the three environmentally different growing seasons.

A glyphosate spray solution was applied PRE to horseweed foliage with and without linuron. When applied without linuron, glyphosate was applied with surfactant (0.5% v/v)

Table 4. Early season horseweed control, horseweed density, soybean injury and late season horseweed control as affected by preemergence application of herbicides.

Herbicide ^a	Rate (kg/ha)	1986				1987				1988						
		Soybean		Horseweed		Soybean		Horseweed		Soybean		Horseweed				
		injury 4 WAP (%)	Density 7 WAP (plants/m ²)	Soybean yield (kg/ha)	Density 7 WAP (plants/m ²)	injury 4 WAP (%)	Density 7 WAP (plants/m ²)	Soybean yield (kg/ha)	Density 7 WAP (plants/m ²)	injury 4 WAP (%)	Density 7 WAP (plants/m ²)	Soybean yield (kg/ha)	Density 7 WAP (plants/m ²)			
Glyphosate ^b	0.21	0	58	45	28	1036	0	43	43	55	1167	0	30	10	129	204
Glyphosate ^b	0.42	0	67	62	7	1377	0	77	69	25	1844	0	43	28	45	690
Glyphosate ^b	0.84	0	78	78	2	1623	0	82	81	3	2194	0	83	89	3	1396
Glyphosate ^c	0.21	--	--	--	--	--	0	32	15	83	618	0	48	23	77	258
Glyphosate ^c	0.42	--	--	--	--	--	0	52	47	33	1395	0	48	33	47	589
HOE-39866	0.56	--	--	--	--	--	2	70	73	6	1999	0	65	55	7	907
HOE-39866	0.84	--	--	--	--	--	0	94	91	1	2359	0	78	73	4	1043
HOE-39866	1.68	0	87	83	1	2083	0	98	94	1	2476	0	80	77	2	1391
Paraquat ^d	0.56	0	38	17	31	852	0	60	55	15	1766	0	15	18	27	261
BAS-514 ^e	0.07	--	--	--	--	--	3	94	94	2	2471	8	55	43	14	693
BAS-514 ^e	0.14	--	--	--	--	--	3	90	95	3	2235	10	82	74	14	1129
BAS-514 ^e	0.25	--	--	--	--	--	47	98	97	1	1951	10	93	92	2	1046
Untreated		0	0	0	93	325	0	0	0	212	79	0	0	0	100	43
LSD(0.05) ^f		n.s.	12	19	20	483	9	17	22	27	570	6	19	20	32	554

^aPRE herbicide treatments include linuron (0.84 kg/ha) plus metolachlor (2.2 kg/ha).^bIncludes surfactant (0.5% v/v) applied with 98 L/ha carrier volume.^cGlyphosate plus surfactant (0.5% v/v) applied early. Metolachlor and linuron applied after the glyphosate application to dry leaf surface.^dIncludes surfactant (0.25% v/v).^eTreatment included paraquat (0.56 kg/ha) plus surfactant (0.25% v/v).^fComparisons valid within columns of the same year.

to the horseweed foliage PRE. After the glyphosate had dried on the leaf surface, linuron was applied late PRE to the horseweed. Antagonism was not apparent since horseweed control did not significantly differ in these different application methods. Selleck and Baird (1981) observed similar results with glyphosate and linuron on annual weedy species.

The nonselective herbicide HOE-39866 was also substituted for paraquat in the standard PRE treatment in 1987 and 1988. When applied at 0.84 kg/ha, HOE-39866 provided 91% and 73% (Table 4) control of horseweed in 1987 and 1988, respectively. The application of HOE-39866 (0.84 kg/ha or greater) provided significantly greater horseweed control than paraquat in 1987 and 1988. Soybean yields were significantly greater in the HOE-39866 treatments than in plots receiving paraquat. Similar observations were reported by Wilson *et al.* (1985).

The addition of chlorimuron to linuron (1:16) in the standard PRE program consistently improved horseweed control (Table 5). Horseweed control and soybean yield were significantly improved without crop injury at total herbicide rates of 0.84 and 0.62 kg/ha in 1987 and 1988, respectively. Good horseweed control was obtained at all rates tested in 1987, however less control was obtained in 1988 probably due to the drought conditions.

The substitution of metribuzin (0.42 kg/ha) for linuron in the standard PRE provided greater horseweed control in all years (Table 5). This concurs with observations made by Kapusta (1979). Adding chlorimuron to metribuzin (1:10) improved horseweed control compared to metribuzin applied alone at the same total herbicide rate. The use of metribuzin with or without chlorimuron provided significantly greater horseweed control in all years and resulted in significantly greater soybean yields in 1986 and 1988 than with linuron in the standard PRE herbicide program.

The herbicides imazaquin and imazethapyr did not provide adequate control of horseweed when substituted for linuron in the standard PRE herbicide program. Slack *et*

Table 5. Early season horseweed control, horseweed density, soybean injury and late season horseweed control as affected by preemergence application of soil active herbicides.

Herbicide ^a	Rate (kg/ha)	1986				1987				1988			
		Soybean		Horseweed		Soybean		Horseweed		Soybean		Horseweed	
		injury 4 WAP (%)	yield (kg/ha)	Density 7 WAP (plts/m ²)	yield (kg/ha)	injury 4 WAP (%)	yield (kg/ha)	Density 7 WAP (plts/m ²)	yield (kg/ha)	injury 4 WAP (%)	yield (kg/ha)	Density 7 WAP (plts/m ²)	yield (kg/ha)
Metribuzin	0.28	--	--	--	--	0	1820	83	79	0	1820	53	43
Metribuzin	0.42	0	83	78	2	0	1856	87	82	0	2130	70	75
Metribuzin + chlorimuron	0.28	--	--	--	--	0	2183	87	88	0	2183	54	53
Metribuzin + chlorimuron	0.42	--	--	--	--	2	2475	93	96	0	2475	60	60
Linuron	0.62	--	--	--	--	0	1435	73	62	0	1435	13	13
Linuron	0.84	0	38	17	31	0	852	60	55	0	1766	15	18
Linuron + chlorimuron	0.62	--	--	--	--	8	2160	92	85	0	2160	28	33
Linuron + chlorimuron	0.84	--	--	--	--	0	2423	88	87	0	2423	40	25
Imazaquin	0.14	0	58	48	14	0	1231	72	58	--	1540	--	--
Imazethapyr	0.14	0	57	30	31	0	1105	75	65	--	1646	--	--
Untreated		0	0	0	93	0	325	0	0	0	79	0	0
LSD(0.05) ^b		n.s.	12	19	20	9	483	17	22	6	570	19	20

^aPRE herbicide treatments include paraquat (0.56 kg/ha) plus metolachlor (2.2 kg/ha) plus surfactant (0.25% v/v).^bComparisons valid within columns of the same year.

al. (1988) observed similar results when imazaquin or imazethapyr was applied with paraquat. Since these herbicides consistently provided inadequate horseweed control in 1986 and 1987 they were not examined in 1988.

There appear to be several options available for improving horseweed control with PRE application of herbicide. The use of the nonselective postemergence herbicides glyphosate or HOE-39866 provide significantly greater horseweed control than paraquat. The addition of BAS-514 to paraquat improves horseweed control, however soybean injury was evident. The soil active herbicides metribuzin and metribuzin plus chlorimuron (10:1) provided significantly greater horseweed control than linuron in all years tested. The addition of chlorimuron to linuron (1:16) significantly improved horseweed control in three of four observations.

PRE applications of soil active herbicides in 1988 provided less horseweed control than the previous two years. This was possibly due to the inadequate rainfall for proper incorporation of these herbicides. According to Fawcett *et al.* (1983), this is one of the main disadvantages of PRE herbicide applications in no-tillage. Sequential applications of herbicides reduce the risk of herbicide failure under these environmental conditions.

EPP applications of nonselective herbicides followed by the standard PRE applied herbicide provided more effective and consistent horseweed control than PRE applications of nonselective herbicides. This is explained in part by (1) the EPP program received a second herbicide application containing paraquat PRE, and (2) due to taller horseweed plants at the PRE application time.

Sequential Applications. Preliminary research was conducted in 1987 to examine sequential applications of soil active herbicides for control of horseweed. The sequential treatments were designed such that 2/3 of the total herbicide rate was applied EPP with a non-ionic

surfactant. The remaining 1/3 of the herbicide was applied PRE with paraquat (0.56 kg/ha) plus metolachlor (2.2 kg/ha) plus non-ionic surfactant (0.25% v/v). The herbicide linuron (0.84 kg/ha) and metribuzin (0.42 kg/ha) were applied PRE and sequentially in 1987. Sequential applications of these herbicides provided equal or greater horseweed control and soybean yield than a single PRE application of the same total amount of herbicide (Table 6).

The research program was expanded in 1988 to include the herbicides linuron plus chlorimuron (16:1) and metribuzin plus chlorimuron (10:1). The herbicides linuron and linuron plus chlorimuron provided significantly greater horseweed control when applied sequentially. Sequential applications of linuron provided significantly greater soybean yields than a single PRE application. Metribuzin applied sequentially with and without chlorimuron also provided greater horseweed control than the single PRE application. Ritter and Harris (1982) and Fawcett *et al.* (1983) observed similar results with sequential applications.

The large differences in horseweed control between sequential and PRE applications in 1988 were probably due to inadequate rainfall for incorporation of the herbicides following the PRE application. The EPP portion of the sequential application received adequate rainfall for herbicide incorporation, however little rainfall occurred after the PRE application resulting in poor weed control. This demonstrates the potential advantages of an EPP or sequential herbicide program.

Table 6. Comparison of single preemergence and sequential application of soil active herbicides for control of horseweed.

1987						
Herbicide	Rate		Soybean injury 4 WAP (%)	Horseweed Control		Soybean yield (kg/ha)
	EPP ^a	PRE ^b		7 WAP	Density 12 WAP 7 WAP (plts/m ²)	
	(kg/ha)			------(%)-----		
Linuron		0.84	0	60	55	1766
Linuron	0.56	0.28	0	68	58	1763
Metribuzin		0.42	0	87	82	2130
Metribuzin	0.28	0.14	2	100	100	2464
Untreated			0	0	0	212
LSD _(0.05) ^c			n.s.	17	22	27
						79
1988						
Linuron		0.84	0	15	18	27
Linuron	0.56	0.28	8	75	82	6
Linuron + chlorimuron		0.63	0	28	33	68
Linuron + chlorimuron	0.35	0.28	0	92	90	2
Metribuzin		0.42	0	70	75	1
Metribuzin	0.28	0.14	0	88	91	2
Metribuzin + chlorimuron		0.42	0	60	60	5
Metribuzin + chlorimuron	0.28	0.14	0	97	95	1
LSD _(0.05) ^c			6	20	20	32
						554

^aHerbicides applied EPP include surfactant (0.25% v/v).^bPRE herbicide applications include paraquat (0.56 kg/ha) plus metolachlor (2.2 kg/ha) plus surfactant (0.25% v/v).^cComparisons valid within columns of a given year.

BIBLIOGRAPHY

- Brown, S. M. and T. Whitwell. 1988. Influence of tillage on horseweed, *Conyza canadensis*. Weed Tech. 2:269-270.
- Buhler, D. D. and O. C. Burnside. 1983. Effect of spray components on glyphosate toxicity to annual grasses. Weed Sci. 31:124-130.
- Carlson, K. L. and O. C. Burnside. 1984. Comparative phytotoxicity of glyphosate, SC-0224, SC-0545 and HOE-00661. Weed Sci. 32:841-844.
- Downs, J. P. 1981. Evaluations of glyphosate rates and carrier volumes for no-till. Proc. North Cent. Weed Control Conf. 36:92.
- Elmore, C. D. and L. G. Heatherly. 1983. Preplant tillage effects on the weed flora in soybeans. Abst. Weed Sci. Soc. Am. 23:66-67.
- Fawcett, R. S., M. D. K. Owen and P. C. Kassel. 1983. Early preplant treatments for weed control in no-till corn and soybeans. Proc. North Central Weed Control Conf. 38:112-117.
- Jordan, T. N. 1981. Effects of diluent volumes and surfactant on the phytotoxicity of glyphosate to bermudagrass (*Cynodon dactylon*). Weed Sci. 29:79-83.
- Kapusta, G. 1979. Seedbed tillage and herbicide influence on soybean (*Glycine max*) weed control and yield. Weed Sci. 27:520-526.
- McCutchen, T. C. and R. M. Hayes. 1983. Control of horseweed, cocklebur, and smartweed in no-till soybeans. Proc. So. Weed Sci. Soc. 37:20-26.
- O'Sullivan, P. A., J. T. O'Donovan and W. M. Hamman. 1981. Influence of non-ionic surfactants, ammonium sulphate, water quality and spray volume on the phytotoxicity of glyphosate. Can. J. Plant Sci. 61:391-400.
- Ritter, R. L. and T. C. Harris. 1982. Weed control in no-tillage corn and full season no-tillage soybeans on the eastern shore of Maryland. Proc. Northeastern Weed Sci. Soc. 36:18.
- Selleck, G. W. and D. D. Baird. 1981. Antagonism with glyphosate and residual herbicide combinations. Weed Sci. 29:185-190.
- Slack, L. H., R. B. Wells and W. W. Witt. 1988. Chlorimuron, imazaquin, and imazethapyr performance in no-tillage, full season soybeans. Abst. Weed Sci. Soc. Am. 28:82-83.

- Stougaard, R. N., G. Kapusta and G. Roskamp. 1984. Early preplant herbicide applications for no-till soybeans weed control. *Weed Sci.* 32:293-298.
- Suwunnamek, U. and C. Parker. 1975. Control of *Cyperus rotundus* with glyphosate: the influence of ammonium sulphate and other additives. *Weed Res.* 15:13-19.
- Wilson, H. P., T. E. Hines, R. R. Bellinder and J. A. Grande. 1985. Comparisons of HOE-39866, Sc-0224, paraquat, and glyphosate in no-till corn (*Zea mays*). *Weed Science* 33:531-536.
- Wilson, J. S. and A. D. Worsham. 1988. Combinations of nonselective herbicides for difficult to control weeds in no-till corn (*Zea mays*), and soybeans (*Glycine max*). *Weed Sci.* 36:648-652.

CHAPTER 4

HORSEWEED [*Conyza canadensis* (L.) Cronq.] CONTROL WITH FOLIAR APPLIED HERBICIDES

ABSTRACT

The nonselective foliar applied herbicides glyphosate, HOE-39866, paraquat and 2,4-D ester were applied to horseweed at 5, 10, and 20-cm average horseweed heights. Glyphosate (0.42 kg/ha) effectively controlled 5-cm horseweed, however 0.84 kg/ha were needed to control 10 and 20-cm tall horseweed. HOE-39866 (0.84 kg/ha) and paraquat (0.56 kg/ha) did not provide adequate control of 5 and 10-cm horseweed but obtained greater than 93% control of 20-cm horseweed in 1987. HOE-39866 provided excellent horseweed control at all timings in 1988. Significantly less control was obtained with paraquat at horseweed heights of 10 and 20 cm in 1988. Applications of 2,4-D ester (1.12 kg/ha) provided less than 83% horseweed control in both years.

Applications of the selective postemergence soybean herbicides bentazon and chlorimuron did not provide consistent effective control of 5, 10 and 20-cm tall horseweed. These herbicides provided some control of 5-cm tall horseweed, however due to horseweed height variability, control was not complete.

Ropewick applications of glyphosate decreased horseweed flower production, however horseweed control was inadequate. Horseweed control was greater with two applications

from opposite directions than from single applications. Complete horseweed control by this method was difficult to obtain due to variability in horseweed height and apparent acropetal translocation of glyphosate. Plant regrowth from axillary meristems below the point of herbicide application was observed with this system of application. Nomenclature: glyphosate, *N*-(phosphonomethyl)glycine; HOE-39866, ammonium-(3-amino-3-carboxy propyl)-methyl-phosphinate; paraquat, 1-1'-dimethyl-4-4'-bipyridinium ion; 2,4-D, (2,4-dichlorophenoxy) acetic acid; bentazon, 3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide; chlorimuron, 2-[[[[[4-chloro-6-methoxy-2-pyrimidinyl]amino]carbonyl]amino]sulfonyl]benzoic acid; horseweed, *Coryza canadensis* (L.) Cronq. #¹ ERICA; soybean, *Glycine max* (L.) Merr. # GLXMA.

¹Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

INTRODUCTION

Effective horseweed control in no-tillage soybean production requires complete control of existing vegetation prior to crop emergence (Anonymous, 1983) as well as full season weed control. Nonselective foliar herbicides are usually applied in combination with soil active herbicides to control existing vegetation and later germinating weed species (Fawcett *et al.*, 1983). When soil active herbicides fail to control germinating weeds, mechanical row cultivation often provides ineffective control due to the firm soil conditions (Richey *et al.*, 1977). No-tillage producers must rely upon selective postemergence herbicides (Fawcett, 1983; Kapusta, 1979) or ropewick application of nonselective herbicides for postemergence weed control.

Ropewick herbicide application is a method by which a nonselective systemic herbicide, such as glyphosate, is applied to weeds extending above the crop canopy. The ropewick applicator uses loosely woven nylon wick to convey herbicide, by capillary movement, to weedy plants contacting the wick. The applicator height is adjustable to allow for varying crop height. This method of glyphosate application provides selective control of tall weeds without crop injury (Dale, 1981).

Researchers have examined the use of nonselective herbicides in combination with soil active herbicides for control of horseweed in no-tillage soybeans. Only limited research has examined the effect of horseweed height on the degree of control provided by nonselective herbicide applications. In Texas, Henniger *et al.* (1989) observed effective control of horseweed rosettes with 2,4-D, glyphosate and HOE-39866. The herbicide 2,4-D applied

at high rates and HOE-39866 effectively controlled 10-cm tall horseweed. HOE-39866 was the only herbicide to effectively control 30-cm tall horseweed. Paraquat did not provide adequate horseweed control according to Henniger *et al.* (1989).

Limited research has examined horseweed control with selective postemergence herbicides. Hagood and Davis (1986) reported unsatisfactory control of horseweed with either acifluorfen [5-[2-chloro-4-(trifluoro methyl)phenoxy]-2-nitrobenzoic acid] or bentazon. Currently, no research has examined ropewick application of glyphosate for control of horseweed.

Studies were conducted in 1987 and 1988 to identify nonselective and selective herbicides which provide effective and consistent horseweed control. Studies examined the effect of herbicide rate and horseweed height on control. A study was also conducted to examine horseweed control from ropewick application of glyphosate.

MATERIALS AND METHODS

Nonselective herbicide applications. Research was conducted in Shiawassee and Ingham Counties in 1987 and 1988, respectively. The soil type in 1987 was a Macomb loam (Fine-loamy, mixed, mesic Aquallic Hapludalfs) with 1.4% organic matter and a 6.5 pH. The soil at the 1988 site consisted of Riddles-Hillsdale sandy loam complex (Riddles, Fine-loamy, mixed, mesic Typic Hapludalfs; Hillsdale, Coarse-loamy, mixed, mesic Typic Hapludalfs) with 1.5% organic matter and a pH of 5.8. The studies were arranged as a randomized complete block with four and three replications in 1987 and 1988, respectively. Plot areas were at least 3 m wide by 9 m in length.

Herbicide applications were made with a tractor mounted compressed air sprayer calibrated to deliver 98 L/ha or 206 L/ha at 207 kPa. Glyphosate treatments were applied

at 98 L/ha carrier volume. Herbicides were applied at three timings with average horseweed heights of 5, 10 and 20 cm. The environmental conditions for each timing are shown in Table 1. Horseweed densities averaged 267 and 124 plants/m² in 1987 and 1988, respectively.

Horseweed control was visually evaluated two, four and six weeks after treatment. Evaluations were based on a scale where zero was no visible horseweed injury and 100 represented dead plants. Data were subjected to analysis of variance with means separated by least significant difference at the 0.05 level of significance.

Selective herbicide applications. Field experiments were conducted in Shiawassee County in 1987 and 1988. The soil at the 1987 site was a Macomb loam with 1.4% organic matter and a 7.1 pH. The 1988 location had a Boyer loamy sand (Coarse-loamy, mixed, mesic Typic Hapludalfs) with 1.2% organic matter and a pH of 5.0. Treatments were arranged as a randomized complete block with three replications in both years. Plots at all locations were at least 3 m wide and 9 m in length.

The soybean varieties 'Hodgson 78', 'BSR 101' were no-tillage planted in 18 and 71-cm row spacings in 1987 and 1988, respectively. Soybeans were planted on May 23, 1987 and May 26, 1988. Prior to soybean emergence, a preemergence application of paraquat (0.56 kg/ha) plus linuron (0.84 kg/ha) plus metolachlor (2.2 kg/ha) plus non-ionic surfactant² (0.25% v/v) was made to the 1987 experiment site. Imazaquin (0.14 kg/ha) was substituted for linuron in the above treatment at the 1988 location.

Herbicide applications were made with a tractor mounted compressed air sprayer calibrated to deliver 281 L/ha at 345 kPa. Selective postemergence herbicides were applied to average horseweed regrowth of 5, 10 and 20 cm in height. Table 2 shows the

²X-77. Valent U.S.A. Corp., 1333 N. California Blvd., Walnut Creek, CA 94596.

Table 1. Environmental conditions for nonselective foliar herbicide applications in 1987 and 1988.

	1987		
Date	5/13	6/2	6/13
Time	4 pm	8 am	8 pm
Cloud cover (%)	10	20	Clear
Air temperature (°F)	70	73	69
Relative humidity (%)	40	80	72
Leaf surface moisture (1=wet, 5=dry)	4	1.5	4
Horseweed height (cm) ave (range)	5 (0.6-7.5)	10 (0.6-29)	20 (3-51)
	1988		
Date	6/3	6/17	6/27
Time	7 am	7 am	7 pm
Cloud cover (%)	10	10	10
Air temperature (°F)	48	55	82
Relative humidity (%)	68	68	20
Leaf surface moisture (1=wet, 5=dry)	4	3.5	5
Horseweed height (cm) ave (range)	5 (2-15)	10 (3-18)	20 (4-48)

Table 2. Environmental conditions for selective foliar herbicide applications in 1987 and 1988.

	1987		
Date	6/10	6/24	7/4
Time	10 am	6 pm	9 am
Cloud cover (%)	Clear	Clear	10
Air temperature (°F)	60	93	64
Relative humidity (%)	50	48	56
Leaf surface moisture (1=wet, 5=dry)	3.5	4	3
Horseweed height (cm) ave (range)	5 (3-30)	10 (4-48)	20 (4-74)
	1988		
Date	6/17	6/23	7/1
Time	10 am	8 am	8 pm
Cloud cover (%)	Clear	25	Clear
Air temperature (°F)	77	75	65
Relative humidity (%)	45	40	44
Leaf surface moisture (1=wet, 5=dry)	5	5	5
Horseweed height (cm) ave (range)	5 (1-10)	10 (3-23)	20 (3-35)

environmental conditions for each application timing. Horseweed densities averaged 152 and 105 plants/m² at the 1987 and 1988 research sites, respectively.

Visual evaluation of horseweed control and soybean injury was taken at 2, 4 and 6 weeks after treatment. Data were subjected to analysis of variance with means separated by least significant difference at the 0.05 level of significance.

Ropewick application of glyphosate. Research was conducted in 1987 at the Michigan State University Soil Science farm to examine ropewick applications of glyphosate for control of horseweed. The soil type was a Riddles-Hillsdale sandy loam with 1.5% organic matter and 5.8 pH. Treatments were designed as a randomized complete block with three replications. Plot dimensions were 3 m wide and 11 m in length.

Treatments were applied with a tractor mounted ropewick, 2.5 m length, travelling 5.6 km/hr. A solution containing 120 g glyphosate/L was applied to horseweed plants on July 14, 1987. Treatments consisted of one and two ropewick applications with opposite directions of travel with application heights of 38, 64 or 89-cm. Horseweed plants averaged 84 cm in height with a range of 15-140 cm. The 38 cm applicator height would not be practical since soybean height would exceed the applicator height at the time of application. Horseweed density averaged 20 plants/m² at this site.

Evaluation for horseweed control was taken visually. Control ratings were based on 0-100 scale with 0 representing no horseweed injury and 100 being horseweed death. The percentage of the total horseweed population having flowers was determined 57 days after treatment. Treatment percentages were calculated from stand counts taken within three randomly chosen 1 m² areas for each plot. These data were subjected to analysis of variance with means separated by least significant difference to the 0.05 level.

RESULTS AND DISCUSSION

Nonselective herbicide application. Foliar application of glyphosate at 0.43 and 0.84 kg/ha provided greater than 87% control of 5 cm tall horseweed in 1987 and 1988 (Table 3). Glyphosate applied at 0.42 kg/ha provided significantly less control of horseweed heights greater than 5 cm. Horseweed control was not significantly affected by plant height in either year to glyphosate rates of 0.84 kg/ha. When horseweed height exceeded 5 cm, the 0.84 kg/ha rate of glyphosate provided significantly greater horseweed control than the 0.42 kg/ha rate. During the 1987 growing season, glyphosate (0.84 kg/ha) applied to 5 and 10-cm tall plants obtained horseweed control superior to the herbicides HOE-39866, paraquat or 2,4-D ester.

When applied to 5 and 10-cm plant heights, the herbicides HOE-39866 and paraquat did not provide adequate horseweed control in 1987. Horseweed plants in these plots were desiccated, however new growth was initiated from apical or axillary meristems within three weeks after treatment. Greater than 93% control of horseweed was obtained when either HOE-39866 (0.84 kg/ha) or paraquat (0.56 kg/ha) were applied to 20-cm tall horseweed in 1987. Wilson *et al.* (1985) observed greater horseweed control when HOE-39866 was applied to taller horseweed plants. The large increase in horseweed control provided by paraquat may be due in part to the 8 p.m. time of application (Table 1). Putnam and Ries (1968) observed greater weed control from evening paraquat applications than mid-day applications. Evening applications allowed paraquat to be transported from the leaves in a non-toxic state. This allowed greater paraquat distribution in the plant prior to light

Table 3. Horseweed control provided by nonselective foliar applied herbicides as affected by horseweed height at application.

Herbicide	Rate (kg/ha)	Horseweed control ^a					
		1987			1988		
		5 cm ^b	10 cm	20 cm	5 cm	10 cm	20 cm
		------(%)-----					
Glyphosate + surfactant	0.42 + 0.5% v/v	88	48	76	88	45	51
Glyphosate + surfactant	0.84 + 0.5% v/v	89	84	96	93	86	76
HOE-39866	0.84	38	43	98	100	94	98
Paraquat + surfactant	0.56 + 0.25% v/v	15	23	94	91	58	77
2,4-D ester	0.56	25	35	58	34	26	41
2,4-D ester	1.12	68	43	82	76	59	40
LSD _(0.05) ^c			11			20	

^aVisual evaluations taken 6 weeks after treatment.^bAverage horseweed height at the time of herbicide application.^cComparisons valid within and between columns of the same year.

conversion into a toxic state.

HOE-39866 (0.84 kg/ha) applied to 5, 10 and 20-cm tall horseweed provided greater than 93% control in 1988. Paraquat (0.56 kg/ha) applications in 1988 provided 91% control of 5 cm tall plants and less control of 10 and 20 cm horseweed heights. Application of 2,4-D ester provided less than 83% horseweed control in 1987 and 1988.

The contact herbicides HOE-39866 and paraquat provided better horseweed control in 1988 than in 1987. Weather conditions for each year were responsible in part for the difference in horseweed control. As shown in Table 4, the 1987 research site received adequate rainfall, however in 1988, rainfall was below normal during the months of May and June. Since there was adequate rainfall in 1987, horseweed plants grew actively and were able to overcome the temporary stress caused by the herbicide. Plants growing in 1988 were moisture stressed before and after herbicide applications. The combination of moisture and herbicide induced stress reduced the chances for plant recovery and regrowth.

Selective herbicide applications. Horseweed control obtained with selective postemergence herbicides varied a great deal from 1987 to 1988. This variability is due in part to the differing weather patterns. The 1987 growing season received adequate rainfall, however both 1988 locations received below normal rainfall in the months of May and June (Table 5). Due to the dry soil conditions, soybean seed planted at the Shiawassee 1988 location did not germinate uniformly.

Postemergence application of bentazon (0.84 kg/ha) provided greater than 91% control of 5-cm tall horseweed in 1987 (Table 6). Liquid nitrogen fertilizer (28% nitrogen) with bentazon was significantly more effective than crop oil concentrate (COC) at the 10-cm horseweed height application. The application of bentazon (1.12 kg/ha) plus COC (2.3 L/ha) to 5-cm tall horseweed was the only 1988 bentazon treatment that provided greater

Table 4. Total and average monthly rainfall for the nonselective herbicide research conducted in 1987 and 1988.

Month	Total monthly rainfall			
	Shiawassee county		Ingham county	
	1987	Average	1988	Average
	------(cm)-----			
April	5.8	12.6	14.8	12.6
May	7.2	8.8	5.8	7.1
June	9.3	4.6	1.3	5.4
July	9.5	7.9	10.1	9.4

Table 5. Total and average monthly rainfall for selective foliar herbicide research conducted in 1987 and 1988, Shiawassee County.

Year	Total monthly rainfall			
	April	May	June	July
	----- (cm) -----			
1987	4.6	6.4	4.9	7.0
1988	9.7	1.1	1.2	8.9
30 year ave	7.2	6.5	8.4	6.9

Table 6. Horseweed control provided by selective foliar applied herbicides as affected by horseweed height at application.

		Horseweed control - 6 weeks after treatment											
Herbicide	Rate (kg/ha)	Shiawassee 1987				Shiawassee 1988				Clinton 1988			
		Average horseweed height at application - (cm)				Average horseweed height at application - (cm)				Average horseweed height at application - (cm)			
		5	10	20	------(%)-----	5	10	20	------(%)-----	5	10	20	------(%)-----
Bentazon + crop oil conc	0.84 + 2.3 L/ha	100	55	87		42	52	53		58	78	40	
Bentazon + crop oil conc	1.12 + 2.3 L/ha	--	--	--		86	57	45		29	65	55	
Bentazon + 28% nitrogen	0.84 + 9.2 L/ha	92	83	80		45	35	18		42	62	48	
Bentazon + 28% nitrogen	1.12 + 9.2 L/ha	--	--	--		68	57	32		48	42	23	
Chlorimuron + surfactant	9.0 g/ha + 0.25% v/v	--	78	83		23	23	12		81	47	72	
Chlorimuron + surfactant	13.0 g/ha + 0.25% v/v	--	56	72		33	27	20		86	38	53	
Chlorimuron + 28% nitrogen	9.0 g/ha + 9.2 L/ha	--	--	--		38	22	8		73	55	43	
Chlorimuron + 28% nitrogen	13.0 g/ha + 9.2 L/ha	--	--	--		23	17	17		80	60	28	

(continued next page)

Table 6. (continued)

Herbicide	Rate (kg/ha)	Horseweed control - 6 weeks after treatment											
		Shiawassee 1987					Shiawassee 1988					Clinton 1988	
		Average horseweed height at application - (cm)											
		5	10	20	20	5	5	10	20	5	10	20	
		------(%)-----					------(%)-----					------(%)-----	
Acifluorfen + surfactant	0.56 + 0.25% v/v	7	27	8	17	5	18	20	7	33			
Fomosaferen + surfactant	0.28 + 0.25% v/v	41	25	27	8	0	2	32	15	13			
Lactofen + surfactant	0.21 + 0.25% v/v	22	15	10	7	0	0	42	8	7			
Chloramben + crop oil conc	2.0 + 2.3 L/ha	--	--	--	15	5	10	37	33	30			
LSD(0.05) ^a		26			25			36					

^aComparisons valid within and between columns of the same year.

than 80% horseweed control. Horseweed control with bentazon applied with either 28% nitrogen or crop oil concentrate in 1988 was similar. Horseweed control with bentazon generally decreased as horseweed height increased. Taller horseweed plants were suppressed by bentazon, however regrowth from apical meristems or axillary meristems was observed approximately two weeks after treatment.

Chlorimuron applied at 9 and 13 g/ha with non-ionic surfactant provided less than 84% horseweed control in 1987. Chlorimuron did not provide adequate horseweed control at the 1988 location. Chlorimuron effectively destroyed horseweed apical meristems and suppressed plant regrowth in 1987. This herbicide did not appear to cause plant death, instead plant growth was suppressed temporarily. Approximately four to six weeks after herbicide treatment, new horseweed shoots were observed at axillary meristems.

The selective postemergence herbicides acifluorfen, lactofen [(±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate], fomesafen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide] and chloramben [3-amino-2,5-dichloro benzoic acid] were also evaluated. Application of these herbicides provided less than 35% horseweed control regardless of horseweed height. In most cases, the plots appeared similar to the untreated control plots.

Currently available selective postemergence herbicide options for use in soybeans do not provide consistent, effective horseweed control. Bentazon will provide control of 5-cm horseweed under optimal growing conditions, however control is often inconsistent. Chlorimuron appears to temporarily suppress the growth of small horseweed for up to four to six weeks after treatment.

Consistent and complete horseweed control with selective postemergence herbicides is currently not feasible for several reasons. Currently available herbicides do not effectively control horseweed greater than 5 cm in height. This is due in part to the ability of

horseweed plants to initiate regrowth from axillary meristems making it difficult to provide complete horseweed control. Horseweed height within a field varies greatly at the time of herbicide application (Table 2). Due to this height variability and the inability of herbicides to effectively control large horseweed, complete horseweed control is very difficult with single applications of currently available selective postemergence herbicides.

Ropewick application of glyphosate. Ropewick applied glyphosate generally did not provide adequate horseweed control (Table 7). The only treatment providing adequate horseweed control required two applications in opposite directions 38 cm above the soil surface. This treatment, however is not practical since crop height at the time of application would exceed the applicator height causing substantial herbicide injury to the crop.

Horseweed control and number of flowering plants were influenced by the amount of plant tissue contacting the herbicide during application. Two ropewick applications of glyphosate made in opposite directions provided significantly greater horseweed control and significantly fewer flowering plants than a single ropewick application at 38 and 89 cm applicator heights. Plants receiving two applications were completely dessicated on both sides of the plant. The single applications caused plant desiccation only to the side of the plant contacted by the herbicide. The opposite side of the plant remained green and continued to grow and flower at axillary meristems. Horseweed control increased and flowering decreased significantly as the ropewick applicator height decreased. Horseweed plants encountered very little herbicide induced desiccation below the point of herbicide contact. This suggests that glyphosate did not translocate downward in the plant treated at this stage of physiological development.

Complete control of horseweed or reduction of flowering is not feasible with ropewick applications of glyphosate. Without basipetal translocation, glyphosate cannot effectively

Table 7. Ropewick application of glyphosate for controlling horseweed and reducing flower production in 1987.

Number of applications	Applicator height (cm)	Horseweed	
		Control 45 DAT	Flower production 57 DAT
		------(%)-----	
0	--	0	100
1	38	58	25
	64	72	28
	89	45	57
2	38	95	11
	64	65	30
	89	70	38
LSD _(0.05) ^a		9	12

^aComparisons valid within columns.

destroy horseweed axillary meristems below the point of herbicide contact. Destruction of these axillary meristems is essential to prohibit further growth and flower production by horseweed plants.

In summary, broadcast application of glyphosate is the only currently registered nonselective herbicide program which provides consistent and effective control of horseweed. When applied at 0.84 kg/ha, horseweed control was not significantly reduced by horseweed heights up to 20 cm. The selective foliar applied herbicides bentazon and chlorimuron provided inconsistent control and suppression of 5-cm tall horseweed. The most probable cause for horseweed control inconsistency was the variability of horseweed height at the time of herbicide application. Ropewick application of glyphosate provided inadequate control of horseweed and flower production.

BIBLIOGRAPHY

- Anonymous. 1983. Control vegetation for successful no-till corn. Conservation Tillage Guide. Successful Farming, Des Moines, IA p.14.
- Dale, J. E. 1981. The rope-wick applicator - A new method of applying glyphosate. Proc. Southern Weed Sci. Soc. 31:332.
- Fawcett, R. S. 1983. Weed control in conservation tillage systems. Proc. North Central Weed Control Conf. 38:67.
- Fawcett, R. S., M. D. K. Owen and P. C. Kassel. 1983. Early preplant treatments for weed control in no-till corn and soybeans. Proc. North Central Weed Control Conf. 38:112-117.
- Hagood, E. S. Jr. and P. H. Davis. 1986. Horseweed control in no-till corn and soybeans. Proc. Northeast Weed Sci. Soc. 40:26.
- Henniger, C. G., J. W. Keeling and J. R. Abernathy. 1989. Horseweed *Conyza canadensis* (L.) Cronq. Control in Conservation Tillage Systems. Weed Sci. Soc. Am. Abst. 19:12.
- Kapusta, G. 1979. Seedbed tillage and herbicide influence on soybean (*Glycine max*). Weed Control and Yield. Weed Sci. 27:520-526.
- Putnam, A. R. and S. K. Ries. 1968. Factors influencing the phytotoxicity and movement of paraquat in quackgrass. Weed Sci. 16:336-339.
- Richey, C. B., D. R. Griffith and S. D. Parsons. 1976. Yields and cultural energy requirements for corn and soybeans with various tillage-planting systems. Adv. Agron. 29:141-182.
- Wilson, H. P., T. E. Hines, R. R. Bellinder and J. A. Grande. 1985. Comparisons of HOE-39886, SC-0224, paraquat, and glyphosate in no-till corn (*Zea mays*). Weed Sci. 33:531-536.

