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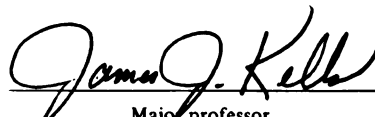
WILD CARROT [DAUCUS CAROTA L.]  
MANAGEMENT IN CONTINUOUS  
NO-TILLAGE SYSTEMS

presented by

Jeff Michael Stachler

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**WILD CARROT [*DAUCUS CAROTA* L.] MANAGEMENT  
IN CONTINUOUS NO-TILLAGE SYSTEMS**

**By**

**Jeff Michael Stachler**

**A THESIS**

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## **ABSTRACT**

### **WILD CARROT [*Daucus carota* L.] MANAGEMENT IN CONTINUOUS NO-TILLAGE SYSTEMS**

**By**

**Jeff Michael Stachler**

Wild carrot is a weed problem in Michigan no-tillage corn and soybean production. Research was conducted to identify effective herbicides for control of wild carrot. In the greenhouse, acetochlor, cyanazine, metribuzin plus chlorimuron, and linuron plus chlorimuron applied preemergence and bentazon, cyanazine, prosulfuron, halosulfuron, and clopyralid applied postemergence provided greater than 75% control of seedling wild carrot. In the field, atrazine, primisulfuron, halosulfuron, and nicosulfuron applied to no-tillage corn and treatments containing chlorimuron applied to no-tillage soybean consistently gave greater than 71% control of overwintered wild carrot. Glyphosate applied in October provided greater than 74% control.

Greenhouse studies were conducted to determine the sensitivity of wild carrot populations to 2,4-D. Among 14 wild carrot populations, control with 2,4-D at 1.1 kg/ha ranged from 18 to 91%. Wild carrot varied in its response to 2,4-D among and within populations, as well as within an umbel.

**The author wishes to dedicate this thesis  
to Wendi Stachler, wife, and  
Clarence and Veronica Stachler, grandparents.**

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## TABLE OF CONTENTS

|                                                |    |
|------------------------------------------------|----|
| List of Tables                                 | ix |
| List of Figures                                | xi |
| <b>Chapter 1. Review of Literature.</b>        |    |
| Introduction                                   | 1  |
| Tillage                                        | 1  |
| History                                        | 1  |
| No-Tillage crop production                     | 3  |
| Influence of tillage on weed population shifts | 4  |
| Wild Carrot                                    | 4  |
| Name                                           | 4  |
| Description                                    | 5  |
| Variation                                      | 6  |
| Biology                                        | 6  |
| Ecology                                        | 8  |
| Habitat                                        | 9  |
| Distribution                                   | 9  |
| Control                                        | 10 |
| Chemical                                       | 10 |

|                                                                                                 |    |
|-------------------------------------------------------------------------------------------------|----|
| Mechanical .....                                                                                | 11 |
| Herbicide Usage in Cultivated Carrot Production .....                                           | 11 |
| Weed Resistance to 2,4-D .....                                                                  | 12 |
| Literature Cited .....                                                                          | 14 |
| <b>Chapter 2. Wild Carrot (<i>Daucus carota</i> L.) Control in No-Tillage Cropping Systems.</b> |    |
| Abstract .....                                                                                  | 18 |
| Introduction .....                                                                              | 19 |
| Materials and Methods .....                                                                     | 21 |
| Control of seedling wild carrot in the greenhouse .....                                         | 21 |
| Preemergence study .....                                                                        | 22 |
| Postemergence study .....                                                                       | 23 |
| Control of established wild carrot with fall-applied herbicides .....                           | 24 |
| Control of overwintered wild carrot .....                                                       | 25 |
| Soybean study .....                                                                             | 26 |
| Corn study .....                                                                                | 27 |
| Results and Discussion .....                                                                    | 27 |
| Control of seedling wild carrot in the greenhouse .....                                         | 27 |
| Preemergence study .....                                                                        | 27 |
| Postemergence study .....                                                                       | 28 |
| Control of established wild carrot with fall-applied herbicides .....                           | 29 |
| Control of overwintered wild carrot .....                                                       | 29 |

|                                                                      |    |
|----------------------------------------------------------------------|----|
| Soybean study . . . . .                                              | 29 |
| Corn study . . . . .                                                 | 32 |
| Conclusions . . . . .                                                | 33 |
| Further Research . . . . .                                           | 34 |
| Literature Cited . . . . .                                           | 36 |
| <br><b>Chapter 3. Differential Response of Wild Carrot to 2,4-D.</b> |    |
| Abstract . . . . .                                                   | 51 |
| Introduction . . . . .                                               | 51 |
| Materials and Methods . . . . .                                      | 52 |
| General experimental procedures . . . . .                            | 52 |
| Field research location study . . . . .                              | 55 |
| Sample study . . . . .                                               | 55 |
| Individual umbel study . . . . .                                     | 55 |
| Results and Discussion . . . . .                                     | 56 |
| Field research location study . . . . .                              | 56 |
| Sample study . . . . .                                               | 56 |
| Individual umbel study . . . . .                                     | 57 |
| Sample D (resistant) . . . . .                                       | 57 |
| Sample F (intermediate) . . . . .                                    | 57 |
| Sample G (susceptible) . . . . .                                     | 58 |
| General discussion . . . . .                                         | 58 |
| Literature Cited . . . . .                                           | 60 |

## LIST OF TABLES

### **Chapter 2. Wild Carrot (*Daucus carota* L.) Control in No-Tillage Cropping Systems.**

|           |                                                                                                                                        |    |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 1.  | Fall herbicide application information study for control of established wild carrot . . . . .                                          | 39 |
| Table 2.  | Herbicide application information for no-tillage soybean study . . . . .                                                               | 40 |
| Table 3.  | Herbicide application information for no-tillage corn study .                                                                          | 41 |
| Table 4.  | Response of seedling wild carrot to various preemergence herbicides . . . . .                                                          | 42 |
| Table 5.  | Response of seedling wild carrot to postemergence herbicides . . . . .                                                                 | 43 |
| Table 6.  | Control of established wild carrot with fall herbicide application, 1994 . . . . .                                                     | 44 |
| Table 7.  | Control of overwintered wild carrot with preemergence herbicides in no-tillage soybean . . . . .                                       | 45 |
| Table 8.  | Control of overwintered wild carrot with early preplant versus preemergence applications of glyphosate in no-tillage soybean . . . . . | 46 |
| Table 9.  | Control of overwintered wild carrot with preemergence herbicides in no-tillage corn . . . . .                                          | 47 |
| Table 10. | Control of overwintered wild carrot with postemergence herbicides in no-tillage corn . . . . .                                         | 48 |

### **Chapter 3. Differential Response of Wild Carrot to 2,4-D.**

|          |                                                                                                                                                                                  |    |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 1. | Location and habitat of the samples in the sample study . .                                                                                                                      | 61 |
| Table 2. | The response of wild carrot to 2,4-D amine kg/ha<br>for the sample study . . . . .                                                                                               | 62 |
| Table 3. | The distribution of individual plants into three groups<br>based on control at 28 DAT for the sample study . . . . .                                                             | 63 |
| Table 4. | The response of wild carrot to 2,4-D amine<br>at 1.1 kg/ha for umbels within samples<br>D (resistant), F (intermediate), and G (susceptible) . . . . .                           | 64 |
| Table 5. | The distribution of individual plants into three groups<br>based on control at 28 DAT of umbels within samples<br>D (resistant), F (intermediate), and G (susceptible) . . . . . | 65 |

## LIST OF FIGURES

|                   |                                                                                                    |    |
|-------------------|----------------------------------------------------------------------------------------------------|----|
| <b>Chapter 2.</b> | <b>Wild Carrot (<i>Daucus carota</i> L.) Control in No-Tillage Cropping Systems.</b>               |    |
| Figure 1.         | Control of overwintered wild carrot with early preplant herbicides in no-tillage soybean . . . . . | 49 |
| Figure 2.         | Control of overwintered wild carrot with postemergence herbicides in no-tillage soybean . . . . .  | 50 |
| <b>Chapter 3.</b> | <b>Differential Response of Wild Carrot to 2,4-D.</b>                                              |    |
| Figure 1.         | Location of the samples in the sample study . . . . .                                              | 66 |
| Figure 2.         | Wild carrot control with 2,4-D at 1.1 kg/ha in field and greenhouse research . . . . .             | 67 |
| Figure 3.         | Wild carrot control with 2,4-D amine at 1.1 kg/ha of samples in the sample study . . . . .         | 68 |

## **Chapter 1**

### **REVIEW OF LITERATURE**

#### **INTRODUCTION**

No-tillage crop production continues to increase in Michigan. A change in tillage practice can cause a shift in weed species within a population. In two to three years of continuous no-tillage, biennial and perennial weed species may become a problem. Wild carrot has been observed to be a serious weed problem in Michigan no-tillage crop production. Chemical control of wild carrot has not been reported for any tillage practice in row crop production. Therefore, research was conducted to determine effective chemical control strategies for control of wild carrot in continuous no-tillage corn and soybean production.

#### **TILLAGE**

**History.** Tillage, as defined by Buckingham (8), is the mechanical, soil-stirring actions done for the purpose of nurturing crops. Therefore, tillage began with the advent of production of domesticated plants by early civilizations. The use of a plow for primary tillage began before the birth of Christ (8). The first United States patent for a plow was obtained by Charles Newbold in 1797 (8). John Lane

developed the first steel plow in 1833 (8). Steam powered tractors were introduced in 1868 (31). The advancements of the plow, tractors, and other tillage equipment into the 1930s allowed for millions of acres of soil to be conventionally tilled with less labor (8, 48). Rice (32) defines conventional tillage as "the combined primary and secondary tillage operations normally performed in growing a given crop in a given geographical area." Much of this land should not have been conventionally tilled and was left exposed to the droughts and devastating floods during the 1920s and 1930s. Millions of tons of soil were lost during this period. Thus, farmers began to conceive new production practices to save our most precious resource, soil. Minimum and no-tillage were two of the new practices, but they were difficult to implement because of the heavy reliance on tillage for weed control (32, 48). Minimum tillage, according to Young (48), can be defined as "reducing tillage to only those operations that are timely and essential to producing the crop and avoiding damage to the soil and growing crops." Young (48) stated, "no-tillage was planting crops in previously unprepared soil by opening a narrow slot, trench or band only of sufficient width and depth to obtain proper seed coverage." With the advent of selective herbicides in the 1950s to control weeds, farmers could successfully produce crops with little or no tillage (32, 48). The most limiting factors for minimum tillage and no-tillage in the 1950s and 1960s were public perception and lack of advancements in tillage and planting equipment (48). Since the 1960s equipment advancements and new herbicides have allowed minimum tillage and no-tillage crop production to dramatically increase (32, 48). Economic pressures and recent government policies

have also forced minimum tillage and no-tillage crop production to increase. Despite these factors, conventional tillage still exists.

**No-tillage crop production.** Young (48) reported that in 1952 and 1953, successful crops of wheat, oats, flax, soybeans, and corn were produced by no-tillage methods. In Michigan in 1994, 35% of soybean and nearly 25% of corn was produced using no-tillage practices<sup>1</sup>. Many advantages and disadvantages exist for no-tillage crop production compared to conventional tillage systems. Phillips and Phillips (31) mentioned several advantages to no-tillage such as erosion control, reduced fuel consumption, flexibility in planting and harvesting, use of highly erodible land, increased land use, reduced labor requirements, improved water retention, and lower equipment requirements. Phillips and Phillips (31) have noted some disadvantages to no-tillage such as lower soil temperatures, increased difficulty in weed control, increased incidence of insects, rodents and diseases, and a lower aesthetical value due to large amounts of residue.

Researchers have reported increased and decreased corn yields with no-tillage practices compared to conventional tillage. Brown et al. (6) reported no-tillage corn produced 13 bu/A greater yield than conventional tillage corn in 1983. Brown et al. (6) reported a significant decrease in corn yield in Iowa in 5 of 8 years under no-tillage compared to conventional tillage. Brown et al. (6) and Kaputsa and Krausz (21) reported no significant difference in average soybean yield for the duration of

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<sup>1</sup>J. Squire. 1994. Personal Communication; Soil Conservation Service, Lansing, MI.

the studies with no-tillage practices compared to conventional tillage practices.

**Influence of tillage on weed population shifts.** Tillage can affect the weed population of a field (5, 9, 10, 21, 23, 25, 40, 43, 48). Triplett and Lytle (43) were the first researchers to report a weed population shift with no-tillage crop production compared to conventional tillage. Maretail (*Conyza canadensis*) can become a problem in the first year of no-tillage (5, 7, 21, 39). Maretail was also observed as the dominant weed species in the first year of abandonment of a corn field (34). Root and Wilson (34) stated during the second year following abandonment of corn production the dominant vegetation of these fields changed from annual to perennial forms. The same successional trend has occurred in the switch from conventional to no-tillage crop production. In 3 to 6 years after continuous no-tillage, perennial weeds were present or were a serious problem (9, 21, 43). Hemp dogbane (*Apocynum cannabinum* L.) (9, 43), dandelion (*Taraxacum officinale* Weber in Wiggers)(9, 21, 43), Canada thistle (*Cirsium arvense* L. Scop.) (43), field bindweed (*Convolvulus arvensis* L.), and gray goldenrod (*Solidago nemoralis* Ait.) (21) are more abundant in no-tillage compared to conventional tillage crop production.

## **WILD CARROT**

**Name.** Wild carrot has several colloquial names such as bird's-nest, devil's-plague, carotte sauvage, carotle commune, and dauce carotte (12). The most notable is

Queen Anne's-lace. Wild and cultivated carrot are considered as one species, *Daucus carota*. *Daucus carota* L. ssp. *carota* (12) and *Daucus carota* ssp. *agg. carota* (35) have been used to differentiate wild carrot from cultivated carrot.

**Description.** Wild carrot emerges with a pair of cotyledons which are approximately 2 mm wide and up to 3.5 cm in length. The first true leaf is much smaller, 1 to 4 cm in length, compared to subsequent leaves. Subsequent leaves originate from the meristatic crown and are 5 to 40 cm long, three-pinnate, and frequently divided into segments (12). Petioles and leaves may be densely sparsely, or void of pubescence. The flower stalk, 0.1 to 1.2 m in height, is solid and may be densely, sparsely or void of pubescence (12). Leaves on the flower stalk are attached by a sheathed base and arranged alternately. Leaves close to the umbel are smaller than at the base. Flower stems end terminally with an umbel. Additional flower stems arise in succession at any node. A single plant may produce up to 100 umbels (12). All umbels are compound with over 1000 white flowers (12). The main flower pedicels originate from one central point of the umbel and are unequal in length which allows the umbel to be arranged as a disc at fertilization (12). The center of the umbel may have one or a few purple flowers. Pinnate bracts are present at the base of each umbel. Each flower gives rise to single-seeded half-fruits (mericarps)(12). Therefore, one flower produces two mericarps which may be separated and referred to as individual seeds with only one embryo per seed. Each seed may be 3 to 4 mm long, 2 mm wide, broadest in the middle, and slightly curved with 5 hairy ribs and 4 rows of large

spines (12). The roots are typically white, although tap roots purple in color have been observed. Roots become woody with age and are unpalatable. Wild carrot has a characteristic odor that is apparent when tissue of any plant part is crushed. Chromosome number is  $2n = 18$  for Canadian and European material (12) as well as for cultivated carrot (35).

**Variation.** Wild carrot shows high variability for morphological characteristics (12, 19, 35, 47) and isozyme analysis (38). Small (35) investigated many vegetative and reproductive plant characteristics, noting variation among and within collections. Dale (12) stated, "collections made in the 18th and 19th centuries in North America were so variable in appearance that several entities were described." The high variability of wild carrot among and within collections has caused much confusion for taxonomists. Therefore, more than 60 species have been proposed within the *Daucus carota* complex (35). St. Pierre et al. (38) stated, "the complex is a young one in terms of evolutionary history, as marginal groups have not yet differentiated into sharply distinguishable subgroups either morphologically or genetically." The young evolutionary history and lack of intrinsic barriers to interbreeding of wild and cultivated carrot provide for the variability within the species.

**Biology.** Wild carrot typically reproduces as a biennial plant, though it is capable of surviving 4-5 years before flowering (14) or may flower in a single season of growth. Lacey (28) summarized that year of reproduction for wild carrot is determined by both environmental and genetic components, and both size and

recent growth are good predictors of year of flowering. Gross (14) reported that wild carrot must reach a minimum root crown diameter to flower. Lacey (28) reported annual mother plants produce the most annual offspring. Gross (14) also reported wild carrot has a higher probability of surviving the winter if root crown diameter exceeds some minimum size.

Seeds buried in the soil for up to 10 years are still viable, but are not viable after 10 years of storage at room temperature (24). In Michigan, most wild carrot germinate in the spring, but Dale and Harrison (13) observed as many as four flushes of germination during a growing season. Therefore, wild carrot may germinate at any time during the growing season as long as seed dormancy has broken and sufficient water is available. Dale and Harrison (13) reported germination is most frequently limited by the amount of water reaching the seed and being absorbed by it. Seeds of the primary umbel are the heaviest and have the highest germination rate (12).

Wild carrot grows initially as a rosette. Once a minimum root size is achieved the plant may begin to bolt. In Michigan, plants may begin bolting as early as June 1. Dale (12) has also observed wild carrot beginning to flower in late June in Canada. Subsequent orders of umbels flower predictably 2 to 4 weeks later (27). Koul et al. (26) stated, "all umbels of one order flower at the same time." Any plant which has flowered will not survive the winter and will not grow the next spring (12, 16). A plant may have up to 65,000 total flowers with the primary umbel having a maximum of 3,000 flowers (26). Wild carrot flowers

can be hermaphroditic, male, female, or sexless (4, 26). The primary umbel has the most hermaphroditic and the least staminate flowers (4, 12, 26). Therefore, the primary umbel has the highest percentage of fruit set with a decrease in fruit set with increasing umbel order (26).

Wild carrot generally is cross-fertilized. There are 200 to 300 insect species which participate in pollination. Wild carrot may also be self-fertilized, although this occurs very little. Koul et al. (26) reported fruit set of bagged umbels ranged from 0 to 1.61 percent. Anthesis of flowers begins at the center of an umbel and umbellet (26).

**Ecology.** Wild carrot in flower may be present in a no-tillage field the season after tillage was performed. In a plant succession study, Root and Wilson (34) observed the presence of wild carrot in a field 1 year after corn production was abandoned. Gross (14) and Lacey (27) also observed mature wild carrot in fields after 1 year of abandonment from crop production. Root and Wilson (34) reported wild carrot as 1 of 3 dominant weed species in a 9-year-old abandoned field.

Several investigators have reported that environment can determine how soon a plant will flower after germination (12, 14, 27, 28). In first-year successional fields, wild carrot plants were larger and flowered earlier than plants in older successional fields (12, 14, 28). Annual plants occurred more frequently under favorable conditions such as low wild carrot densities or a higher nutrient supply. More perennial plants existed in an old field community compared to a

first-year field community according to Gross (14). Lacey (28) reported the presence of annual plants only with high nutrient supply and that more perennial plants existed with low nutrient supply. The rapid expansion of a wild carrot population in no-tillage systems may be caused by high nutrient levels which allow more annual plants to appear.

**Habitat.** Wild carrot occurs in areas with >25,000 °F days of heat, >120 consecutive frost free days, and 80 to 100 cm of annual precipitation (12). The species exists in areas at sea level and up to an altitude of 450 m (12). In Canada, Britain, and the United States wild carrot can generally be found growing in calcareous parent material soils, though it can be found growing in many different soil types or moisture regimes (12).

Wild carrot is not a weed problem in cultivated fields. It occurs in waste places (12), road allowances (12), meadows (12), and underutilized or depleted pastures (12), fence rows, waterways, and ditches. Lacey (27) stated, "wild carrot is a common weed of abandoned fields and disturbed habitats." Wild carrot can also be a weed problem in continuous no-tillage crop production (36, 37), forage production (16), and lawns.

**Distribution.** Wild carrot is found throughout the British Isles (12). It also occurs in Norway and central Sweden and south to North Africa and the Canary Islands (12). It is present as far east as Siberia and India (12). Wild carrot also occurs throughout North America, especially the eastern States and Provinces, Central America and the West Indies (12). Wild carrot is not native to North

America and has a longer documented history in the United States compared to Canada (12). The species was first documented in the United States in 1739 (12). In North America, wild carrot originated from Eurasia, according to Dale (12).

**Control.** According to Dale (12), wild carrot was considered a serious weed problem in Connecticut in 1881 and Harvey (17) called wild carrot a troublesome weed in Maine in 1897. Mechanical control recommendations at this time made wild carrot obsolete in row crop production. Since wild carrot reproduces by seeds only, several researchers have said wild carrot control should be focused on prevention of seed production (13, 16, 17, 42). Dale (12) stated, "prevention of seed production is paramount in the control of wild carrot as a weed."

*Chemical.* Prior to this research, there were no reports of chemical control of wild carrot in row crop production. The majority of research on chemical control of wild carrot has been in roadsides. Atrazine, ((6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine)) (11), sulfometuron-methyl (methyl 2-[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoate) (11, 44), and picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) plus triclopyr (bee<sup>2</sup>) ([3,5,6-trichloro-2-pyridinyl]oxy)butoxyethylester), triclopyr (bee) plus 2,4-D, ((2,4-dichlorophenoxy)acetic acid), and picloram plus 2,4-D (15) provided greater than 75% control of wild carrot in roadsides. Two applications of 2,4-D at 1.0 lb ai/A virtually eliminated wild carrot from pasture production (18). Slywester (42) reported applications of 2,4-D provided effective control.

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<sup>2</sup>The abbreviation "bee" refers to the butoxyethylester of triclopyr.

*Mechanical.* According to Slywester (42), thorough cultivation will kill existing plants, encourage seed germination and destroy young seedlings. Tillage is the best method of control of wild carrot (12, 42). Wild carrot plants in bud stage are not effectively controlled with a single mowing (16, 17). Harrison and Dale (16) reported that, based on the criteria of high mortality and low reproductive capacity, mowing three times per season or mowing once in July, were the most effective.

## HERBICIDE USAGE IN CULTIVATED CARROT PRODUCTION

It is important to know the sensitivity of cultivated carrot to herbicides, since information is not available for chemical control of wild carrot in row crop production. Many herbicides have been tested on cultivated carrot. Cultivated carrot has shown excellent safety to diethatyl-ether (*N*-(chloroacetyl)-*N*-(2,6-diethylphenyl)glycine), ethofumesate (( $\pm$ )-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate), fluazifop ((*R*)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid), linuron (*N*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea), oryzalin (4-(dipropylamino)-3,5-dinitrobenzenesulfonamide), pendimethalin (*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine), prodiamine (2,4-dinitro-*N*<sup>3</sup>,*N*<sup>3</sup>-dipropyl-6-(trifluoromethyl)-1,3-benzenediamine), prometryn (*N,N*-bis(1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine), sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one), and

trifluralin (2,6-dinitro-*N,N*-dipropyl-4-(trifluoromethyl)benzenamine) according to Kempen (22). Bewick et al. (3) reported excellent safety of carrot to clomazone and metribuzin, while Kempen (22) reported reduced stand and yield with metribuzin. Carrot has also shown excellent safety to fluorchloridone ((3-chloro-4-(chloromethyl)-1-[3-trifluoromethyl]-phenyl]-2-pyrrolidinone) and haloxyfop (( $\pm$ )-2-[4-[[3-chloro-5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) (1,2). Cultivated carrot have been shown to be sensitive to EPTC (*S*-ethyl dipropyl carbamothioate) and simazine (6-chloro-*N,N'*-diethyl-1,3,5-triazine-2,4-diamine) (20) and oxyfluorfen (2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene) and clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) (33).

### WEED RESISTANCE TO 2,4-D

The first report of any weed being resistant to a particular herbicide was wild carrot which was resistant to 2,4-D. Switzer (41) first reported this resistance in Ontario in 1957. In a survey by Switzer (41), of the 22 infested areas, five reported satisfactory control and eight reported inadequate control with 2,4-D. The biotypes resistant to 2,4-D were not resistant to 2,4,5-T ((2,4,5-trichlorophenoxy)acetic acid)) and 2,4,5-TP ((2,4,5-trichlorophenoxy)propionic acid)) (46). There were no differences in germination of seeds in petri dishes with 2,4-D between susceptible and resistant biotypes (46). Whitehead and Switzer (46) stated that resistance to 2,4-D appeared to develop between germination and the cotyledon stage of growth.

Whitehead and Switzer (46) suggested the initial injury of the resistant plants may be explained if some 2,4-D was not adsorbed on inactive sites, leaving a sub-lethal concentration present in the plant. *Carduus nutans* L., *Cirsium arvense* (L.) Scop., *Ranunculus acris* L., and *Sphenoclea zeylandica* Gaertn. (29) and *Kochia scoparia* (L.) Schrad.(30) have been reported as being resistant to 2,4-D.

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## **Chapter 2**

### **Wild Carrot (*Daucus carota* L.) Control in No-Tillage Cropping Systems**

#### **ABSTRACT**

Wild carrot is an increasing weed problem in Michigan continuous no-tillage crop production. Therefore, greenhouse and field research was conducted to determine the best management strategy for control of wild carrot in a no-tillage cropping system. Acetochlor plus dichlormid (5.8:1), cyanazine, metribuzin plus chlorimuron (10:1), and linuron plus chlorimuron (18:1) applied preemergence and bentazon, cyanazine, prosulfuron, halosulfuron, and clopyralid applied postemergence provided the greatest control of seedling wild carrot. Glyphosate at 0.84 and 1.68 kg/ha applied alone and in combination with 2,4-D ester at 0.56 and 1.12 kg/ha in October, provided greater than 74% control. Treatments containing chlorimuron consistently gave greater than 71% control of overwintered wild carrot in no-tillage soybean. Atrazine, primisulfuron, halosulfuron, and nicosulfuron applied postemergence consistently provided greater than 78% control of overwintered wild carrot in no-tillage corn. Prosulfuron and flumetsulam plus clopyralid plus 2,4-D (1:2.7:5.5) applied postemergence gave greater than 88% control of overwintered wild carrot in no-tillage corn in the one year tested. Differential response of wild carrot to 2,4-D and glyphosate was observed in the field. **Nomenclature:** acetochlor, 2-

chloro-*N*-(ethoxymethyl)-*N*-(2-ethyl-6-methylphenyl)acetamide; atrazine, 6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine; 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; clopyralid, 3,6-dichloro-2-pyridinecarboxylic acid; cyanazine, 2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile; dichlormid, 2,2-dichloro-*N,N*-di-2-propenylacetamide; flumetsulam, *N*-(2,6-difluorophenyl)-5-(1,3,4,5,6,7-hexahydro-1,3-dioxo-2*N*-isoindol-2-yl)phenoxy]acetic acid; glyphosate, *N*-(phosphonomethyl)glycine; halosulfuron, methyl 5-[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonylamino]sulfonyl]-3-chloro-1-methyl-1-*H*-pyrazole-4-carboxylate; linuron, *N'*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea; metribuzin, 4-amino-6-(1,1-dimethylrthyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one; nicosulfuron, 2-[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl)-*N,N*-dimethyl-3-pyridinecarboxamide; primisulfuron, 2-[[[(4,6-bis(difluoromethoxy)-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid; prosulfuron, 1-(4-methoxy-6-methyl-triazin-2-yl)-3-[2-(3,3,3-trifluoropropyl)-phenylsulfonyl]-urea; 2,4-D, (2,4-dichlorophenoxy)acetic acid; wild carrot, *Daucus carota* L.; corn, *Zea mays* L.; soybean, *Glycine max* L. **Additional index words:** no-tillage, DAUCA.

## INTRODUCTION

No-tillage corn, soybean, and wheat (*Triticum aestivum* L.) acreage has

increased dramatically over the past 10 years in Michigan<sup>1</sup>. A change in tillage practice has caused a shift in weed populations (2,12,25). One of the first weed problems observed in no-tillage soybean was marestalk (*Conyza canadensis* L.) (3,12). Root and Wilson (20) conducted plant successional research following the abandonment of corn production and found wild carrot present in the first year and as one of three dominant plant species 9 years after study initiation. Observations have indicated that wild carrot may become a weed problem as early as 2 years of continuous no-tillage. Wild carrot, as a weed problem in row crop production, is unique to no-tillage and has not previously been reported. Wild carrot has been observed to be a problem in no-tillage soybean, but may also occur in no-tillage corn and wheat. Wild carrot becomes a problem by encroaching from the perimeter of the crop area. Seeds may then be dispersed throughout the field during harvesting of corn or soybean.

The life cycle of wild carrot is typically as a biennial, although plants may complete their life cycle as an annual or perennial. Root crown diameter is a good predictor for the fate of the plant (7,15). Wild carrot must reach a minimum root crown diameter to successfully overwinter and to bolt (7). Factors affecting growth will determine the age of the plant at flowering (7,15). Wild carrot reproduces by seeds only, which may stay dormant in the soil for up to 10 years (6,14,24). In Michigan, wild carrot may emerge as early as April and continue until October,

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<sup>1</sup>J. Squire. 1993. Personal Communication; Soil Conservation Service, Lansing, MI.

during periods of large amounts of rainfall, with most seeds emerging in the spring (6). Wild carrot may begin to bolt as early as June and flower as early as late June, continuing until frost. Plants cut at the time of flowering may rebolt and flower (36). Each flower produces two seeds on a compound umbel. Most wild carrot are cross-fertilized, but self-fertilization may occur (5). Wild carrot populations are highly variable for morphological characteristics and isozyme analysis (36,37,22).

Michigan farmers have reported poor control of wild carrot with herbicides in no-tillage soybean. Chemical control of wild carrot in row crop production has not previously been reported. Chemical control has been reported for roadsides, turf, and pastures (36,11,19,26). Harrison and Dale (9) reported that one cutting of wild carrot in July at full bloom was an effective treatment based upon high mortality and low reproductive capacity. Harvey (10), Sylwester (24) and Harrison and Dale (9) suggested that the best way to control wild carrot is to inhibit seed production.

Studies were conducted to evaluate the efficacy of herbicides applied to wild carrot at three stages of growth: 1) seedling; 2) established; and 3) overwintered.

## **MATERIALS AND METHODS**

**Control of seedling wild carrot in the greenhouse.** Two greenhouse studies were conducted to evaluate the control of seedling wild carrot. One study involved the application of preemergence (PRE) herbicides and the other involved application of postemergence (POST) herbicides. Primary umbels were collected at maturity from

untreated plots at the St. Clair County, Michigan field research location. The seeds were removed from each umbel and rubbed across a number 20 sieve to separate the paired seeds. Greenhouse temperature was maintained at 18 to 37 C. The seeds were planted at a depth of 0.64 cm in 945 ml plastic pots. Pots were watered to saturation immediately after planting. When fertilization of the soil was required, a fertilizer solution (71 mg of Peters 20-20-20 water soluble fertilizer per liter of water) was applied at 50 ml per pot. Herbicide treatments were applied with a single Teejet<sup>2</sup> 8001E flat fan nozzle at 31 cm above the target on a continuous link belt sprayer calibrated to deliver 234 L/ha at a pressure of 200 kPa.

Each study was designed as a randomized complete block with four replications and was repeated. Control was evaluated for all studies based on a scale with zero representing no visible injury and 100 representing complete plant death. All data were subjected to analysis of variance and the means separated by Fisher's Protected LSD at the 5% level.

*Preemergence study.* Supplemental lighting was provided by pressurized sodium lamps at a 16 hour photoperiod with an average midday photosynthetic photon flux density (PPFD) of 650  $\mu\text{E}/\text{m}^2/\text{s}$  measured with a photometer<sup>3</sup> at plant height, 110 cm from the light source. The collected seed was cleaned by placing two heaping teaspoons of seeds in a Dakota blower at a 4 cm setting for 3 minutes. Twenty seeds were

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<sup>2</sup>Spraying Systems Co., North Avenue, Wheaton, IL 60188.

<sup>3</sup>Li-1985B Quantum Photometer. Lambda Instruments Corp., Lincoln, NE 68504.

planted per pot in a steam treated sandy loam soil mixture comprised of 73% sand, 14% silt, 13% clay, and 5.2% organic matter, at a pH of 7.1. The next day herbicide treatments were applied and 100 ml of water was applied to each pot for herbicide incorporation. After the initial water application, all pots were sub-irrigated as needed. The study was sub-fertilized at 14 days after treatment (DAT).

Wild carrot seedlings were counted and visually evaluated for control at 21 and 28 DAT. All above-ground plant tissue was removed and fresh weight determined 28 DAT.

*Postemergence study.* Supplemental lighting was provided by metal halide lamps at a 16 hour photoperiod with an average midday photosynthetic photon flux density (PPFD) of  $700 \mu\text{E}/\text{m}^2/\text{s}$  measured with a photometer at plant height, 150 cm from the light source. Several seeds were planted in a steam treated sandy clay loam soil mixture comprised of 61% sand, 19% silt, 20% clay, and 5.0% organic matter, at a pH of 6.4. Approximately 25 ml of Etridiazole (5-ethoxy-3-trichloromethyl-1,2,4-thiodiazole) plus thiophanate-methyl (dimethyl 4, 4-o-phenylenebis (3-thioallophanate) (3:5) was applied to each pot at a rate of 30 mg/L of water as a soil fungicide drench 3 days after planting. The soil of each pot was fertilized every 10 days beginning 17 days after planting. Wild carrot were thinned to two uniform plants per pot 4 days before herbicide application. Herbicide treatments were applied with appropriate additives at four to five fully expanded leaves.

Control was visually evaluated at 7, 14, 21, and 28 DAT. The entire plant was harvested at 28 DAT by washing the soil from the plant. The shoot was removed

from the root at the base of the crown. Fresh and dry weights were determined for the shoot and root. Growth reduction was calculated within each replication by dividing the weight of each treatment by the weight of the untreated.

**Control of established wild carrot with fall-applied herbicides.** Two field studies were initiated, one in Lenawee County, Michigan on October 7, 1993 and one in Clinton County, Michigan on October 6, 1994. The soil was a Macomb sandy clay loam (fine-loamy, mixed, mesic Aquallic Hapludalfs) with 2.6% organic matter and a pH of 6.5 at the Lenawee County location and a Capac loam (fine-loamy, mixed, mesic Aeric Ohchraqualfs) at the Clinton County location. Both studies were conducted in wheat stubble. The site was mowed to 6 cm in height 3 weeks before application at Lenawee County and was mowed above the wild carrot 1.5 weeks before application at Clinton County. The wild carrot population was 50 and 20 plants/m<sup>2</sup> at Lenawee and Clinton Counties, respectively. Glyphosate, dicamba (3,6-dichloro-2-methoxybenzoic acid), and 2,4-D ester were applied alone. Glyphosate and 2,4-D ester were also applied in combination. All glyphosate treatments contained nonionic surfactant<sup>4</sup> (NIS) and ammonium sulfate (AMS) applied at 0.5 %v/v and 2.0 %w/w, respectively. A tractor mounted compressed air sprayer was used to apply all herbicide treatments and was calibrated to deliver 103 L/ha at a pressure of 172 kPa using Teejet 80015 flat fan nozzles. Wild carrot height and

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<sup>4</sup>X-77®-Nonionic-type spreader and activator. Principle functioning agents: Alkylaryl polyoxyethylene, free fatty acids, glycols, isopropanol. Constituents effective as spray adjuvant-90%. Constituents ineffective as spray adjuvant-10%. Valent U.S.A. Corp., 1333 N. California Blvd., P.O. Box 8025, Walnut Creek, CA 94596-8025.

environmental application information is listed in Table 1.

The studies were designed as a randomized complete block with three replications. The plot size was 3 m wide and 9.1 m long. Wild carrot control was evaluated on April 23, May 16, and June 14, 1994 at Lenawee County and at Clinton County on November 18, 1994. All data were subjected to analysis of variance and treatment means separated by Fisher's Protected LSD at the 5% level.

**Control of overwintered wild carrot.** Field studies were conducted in St. Clair County, Michigan in 1993 and in Lenawee County, Michigan in 1994. The soil was a Londo clay loam (fine-loamy, mixed, mesic Aeric Glossaqualfs) with 3.2% organic matter and a pH of 7.6 at the St. Clair County location. The soil was a Blount clay loam (fine, illitic, mesic Aeric Ochraqualfs) with 2.6% organic matter and a pH of 7.2 at the Lenawee County location. One study was conducted in no-tillage soybean and one in no-tillage corn at each location. All studies were conducted in wheat stubble and were positioned near the perimeter of the field. Corn and soybeans were planted in 76 cm rows on May 21, 1993 and May 16, 1994. All treatments were applied with a tractor mounted compressed air sprayer calibrated to deliver 206 L/ha at a pressure of 207 kPa using Teejet 8003 flat fan nozzles. On May 12, 1994, quizalafop {(±)-2-[4-[(6-chloro-2-quinoxalinyloxy]phenoxy]propanoic acid} at 77 g/ha plus crop oil concentrate<sup>5</sup> (COC) at 1 %v/v was applied as a blanket treatment to each study for control of volunteer winter wheat. The wild carrot density and height

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<sup>5</sup>Herbimax. 83% petroleum oil, 17% adjuvant. Loveland Industries, Inc., Greeley, CO 80632.

and environmental conditions at application for the soybean and corn studies are listed in Tables 2 and 3, respectively.

Each study was designed as a randomized complete block with three replications. The plot size was 3 m wide and 12.2 m long. Treatments were evaluated on July 24, 1993 and July 12, 1994. Analysis of variance was performed on the data and the means separated by Fisher's Protected LSD at the 5% level. There was a significant interaction between location and treatment for each study, therefore the means are shown separately for each location.

*Soybean study.* Herbicide treatments were applied early preplant (EPP), PRE, and POST at the dates and times indicated in Table 2. Soybeans were planted 10 days after application of the EPP treatments. The soybean variety planted at St. Clair County and Lenawee County was Asgrow 1929 and DeKalb 298, respectively. The EPP glyphosate treatments were applied at a volume of 103 L/ha and a pressure of 172 kPa with Teejet 80015 flat fan nozzles. On June 1, 1993 quizalafop at 77 g/ha plus COC at 1.0 %v/v was applied to the entire study to control volunteer winter wheat. Linuron at 840 g/ha plus pendimethalin (*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) at 1121 g/ha plus COC at 1.0 %v/v was applied PRE to the EPP and POST treatments to control other weeds. Pendimethalin at 1121 g/ha plus paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) at 515 g/ha plus NIS at 0.125 %v/v was tank-mixed with all PRE treatments to control other weeds, except those containing glyphosate. Glyphosate treatments applied PRE were tank-mixed with linuron at 840 g/ha plus pendimethalin at 1121 g/ha plus NIS at 0.5 %v/v to control other weeds.

*Corn Study.* Herbicide treatments were applied PRE and POST at the dates and times indicated in Table 3. The corn hybrid planted at St. Clair and Lenawee Counties was Asgrow 350 and Cargill 5547, respectively. Paraquat at 515 g/ha plus pendimethalin at 1121 g/ha plus NIS at 0.125 %v/v were applied PRE as a tank-mix with the PRE treatments, except those containing glyphosate or alone to all POST treatments to control other weeds. Glyphosate treatments applied PRE were tank-mixed with pendimethalin at 1121 g/ha plus NIS at 0.5 %v/v plus AMS at 2.0 %w/w and followed by bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at 420 g/ha to control other weeds.

## RESULTS AND DISCUSSION

**Control of seedling wild carrot in the greenhouse. *Preemergence study.*** Acetochlor plus dichlormid (5.8:1), cyanazine, metribuzin plus chlorimuron (10:1), and linuron plus chlorimuron (18:1) applied PRE provided greater than 75% control and reduced wild carrot growth greater than 91% 28 DAT (Table 4). Acetochlor plus dichlormid (5.8:1), cyanazine, and metribuzin significantly decreased emergence compared to the untreated (Table 4). All other treatments providing greater than 50% control did not significantly decrease emergence compared to the untreated, but significantly reduced wild carrot growth compared to the untreated. Pendimethalin and linuron did not reduce wild carrot seedling emergence or growth. Kempen (13) stated that linuron and pendimethalin are very safe to cultivated carrot.

*Postemergence study.* Bentazon, cyanazine, and prosulfuron applied POST provided greater than 90% control and reduced total plant growth by 79% 28 DAT (Table 5). Halosulfuron, clopyralid, and chlorimuron provided 70 to 76% control and reduced total plant growth by 61 to 72% (Table 5). Richardson and Parker (18) reported cultivated carrot was highly sensitive to clopyralid. Acifluorfen (5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid), bromoxynil, dicamba, flumiclorac-pentyl ([2-chloro-4-fluoro-5-(1,3,4,5,6,7-hexahydro-1,3-dioxo-2H-isoindol-2-yl)phenoxy]acetic acid pentyl ester), fomesafen (5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide), glyphosate, imazaquin (2-[4,5-dihydro -4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid), lactofen (( $\pm$ )-2-ethoxy-1-methyl-2-oxoethyl-5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate), nicosulfuron, and thifensulfuron (3-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid) did not significantly reduce total plant growth compared to the untreated. Control increased over time for all treatments, except fomesafen, lactofen, bromoxynil, and flumiclorac-pentyl (Table 5). The decrease in control over time was due to emergence of new leaves. Clopyralid, dicamba, and 2,4-D were the only herbicides that consistently reduced root growth more than shoot growth. Tumors were observed on the roots of wild carrot treated with these herbicides. These growth regulating herbicides have been demonstrated to affect root growth.

The use of effective herbicides applied PRE or POST for control of seedling wild carrot may prevent overwintering. Eliminating the overwintered plants with this

method will prevent seed production and eventually deplete the seedbank, since seeds are short-lived (6,14,37). This control strategy, however, must over-come the multiple emergence times during the growing season (6). One approach to address this problem is to apply a PRE herbicide and follow with a POST herbicide if needed.

**Control of established wild carrot with fall-applied herbicides.** Control decreased over time for all treatments at Lenawee county, except 2,4-D ester at 1.12 kg/ha (Table 6). The decreased control over time for all glyphosate treatments was due to regrowth of plants. There was a rate response observed with glyphosate applied alone, with a significant difference between the 0.42 and 0.84 kg/ha rates for three of the four ratings (Table 6). Treatments with 2,4-D ester, applied alone, gave greater than 75% control at Lenawee County, but only 32% control at Clinton County.

Adding 2,4-D ester to glyphosate at 0.21 and 0.42 kg/ha significantly increased the control at Lenawee County compared to glyphosate alone. At the June 14 rating, the addition of 2,4-D to glyphosate at 0.84 kg/ha significantly increased control compared to glyphosate alone. The increased control provided by 2,4-D ester will only be effective if the population is susceptible to 2,4-D. If the 2,4-D ester, applied alone, provided effective control, then the addition of glyphosate did not significantly improve control. Dicamba provided less than 50% control at both locations.

**Control of overwintered wild carrot. Soybean study.** The linuron treatment used for controlling other weeds, gave 7 and 8% control of overwintered wild carrot for St. Clair and Lenawee Counties, respectively (Table 7). Therefore, the control provided

by the EPP and POST treatments was not affected by the linuron treatment. The paraquat plus linuron treatment used for controlling other weeds, provided 35 and 55% control at St. Clair and Lenawee Counties, respectively (Table 7). The higher control at Lenawee was caused by the plants inability to regrow after the herbicide application because of decreased rainfall in May at this location.

Glyphosate at 0.42, 0.84, and 1.68 kg/ha, applied EPP, provided 87, 95, and 95% control, respectively at St. Clair County (Figure 1). Glyphosate at 0.42, 0.84, and 1.68 kg/ha, applied EPP, gave 17, 24, and 17% control, respectively at Lenawee County. Early preplant application of 2,4-D ester at 0.56 and 1.12 kg/ha provided 0 and 7% control, respectively at St. Clair County, but the 2,4-D gave 63 and 72% control, respectively at Lenawee County (Figure 1).

Linuron plus chlorimuron (18:1) and metribuzin plus chlorimuron (10:1) provided greater than 72% control at both locations. Most overwintered wild carrot plants were controlled but the ones left behind appeared as healthy as the control plants. Glyphosate at 1681 kg/ha gave 70% control at St. Clair County. Metribuzin provided greater than 56% control at both locations. Bewick et al. (1) reported excellent safety to cultivated carrot with metribuzin applied POST.

Glyphosate applied EPP provided greater control compared to PRE applications at St. Clair County (Table 8). Neither EPP nor PRE applications provided greater than 60% control at Lenawee County. The lower control may be attributed to taller plants or more biomass (not recorded, but observed) at application, lower soil moisture, and/or lower temperatures after application (Table

2). Caseley and Coupland (4) reported that larger plants may have more metabolic sinks compared to smaller plants and require a larger dose of glyphosate for control. McWhorter and Azlin (16) reported decreased johnsongrass (*Sorghum halepense* L.) control with glyphosate 2 weeks after application due to lower temperature and soil moisture. McWhorter et. al. (17) reported decreased absorption and translocation of glyphosate shortly after application due to lower temperature and soil moisture. The size of the wild carrot at the PRE glyphosate application may have been the greatest factor resulted in poorer control.

Chlorimuron, imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid), and tribenuron-methyl (2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoic acid methyl ester) applied POST gave the greatest control at both locations (Figure 2). In general, the POST herbicide treatments provided greater control at Lenawee County compared to St. Clair County. The difference in control may be attributed to higher temperatures and time of day during application at Lenawee County (Table 2).

Treatments containing chlorimuron consistently gave the most effective control (Table 7 and Figure 2). With the introduction of STS soybean varieties, chlorimuron may be applied POST at higher rates and with other additives which may increase efficacy. Glyphosate at 420 g/ha, linuron, and pendimethalin applied PRE and bentazon, acifluorfen, and thifensulfuron applied POST gave less than 36% control at both locations.

Crop injury is not reported because data was only collected in 1993, and the herbicides caused minimal crop injury, with one exception. Tribenuron-methyl caused 85% injury on the July 24, 1993 rating. Crop injury was not evaluated in 1994 due to poor soybean emergence because of below normal rainfall. The St. Clair County location received 5.7 cm of rainfall in May, while Lenawee County received only 2.4 cm.

*Corn study.* Atrazine, Cyanazine, and Halosulfuron + flurilazole (3-dichloro acetyl-5-(2-furanyl)-2,2-dimethyl-oxazolidine) (1:3) provided greater than 69% control of overwintered wild carrot at St. Clair County (Table 9). Halosulfuron + flurilazole (1:3) gave the greatest control (67%) of the PRE treatments at Lenawee County. The difference in control between the two locations is most likely due to the reduced rainfall at Lenawee County (2.4 cm) compared to St. Clair County (5.7 cm). The reduced rainfall at Lenawee County would not have been adequate for root uptake of the herbicides, resulting in poor control.

Atrazine, halosulfuron, nicosulfuron, and primisulfuron, applied POST, gave greater than 78% control at St. Clair County (Table 10). Atrazine, cyanazine, flumetsulam plus clopyralid plus 2,4-D (1:2.7:5.5), halosulfuron, nicosulfuron, primisulfuron, prosulfuron, and 2,4-D amine, applied POST, provided greater than 77% control at Lenawee County. Atrazine, halosulfuron, primisulfuron, and nicosulfuron applied POST consistently gave greater than 75% control (Table 10). The increased control of the POST herbicides at Lenawee County may be due to the shorter plants at time of application compared to St. Clair County (Table 3). The

shorter plants at Lenawee County were caused by the plant's inability to recover from the paraquat treatment due to reduced rainfall. The PRE treatment of paraquat plus pendimethalin used to control other weeds provided 38 and 46% control at St. Clair and Lenawee Counties, respectively (Table 9).

There are more herbicides providing effective control applied POST than applied PRE. Crop injury is not reported because data was only collected in 1993, and the herbicides caused minimal crop injury. Crop injury was not evaluated in 1994 due to poor corn emergence because of reduced rainfall. Glyphosate, applied PRE, gave greater control at St. Clair County, than Lenawee County, for the same reasons discussed in the soybean study. The control with the paraquat plus pendimethalin followed by bromoxynil treatment compared to the paraquat plus pendimethalin treatment was not significantly different, therefore bromoxynil provided ineffective control (Table 9).

## CONCLUSIONS

More herbicides providing effective control exist for corn than for soybean. Glyphosate applied at 0.84 and 1.68 kg/ha in October may consistently provide effective control compared to glyphosate applied EPP or PRE. The differential response of 2,4-D at the three locations suggests either a genetic factor or an environmental factor is involved. Wild carrot resistant to 2,4-D was first reported as early as 1957 by Switzer (23 ) in Ontario, Canada. The high degree of variability in

wild carrot (21) may help to explain the existence of resistant biotypes. At least one application timing of glyphosate at 1.68 kg/ha provided greater than 80% control at all locations. Therefore, the wild carrot population tested do not appear to be resistant to glyphosate. This differential response of wild carrot to glyphosate observed in the corn and soybean studies may be attributed to some environmental and/or physiological factor. Including winter wheat into the crop rotation may inhibit seed production because at wheat harvest the flowers are cut by the combine.

Preventative management such as tillage and mowing of the field perimeters may provide effective control of wild carrot. Tillage provides the most effective and consistent control (10,24). Harrison and Dale (9) reported successful control with mowing. Therefore, preventative management such as tillage and mowing of the field perimeters may provide effective control of wild carrot.

### **FURTHER RESEARCH**

Based upon this research, many new questions need to be answered about controlling wild carrot. At what growth stage and/or environmental condition is wild carrot most vulnerable to glyphosate and other herbicides? Can control of seedling wild carrot withstand the multiple germination times during the growing season in the field? What is the minimum amount of tillage required to control wild carrot? What is the effectiveness of new herbicides? What role do additives play in herbicide effectiveness on wild carrot? Do biotypes exist which are resistant to triazines, ALS-

inhibiting, and other herbicides? Are wild carrot biotypes resistant to 2,4-D and cross resistant to various herbicides? What is the genetic basis for 2,4-D resistance and any other herbicide resistance that may be found? All of these questions are extremely important if wild carrot continues to be a problem for no-tillage farmers.

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*Table 1.* Fall herbicide application information study for control of established wild carrot.

|                                                 | Lenawee County | Clinton County |
|-------------------------------------------------|----------------|----------------|
| Wild carrot population (plants/m <sup>2</sup> ) | 50             | 20             |
| Wild carrot height (cm) (range)                 | 5-15           | 5-18           |
| Wild carrot height (cm) (average)               | 10             | 13             |
| Application date                                | 10-07-93       | 10-06-94       |
| Time of application                             | 8:00 PM        | 6:00 PM        |
| Temperature (° C)                               | 18             | 17             |
| Relative humidity (%)                           | 78             | 55             |

Table 2. Herbicide application information for no-tillage soybean study.

|                                                 | EPP       |         | PRE       |         | POST      |          |
|-------------------------------------------------|-----------|---------|-----------|---------|-----------|----------|
|                                                 | St. Clair | Lenawee | St. Clair | Lenawee | St. Clair | Lenawee  |
| Wild carrot population (plants/m <sup>2</sup> ) | 30        | 50      | 30        | 50      | 30        | 50       |
| Wild carrot height (cm) (range)                 | 5-15      | 8-20    | 5-15      | 8-25    | 8-64      | 13-56    |
| Wild carrot height (cm) (average)               | 10        | 12      | 11        | 20      | 28        | 26       |
| Application date                                | 5-11-93   | 5-06-94 | 5-21-93   | 5-19-94 | 6-22-93   | 6-15-94  |
| Time of application                             | 12:40 PM  | 7:00 PM | 11:30 AM  | 8:00 PM | 10:15 PM  | 12:50 PM |
| Temperature (° C)                               | 22        | 15      | 18        | 14      | 12        | 33       |
| Relative humidity (%)                           | 65        | 55      | 53        | 56      | 90        | 54       |

Table 3. Herbicide application information for no-tillage corn study.

|                                                 | PRE       |         | POST      |         |
|-------------------------------------------------|-----------|---------|-----------|---------|
|                                                 | St. Clair | Lenawee | St. Clair | Lenawee |
| Wild carrot population (plants/m <sup>2</sup> ) | 32        | 38      | 32        | 38      |
| Wild carrot height (cm) (range)                 | 5-18      | 8-38    | 8-71      | 5-15    |
| Wild carrot height (cm) (average)               | 9         | 20      | 18        | 10      |
| Application date                                | 5-21-93   | 5-18-94 | 6-22-93   | 6-14-94 |
| Time of application                             | 2:00 PM   | 8:30 PM | 9:40 PM   | 9:45 PM |
| Temperature (° C)                               | 11        | 7       | 13        | 26      |
| Relative humidity (%)                           | 61        | 45      | 82        | 68      |

Table 4. Response of seedling wild carrot to various preemergence herbicides<sup>a</sup>.

| Herbicide                       | Rate | Emergence   | Control | Fresh weight reduction |
|---------------------------------|------|-------------|---------|------------------------|
|                                 | g/ha | ———— % ———— | ————    | % of untreated         |
| Acetochlor +                    |      |             |         |                        |
| dichlormid (5.8:1)              | 1793 | 4           | 93      | 97                     |
| Alachlor                        | 2521 | 14          | 36      | 55                     |
| Atrazine                        | 2241 | 18          | 44      | 59                     |
| Cyanazine                       | 3026 | 4           | 86      | 96                     |
| Dimethenamid                    | 1311 | 13          | 56      | 61                     |
| Flumetsulam +                   |      |             |         |                        |
| clopyralid (1:2.7)              | 238  | 19          | 51      | 72                     |
| Flumetsulam +                   |      |             |         |                        |
| metolachlor (1:37.4)            | 2417 | 20          | 65      | 76                     |
| Halosulfuron + furilazole (1:3) | 84   | 20          | 69      | 86                     |
| Imazaquin                       | 140  | 23          | 56      | 64                     |
| Imazethapyr                     | 70   | 19          | 56      | 69                     |
| Linuron                         | 1121 | 27          | 9       | -21                    |
| Linuron +                       |      |             |         |                        |
| chlorimuron (18:1)              | 588  | 12          | 76      | 93                     |
| Metolachlor                     | 2241 | 23          | 29      | 40                     |
| Metribuzin                      | 420  | 6           | 68      | 85                     |
| Metribuzin +                    |      |             |         |                        |
| chlorimuron (10:1)              | 368  | 13          | 80      | 92                     |
| Pendimethalin                   | 1681 | 26          | 13      | -32                    |
| Untreated                       |      | 21          | 0       | 0                      |
| LSD (0.05)                      |      | 12          | 21      | 34                     |

<sup>a</sup>Evaluated 28 DAT.

Table 5. Response of seedling wild carrot to postemergence herbicides.

| Treatment <sup>c</sup>       | Rate                   | Control |        | Growth reduction <sup>a</sup> |      |       |
|------------------------------|------------------------|---------|--------|-------------------------------|------|-------|
|                              |                        | 7 DAT   | 28 DAT | Shoot                         | Root | Total |
|                              | g/ha + %v/v            | —— % —— |        | — % of untreated —            |      |       |
| 2,4-D amine                  | 798.0                  | 41      | 57     | 49                            | 59   | 55    |
| Acifluorfen + NIS            | 420.0 + 0.125          | 11      | 13     | -8                            | -23  | -15   |
| Atrazine + COC               | 2241.0 + 1.0           | 28      | 64     | 69                            | 86   | 79    |
| Bentazon + COC               | 1121.0 + 1.0           | 58      | 100    | 100                           | 99   | 100   |
| Bromoxynil                   | 420.0                  | 21      | 12     | 6                             | -5   | 2     |
| Chlorimuron + NIS            | 11.7 + 0.25            | 44      | 70     | 71                            | 73   | 72    |
| Clopyralid                   | 140.0                  | 55      | 76     | 50                            | 67   | 61    |
| Cyanazine                    | 2219.0                 | 47      | 100    | 99                            | 90   | 94    |
| Dicamba                      | 560.0                  | 48      | 49     | 12                            | 16   | 15    |
| Flumiclorac-pentyl           | 59.0                   | 13      | 6      | -18                           | -33  | -25   |
| Fomesafen + NIS              | 420.0 + 0.25           | 25      | 21     | 2                             | 26   | 17    |
| Glyphosate + NIS + AMS       | 840.0 + 0.5 + 2.0 %w/w | 18      | 26     | 19                            | 18   | 19    |
| Halosulfuron + NIS           | 41.5 + 0.25            | 40      | 76     | 68                            | 66   | 67    |
| Imazaquin + NIS <sup>b</sup> | 140.0 + 0.25           | 18      | 57     | 26                            | 24   | 26    |
| Imazethapyr + NIS + 28% N    | 70.0 + 0.25 + 4.0 %v/v | 23      | 67     | 49                            | 44   | 47    |
| Lactofen + COC               | 219.0 + 1.0            | 59      | 17     | -19                           | 4    | -4    |
| Metribuzin + NIS             | 420.0 + 0.25           | 51      | 64     | 63                            | 70   | 67    |
| Nicosulfuron + NIS           | 35.0 + 0.25            | 20      | 34     | 20                            | 18   | 20    |
| Primisulfuron + NIS + 28% N  | 40.0 + 0.25 + 4.0 %v/v | 39      | 69     | 67                            | 69   | 68    |
| Prosulfuron                  | 30.1                   | 33      | 91     | 89                            | 74   | 80    |
| Thifensulfuron + NIS         | 4.4 + 0.125            | 5       | 12     | -9                            | -12  | -10   |
| Tribenuron + NIS             | 17.3 + 0.25            | 37      | 64     | 54                            | 62   | 59    |
| Untreated                    |                        | 0       | 0      | 0                             | 0    | 0     |
| LSD (0.05)                   |                        | 13      | 15     | 27                            | 33   | 28    |

<sup>a</sup>Evaluated 28 DAT. Growth reduction determined with dry weights.

<sup>b</sup>Evaluated with only four replications rather than eight.

<sup>c</sup>Abbreviations: AMS = ammonium sulfate; COC = crop oil concentrate; N = nitrogen; NIS = nonionic surfactant.

Table 6. Control of established wild carrot with fall herbicide application, 1994.

| Treatment <sup>a</sup>                | Rate        | Control        |        |         |                |
|---------------------------------------|-------------|----------------|--------|---------|----------------|
|                                       |             | Lenawee County |        |         | Clinton County |
|                                       |             | April 23       | May 16 | June 14 | November 18    |
|                                       | kg/ha       | %              |        |         |                |
| Glyphosate <sup>b</sup>               | 0.21        | 48             | 35     | 22      | 39             |
| Glyphosate <sup>b</sup>               | 0.42        | 67             | 50     | 47      | 57             |
| Glyphosate <sup>b</sup>               | 0.84        | 85             | 75     | 62      | 88             |
| Glyphosate <sup>b</sup>               | 1.68        | 91             | 82     | 76      | 93             |
| 2,4-D ester                           | 0.56        | 82             | 78     | 76      | 25             |
| 2,4-D ester                           | 1.12        | 81             | 88     | 88      | 32             |
| Glyphosate + 2,4-D ester <sup>b</sup> | 0.21 + 0.56 | 88             | 86     | 81      | 43             |
| Glyphosate + 2,4-D ester <sup>b</sup> | 0.42 + 0.56 | 90             | 87     | 84      | 75             |
| Glyphosate + 2,4-D ester <sup>b</sup> | 0.84 + 0.56 | 94             | 89     | 83      | 75             |
| Glyphosate + 2,4-D ester <sup>b</sup> | 1.68 + 0.56 | 97             | 95     | 87      | 83             |
| Glyphosate + 2,4-D ester <sup>b</sup> | 0.21 + 1.12 | 83             | 74     | 73      | 61             |
| Glyphosate + 2,4-D ester <sup>b</sup> | 0.42 + 1.12 | 91             | 89     | 83      | 65             |
| Glyphosate + 2,4-D ester <sup>b</sup> | 0.84 + 1.12 | 92             | 85     | 84      | 75             |
| Glyphosate + 2,4-D ester <sup>b</sup> | 1.68 + 1.12 | 84             | 76     | 52      | 83             |
| Dicamba                               | 0.56        | 27             | 13     | 3       | 49             |
| Dicamba                               | 1.12        | 32             | 18     | 3       | 47             |
| Untreated                             |             | 0              | 0      | 0       | 0              |
| LSD (0.05)                            |             | 18             | 21     | 22      | 13             |

<sup>a</sup>Applied at 103 L/ha.<sup>b</sup>Nonionic surfactant (X-77) at 0.5 %v/v + ammonium sulfate at 2.0 %w/w was added.

Table 7. Control of overwintered wild carrot with preemergence herbicides in no-tillage soybean.

| Herbicide                                    | Rate<br>g/ha | Control <sup>a</sup> |                |
|----------------------------------------------|--------------|----------------------|----------------|
|                                              |              | St. Clair County     | Lenawee County |
|                                              |              | %                    |                |
| Glyphosate <sup>b</sup>                      | 420          | 28                   | 35             |
| Glyphosate <sup>b</sup>                      | 840          | 35                   | 44             |
| Glyphosate <sup>b</sup>                      | 1681         | 70                   | 59             |
| Imazaquin <sup>c</sup>                       | 140          | 52                   | 64             |
| Imazethapyr <sup>c</sup>                     | 70           | 42                   | 68             |
| Linuron + chlorimuron (18:1) <sup>c</sup>    | 594          | 73                   | 78             |
| Metribuzin <sup>c</sup>                      | 420          | 57                   | 64             |
| Metribuzin + chlorimuron (10:1) <sup>c</sup> | 325          | 76                   | 78             |
| Paraquat + linuron <sup>d</sup>              | 515 + 840    | 35                   | 55             |
| Linuron <sup>e</sup>                         | 840          | 7                    | 8              |
| Untreated                                    |              | 0                    | 0              |
| LSD (0.05)                                   |              | 20                   | 13             |

<sup>a</sup>Evaluated on July 24, 1993 at St. Clair County and on July 12, 1994 at Lenawee County.

<sup>b</sup>Linuron at 840.0 g/ha + pendimethalin at 1121.0 g/ha + nonionic surfactant (X-77) at 0.5 %v/v + ammonium sulfate at 2.0 %w/w was added for control of other weeds.

<sup>c</sup>Paraquat at 515.0 g/ha + pendimethalin at 1121.0 g/ha + nonionic surfactant (X-77) at 0.5 %v/v was added for control of other weeds.

<sup>d</sup>Pendimethalin at 1121.0 g/ha + nonionic surfactant (X-77) at 0.125 %v/v was added.

<sup>e</sup>Pendimethalin at 1121.0 g/ha + crop oil concentrate at 1.0 %v/v was added.

**Table 8. Control of overwintered wild carrot with early preplant versus preemergence applications of glyphosate in no-tillage soybean.**

|                  |            |      | Control <sup>a</sup> |                  |
|------------------|------------|------|----------------------|------------------|
| Location         | Herbicide  | Rate | EPP <sup>b</sup>     | PRE <sup>c</sup> |
|                  |            |      | ———— % ————          |                  |
| St. Clair County | Glyphosate | 0.42 | 87                   | 28               |
|                  | Glyphosate | 0.84 | 95                   | 35               |
|                  | Glyphosate | 1.68 | 95                   | 70               |
| LSD (0.05)       |            |      | ———— 20 ————         |                  |
| Lenawee County   | Glyphosate | 0.42 | 17                   | 35               |
|                  | Glyphosate | 0.84 | 24                   | 44               |
|                  | Glyphosate | 1.68 | 17                   | 59               |
| LSD (0.05)       |            |      | ———— 13 ————         |                  |

<sup>a</sup>Evaluated on July 12, 1993 at St. Clair County and on July 12, 1994 at Lenawee County.

<sup>b</sup>Nonionic surfactant (X-77) at 0.5 %v/v + ammonium sulfate at 2.0 %w/w was added and the treatment applied at 103 L/ha. Linuron at 0.84 kg/ha + pendimethalin at 1.12 kg/ha + crop oil concentrate at 1.0 %v/v was applied PRE.

<sup>c</sup>Linuron at 0.84 kg/ha + pendimethalin at 1.12 kg/ha + nonionic surfactant (X-77) at 0.5 %v/v + ammonium sulfate at 2.0 %w/w was added and the treatment applied at 206 L/ha.

Table 9. Control of overwintered wild carrot with preemergence herbicides in no-tillage corn.

| Treatment                                                   | Rate<br>g/ha       | Control <sup>a</sup> |                |
|-------------------------------------------------------------|--------------------|----------------------|----------------|
|                                                             |                    | St. Clair County     | Lenawee County |
| Atrazine + pendimethalin <sup>b</sup>                       | 1681 + 1121        | 70                   | 48             |
| Cyanazine + pendimethalin <sup>b</sup>                      | 2241 + 1121        | 85                   | 39             |
| Flumetsulam + clopyralid (1:2.7) + metolachlor <sup>b</sup> | 235 + 2241         | —                    | 45             |
| Flumetsulam + metolachlor (1:37.4) <sup>b</sup>             | 2297 <sup>c</sup>  | 42                   | 32             |
| Glyphosate + pendimethalin <sup>d</sup>                     | 420 + 1121         | 35                   | 10             |
| Glyphosate + pendimethalin <sup>d</sup>                     | 840 + 1121         | 68                   | 18             |
| Halosulfuron + furlazole (1:3) + pendimethalin <sup>b</sup> | 84 + 1121          | 80                   | 67             |
| Paraquat + pendimethalin <sup>e</sup>                       | 515 + 1121         | 38                   | 46             |
| Paraquat + pendimethalin fb. bromoxynil <sup>e,f</sup>      | 515 + 1121 fb. 420 | 33                   | 50             |
| Paraquat + metolachlor fb. bromoxynil <sup>e,f</sup>        | 515 + 2241 fb. 420 | 30                   | 58             |
| Untreated                                                   |                    | 0                    | 0              |
| LSD (0.05)                                                  |                    | 25                   | 14             |

<sup>a</sup>Evaluated on July 24, 1993 at St. Clair County and on July 12, 1994 at Lenawee County.

<sup>b</sup>Paraquat at 515.0 g/ha + nonionic surfactant (X-77) at 0.125 %v/v was added.

<sup>c</sup>In Lenawee County, the flumetsulam + metolachlor rate was 2689.0 g/ha.

<sup>d</sup>Nonionic surfactant (X-77) at 0.5 %v/v + ammonium sulfate at 2.0 %w/w was added.

<sup>e</sup>Nonionic surfactant (X-77) at 0.125 %v/v was added.

<sup>f</sup>Abbreviation: fb = followed by.

*Table 10. Control of overwintered wild carrot with postemergence herbicides in no-tillage corn.*

| Treatment <sup>b</sup>                          | Rate   | Control <sup>a</sup> |                |
|-------------------------------------------------|--------|----------------------|----------------|
|                                                 |        | St. Clair County     | Lenawee County |
|                                                 | g/ha   | %                    |                |
| 2,4-D amine                                     | 560.0  | 35                   | 79             |
| 2,4-D ester                                     | 399.0  | 38                   | 63             |
| Atrazine <sup>c</sup>                           | 2241.0 | 92                   | 85             |
| Clopyralid                                      | 70.6   | 48                   | 49             |
| Clopyralid                                      | 140.0  | 71                   | 62             |
| Clopyralid                                      | 280.0  | 68                   | —              |
| Cyanazine                                       | 2241.0 | —                    | 78             |
| Dicamba                                         | 560.0  | 51                   | 49             |
| Flumetsulam + clopyralid +<br>2,4-D (1:2.7:5.5) | 235.0  | —                    | 89             |
| Halosulfuron <sup>e</sup>                       | 41.4   | 79                   | 95             |
| Nicosulfuron <sup>f</sup>                       | 35.0   | 81                   | 87             |
| Pimisulfuron <sup>f</sup>                       | 39.2   | 82                   | 89             |
| Prosulfuron <sup>e</sup>                        | 30.1   | —                    | 96             |
| Untreated                                       |        | 0                    | 0              |
| LSD (0.05)                                      |        | 25                   | 14             |

<sup>a</sup>Evaluated on July 24, 1993 at St. Clair County and on July 12, 1994 at Lenawee County.

<sup>b</sup>Pendimethalin at 1121.0 g/ha + paraquat at 515.0 g/ha + nonionic surfactant (X-77) at 0.125 %v/v was applied PRE.

<sup>c</sup>Crop oil concentrate at 1.0 %v/v was added.

<sup>d</sup>Nonionic surfactant (X-77) at 0.25 %v/v + 28% Nitrogen at 4.0 %v/v was added.

<sup>e</sup>Nonionic surfactant (X-77) at 0.25 %v/v was added.

<sup>f</sup>Crop oil concentrate at 1.0 %v/v + 28% Nitrogen at 4.0 %v/v was added.

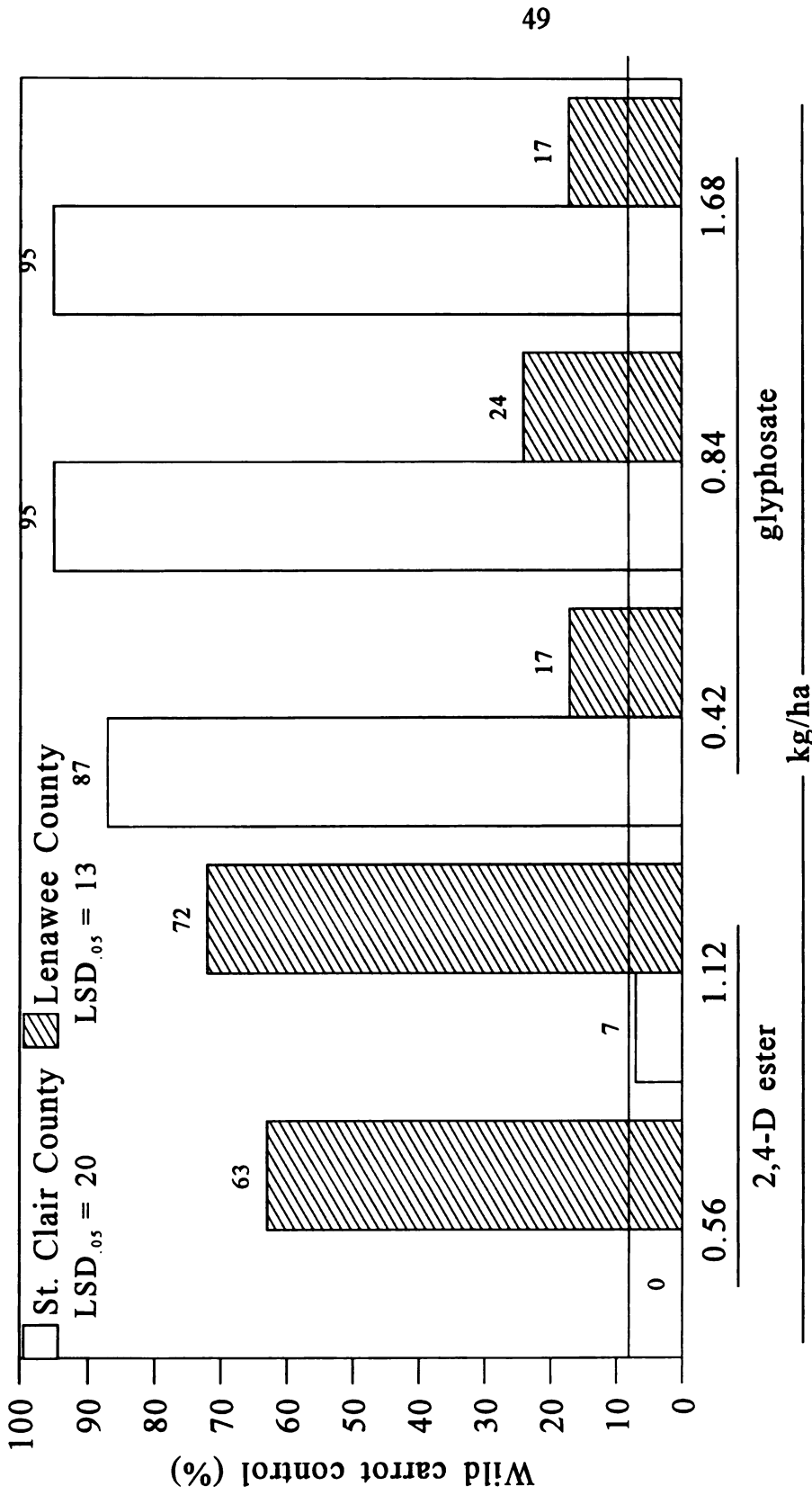


Figure 1. Control of overwintered wild carrot with early preplant herbicides in no-tillage soybean. Evaluated on July 24, 1993 at St. Clair County and on July 12, 1994 at Lenawee County. The line in the chart represents the level of control at these ratings provided by linuron at 840 g/ha + pendimethalin at 1121 g/ha + crop oil concentrate at 1.0 %v/v applied PRE for control of other weeds. The glyphosate treatments were applied at 103 L/ha.

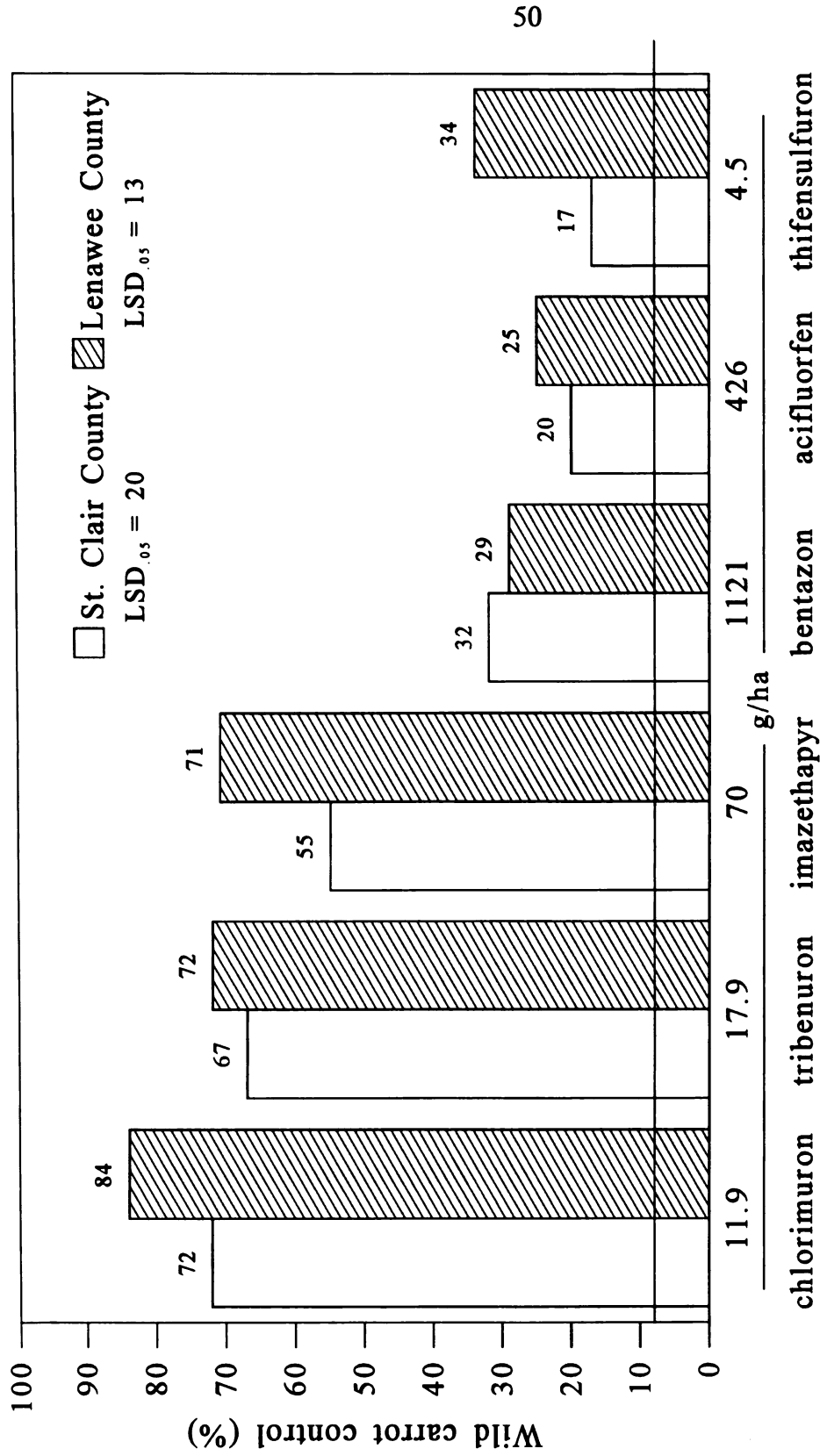


Figure 2. Control of overwintered wild carrot with postemergence herbicides in no-tillage soybean. Evaluated on July 24, 1993 at St. Clair County and on July 12, 1994 at Lenawee County. The line in the chart represents the level of control for linuron at 840 g/ha + pendimethalin at 1121 g/ha + crop oil concentrate at 1.0 %v/v applied PRE for control of other weeds.

## **Chapter 3**

### **DIFFERENTIAL RESPONSE OF WILD CARROT TO 2,4-D**

#### **ABSTRACT**

Differential response of wild carrot to 2,4-D has been reported in field research in Michigan. Ten primary umbels within a population were collected from several locations and stored separately. Greenhouse studies were conducted with plants grown from the collected seed to study resistance to 2,4-D among and within wild carrot populations. The differential response of wild carrot to 2,4-D in field research was explained by the presence of resistant wild carrot. Among 14 populations, wild carrot control with 2,4-D ranged from 18 to 91%. Wild carrot varied in its response to 2,4-D among and within populations as well as within an individual umbel. In more than one-half of the populations tested, at least one wild carrot plant was resistant to 2,4-D. Therefore, resistance to 2,4-D is widespread throughout Michigan and the Midwest. **Nomenclature:** 2,4-D, (2,4 dichlorophenoxy)acetic acid; wild carrot, *Daucus carota* L. **Additional Index Words:** resistance, differential response, DAUCA.

#### **INTRODUCTION**

**Wild** carrot is increasing as a weed problem in continuous no-tillage crop

production (6). Stachler and Kells (6) reported that wild carrot at three field research locations showed a differential response to 2,4-D. Differences in weed control with field research are often explained by environmental conditions before, during, and/or after herbicide application. Location characteristics, such as the genetic base of a species, may also explain differences in weed control (3). Kosinski and Weller (3) reported morphologically different field bindweed biotypes that responded differentially to glyphosate. Morphological characteristics (5) and isozyme analysis (7) of wild carrot are variable among and within wild carrot collections. Switzer (8) reported the existence of strains of wild carrot resistant to 2,4-D as early as 1957. Whitehead and Switzer (9) reported that resistance to 2,4-D appeared to develop between germination and the cotyledon stage of growth .

Three studies were conducted in the greenhouse to: 1) determine the basis of the differential response reported in field research, 2) examine the response of wild carrot from several locations to 2,4-D, and 3) determine the variability of the response of wild carrot to 2,4-D within a population.

## **MATERIALS AND METHODS**

**General experimental procedures.** Greenhouse studies were conducted with established wild carrot grown from seed collected from several locations in the North Central United States and Canada (Table 1). For all greenhouse studies, ten primary umbels were collected from each location and stored separately at

room temperature until threshed. For sample N (Table 1), primary and secondary umbels were collected from eight plants. The umbels from a single plant were composited as one sub-sample and the eight sub-samples were stored separately. Fifteen primary umbels were collected for sample C and stored as a composite sample. Only mature, brown umbels were collected at each location. The seeds of each umbel were removed by hand and rubbed across a number 20 sieve to separate the paired seeds and to remove the bristles from the seed. Seeds were placed in a sealed plastic bag and stored at 4 C. The geographic distribution of sampling sites is illustrated in Figure 1. The habitats of samples A through N were roadside, fallow, corn, soybean, or wheat production (Table 1). The dominant habitats were roadside and soybean production. Samples D and E were collected from the same location. Sample E was visibly different than sample D in that the seeds and respective plant parts were purplish. All seeds were collected in the fall of 1993.

A 16-hour photoperiod was maintained using natural and supplemental metal halide lighting with an average midday photosynthetic photon flux density (PPFD) of  $700 \mu\text{E}/\text{m}^2/\text{s}$  measured with a photometer<sup>1</sup> at plant height, 150 cm from the light source. Wild carrot seeds were planted at a depth of 0.64 cm in 945 ml plastic pots. The pots were watered to saturation after planting and maintained between field capacity and wilting point for the duration of the study. Three to four days after planting, each pot received approximately 25 ml of etridiazole (5-ethoxy-3-

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<sup>1</sup>Li-1985B Quantum Photometer. Lambda Instruments Corp., Lincoln, NE 68504.

trichloromethyl-1,2,4-thiodiazole) plus thiophanate-methyl (dimethyl 4,4'-O-phenylenebis(3-thioallophanate)) (3:5) solution (30 mg/L of water) as a soil fungicide drench. At 18 - 20 days after planting for all studies, a fertilizer solution (71 mg of Peters 20-20-20 water soluble fertilizer per liter of water) was applied at 50 ml per pot. After the initial fertilization, each pot was fertilized at the same rate every 7 days until the completion of the study. Wild carrot were thinned over time to a final population of one plant per pot 10 days before herbicide application. Herbicide treatments were applied with a single Teejet<sup>2</sup> 8001E flat fan nozzle at 31 cm above the target on a continuous link belt sprayer calibrated to deliver 234 L/ha at a pressure of 200 kPa. The herbicide treatments for all studies were 2,4-D amine at 0 or 1.1 kg/ha.

All studies were designed as randomized complete blocks with four replications and arranged as a factorial. Factors were sampling location and 2,4-D application rate. All studies were repeated. Each study was visually evaluated for control at 7, 14, 21, and 28 days after treatment (DAT). Control was evaluated based on a scale with zero representing no visible injury and 100 representing complete plant death. At 28 DAT, the plants were harvested by removing soil and roots with a diameter less than 1.0 mm from the tap root. The entire plant was washed to remove any remaining soil. The shoot was then separated from the root at the base of the crown. Fresh and dry weights were determined for the shoot and root. Data were subjected to analysis of variance and means separated by Fisher's

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<sup>2</sup>Spraying Systems Co., North Avenue. Wheaton, IL 60188.

Protected LSD at the 5 or 10% level.

**Field research location study.** Seed was collected in 1993 and 1994 as previously described from the untreated areas of the 3 field research sites, St. Clair, Lenawee, and Clinton Counties, reported by Stachler and Kells (6). Seeds from the ten umbels were composited into a single sample for each of the field research sites. Twenty-five seeds from the Lenawee and Clinton County locations were planted in each pot and 10 seeds from the St. Clair County location were planted in each pot. The seeds were planted into Baccto<sup>3</sup> potting soil. At the time of herbicide application, the plants had 9 to 13 leaves. Five replications were used. Data was compared with the 2,4-D ester treatments from the field results reported by Stachler and Kells (6).

**Sample study.** For all samples (Table 1), except sample C, an equal volume of seed from the 10 umbels within a sample were composited. At least 22 seeds were planted per pot for each composite sample. The seeds were planted in a steam-treated sandy clay loam soil mixture comprised of 61% sand, 19% silt, 20% clay, and 5% organic matter with a pH of 6.4. The plants had 7 to 12 leaves at the time of herbicide application. Plants from each sample were treated with 2,4-D amine at 0, 0.6, or 1.1 kg/ha. The control values of individual plants within a sample were distributed into three groups to determine variability within a sample. The three groups are resistant (0 to 25% control), intermediate (26 to 74% control), and susceptible (75 to 100% control).

**Individual umbel study.** To determine variability within a population, at least 10

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<sup>3</sup>Baccto is a product of Michigan Peat Co., Houston, TX 77098.

seeds were planted per pot from each umbel from samples D, F, and G. The seeds were planted in Baccto potting soil. At the time of herbicide application, the plants had 9 to 14 leaves. Samples D, F, and G were chosen from the resistant, intermediate, and susceptible groups from the sample study. The control values of individual plants within an umbel were distributed into the three groups to make conclusions about within umbel variation.

## **RESULTS AND DISCUSSION**

**Field research location study.** Control of wild carrot in the greenhouse from St. Clair, Lenawee, and Clinton County field research sites were 25, 93, and 34%, respectively (Figure 2). The results in the greenhouse showed the same trend as observed at the field research sites (Figure 2). The plants in the greenhouse were grown and treated under the same environment, therefore the cause for the differential response to 2,4-D has some genetic basis. The poor control of wild carrot at the St. Clair and Clinton County field research locations verifies the presence of 2,4-D resistance as reported by other researchers (8, 9).

**Sample study.** Wild carrot from the 14 composite samples showed a differential response to 2,4-D. At 28 DAT, the mean control of the 14 composite samples with 2,4-D ranged from 18 to 91% (Table 2). The application of 2,4-D reduced total plant growth of all samples 19 to 72% of the untreated. Wild carrot from sample F showed the highest control and shoot, root, and total plant growth reduction with 2,4-

D (Table 2). Figure 3 illustrates the level of control of the 14 samples based on location. There appears to be no geographical pattern to the resistance of wild carrot to 2,4-D. The mean wild carrot control at 28 DAT of samples D and E, which were collected at the same location, was 19 and 44%, respectively (Table 2). There is no correlation with control to the habitat from which the seed was collected.

No individual plants from samples C, D, and H responded with greater than 74% control with 2,4-D (Table 3). No individual plants from samples A, B, G, I, and M responded with less than 26% control from 2,4-D. At least one plant of all 14 samples was controlled at 26-74% with 2,4-D (Table 3). Therefore, variation within population exists based on response of wild carrot to 2,4-D. Small (5) has reported variation for morphological characteristics within a population.

**Individual umbel study. Sample D (resistant).** Control of wild carrot at 28 DAT from umbels from sample D ranged from 15 to 76% (Table 4). Growth reduction of plants from umbels from sample D were not significantly different. All umbels of sample D had at least 2 individual plants responding to 2,4-D in 2 or 3 groups (Table 5). Therefore, variation based on response to 2,4-D is present within an umbel. At least one individual plant from nearly all umbels responded with 26 to 74% control (Table 5).

**Sample F (intermediate).** The mean wild carrot control at 28 DAT from the 10 umbels ranged from 20 to 92% (Table 4). Total plant growth reduction ranged from -2 to 68%. All plants from umbel 9 responded with greater than 75% control with 2,4-D. Only 60% of the umbels had individual plants responding with 26 to 74%

control with 2,4-D (Table 5).

*Sample G (susceptible).* Wild carrot from the four umbels were controlled 86 or 87% at 28 DAT (Table 4). There was no significant difference between umbels from this collection. No plants from any umbel responded with less than 26% control with 2,4-D, but all umbels had at least one plant which responded at 26 to 74% control (Table 5).

**General discussion.** Plants varied in their response to 2, 4-D among samples, within samples, among umbels from a sample, and within an umbel. Variation among and within populations has also been reported for morphological characteristics of wild carrot (2, 5). The variable response of wild carrot to 2,4-D may partially be explained by the reproductive system of wild carrot (4). Each flower within an umbel has the possibility of pollen entering from a different source.

All plants were initially injured but the resistant plants recovered over time, though not completely. Root growth of wild carrot for all collections and umbels was usually reduced more than shoot growth by application of 2,4-D. Apparently the shoot metabolizes 2,4-D faster than the roots or at this stage of growth the root is the largest sink and receives more 2,4-D than the shoot. When significant differences in control occurred, total plant growth reduction was always correlated to 28 DAT evaluation at an  $r$  value greater than 0.82. Of the three growth reduction parameters, the shoot growth reduction typically had the lowest correlation to 28 DAT visual evaluation.

Hay and Quellette (1) and Switzer (8) have reported that wild carrot is

susceptible to intermediate in its response to 2,4-D. In a survey by Switzer (8) 8 of 22 heavily infested areas reported inadequate control with 2,4-D. At least one plant responded with less than 26% control from 2,4-D in 63% of the tested samples. Therefore, this research and research of previous investigators confirms that resistance of wild carrot to 2,4-D is widespread throughout Michigan, other North Central States, and Canada.

## **LITERATURE CITED**

## LITERATURE CITED

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*Table 1.* Location and habitat of the samples in the sample study.

| Sample         | Location         | Habitat  |
|----------------|------------------|----------|
|                | county           |          |
| A              | Mackinac, MI     | Roadside |
| B              | Presque Isle, MI | Roadside |
| C              | Bay, MI          | Soybean  |
| D <sup>a</sup> | St. Clair, MI    | Soybean  |
| E <sup>a</sup> | St. Clair, MI    | Soybean  |
| F              | Ingham, MI       | Fallow   |
| G              | Lenawee, MI      | Soybean  |
| H              | Hillsdale, MI    | Corn     |
| I              | Berrien, MI      | Roadside |
| J              | Ogle, IL         | Roadside |
| K              | Darke, OH        | Roadside |
| L              | Delaware, OH     | Wheat    |
| M              | Coshocton, OH    | Fallow   |
| N              | Middlesex, ONT   | Soybean  |

<sup>a</sup>Samples are from the same location, but sample E had purplish seeds.

*Table 2.* The response of wild carrot to 2,4-D amine at 1.1 kg/ha for the sample study.

| Sample         | Control     |        | Dry weight growth reduction <sup>a</sup> |      |       |
|----------------|-------------|--------|------------------------------------------|------|-------|
|                | 7 DAT       | 28 DAT | Shoot                                    | Root | Total |
|                | ———— % ———— |        | ———— % of untreated ————                 |      |       |
| A              | 65          | 82     | 51                                       | 80   | 66    |
| B              | 73          | 91     | 52                                       | 88   | 72    |
| C              | 20          | 18     | 8                                        | 29   | 21    |
| D <sup>b</sup> | 24          | 19     | 1                                        | 31   | 19    |
| E <sup>b</sup> | 43          | 44     | 21                                       | 46   | 36    |
| F              | 47          | 67     | 33                                       | 43   | 37    |
| G              | 60          | 84     | 32                                       | 81   | 61    |
| H              | 18          | 19     | 7                                        | 37   | 23    |
| I              | 59          | 75     | 47                                       | 79   | 63    |
| J              | 28          | 29     | 5                                        | 35   | 23    |
| K              | 46          | 51     | 31                                       | 51   | 41    |
| L              | 56          | 77     | 42                                       | 76   | 60    |
| M              | 56          | 89     | 51                                       | 78   | 66    |
| N              | 32          | 39     | 21                                       | 32   | 25    |
| LSD (0.05)     | 15          | 26     | 27                                       | 30   | 25    |

<sup>a</sup>Evaluated 28 DAT.

<sup>b</sup>Samples are from the same location, but sample E had purplish seeds.

**Table 3.** The distribution of individual plants into three groups based on control at 28 DAT for the sample study<sup>a</sup>.

| Sample | Control | Groups            |                       |                       |
|--------|---------|-------------------|-----------------------|-----------------------|
|        | 28 DAT  | Resistant (0-25%) | Intermediate (26-74%) | Susceptible (75-100%) |
|        | %       | Individual plants |                       |                       |
| A      | 82      | 0                 | 3                     | 5                     |
| B      | 91      | 0                 | 2                     | 6                     |
| C      | 18      | 6                 | 2                     | 0                     |
| D      | 19      | 6                 | 2                     | 0                     |
| E      | 44      | 4                 | 2                     | 2                     |
| F      | 67      | 2                 | 1                     | 5                     |
| G      | 84      | 0                 | 2                     | 6                     |
| H      | 19      | 7                 | 1                     | 0                     |
| I      | 75      | 0                 | 3                     | 5                     |
| J      | 29      | 5                 | 2                     | 1                     |
| K      | 51      | 2                 | 3                     | 3                     |
| L      | 77      | 1                 | 1                     | 6                     |
| M      | 89      | 0                 | 2                     | 6                     |
| N      | 39      | 4                 | 2                     | 2                     |

<sup>a</sup>2,4-D amine at 1.1 kg/ha was applied.

**Table 4.** The response of wild carrot to 2,4-D amine at 1.1 kg/ha for umbels within samples D (resistant), F (intermediate), and G (susceptible).

| Individual | Control                           |                 | Dry weight growth reduction <sup>a</sup> |      |       |
|------------|-----------------------------------|-----------------|------------------------------------------|------|-------|
| umbel      | 7 DAT                             | 28 DAT          | Shoot                                    | Root | Total |
|            | ———— % ————                       |                 | ———— % of untreated ————                 |      |       |
|            | ———— Sample D (resistant) ————    |                 |                                          |      |       |
| 1          | 34                                | 42              | 19                                       | 38   | 28    |
| 2          | 40                                | 57              | 24                                       | 57   | 39    |
| 3          | 15                                | 15              | -6                                       | 21   | 7     |
| 4          | 35                                | 42              | 18                                       | 2    | 12    |
| 5          | 38                                | 41              | 12                                       | 31   | 21    |
| 6          | 46                                | 76              | 32                                       | 64   | 48    |
| 7          | 29                                | 41              | 23                                       | 51   | 37    |
| 8          | 37                                | 39              | 1                                        | 36   | 15    |
| LSD (0.05) | 17                                | 28 <sup>b</sup> | ———— NS ————                             |      |       |
|            | ———— Sample F (intermediate) ———— |                 |                                          |      |       |
| 1          | 57                                | 92              | 62                                       | 71   | 68    |
| 2          | 52                                | 85              | 47                                       | 84   | 65    |
| 3          | 44                                | 62              | 22                                       | 58   | 40    |
| 4          | 40                                | 60              | 24                                       | 32   | 30    |
| 5          | 48                                | 66              | 32                                       | 58   | 46    |
| 6          | 31                                | 39              | -1                                       | 41   | 22    |
| 7          | 31                                | 20              | -1                                       | -4   | -2    |
| 8          | 54                                | 77              | 46                                       | 73   | 60    |
| 9          | 58                                | 88              | 37                                       | 81   | 55    |
| 10         | 42                                | 61              | 26                                       | 50   | 39    |
| LSD (0.05) | 14                                | 30              | 25                                       | 39   | 27    |
|            | ———— Sample G (susceptible) ————  |                 |                                          |      |       |
| 1          | 54                                | 87              | 45                                       | 79   | 61    |
| 2          | 55                                | 86              | 46                                       | 76   | 61    |
| 3          | 55                                | 86              | 39                                       | 79   | 56    |
| 4          | 52                                | 86              | 38                                       | 84   | 62    |
| LSD (0.05) | ———— NS ————                      |                 |                                          |      |       |

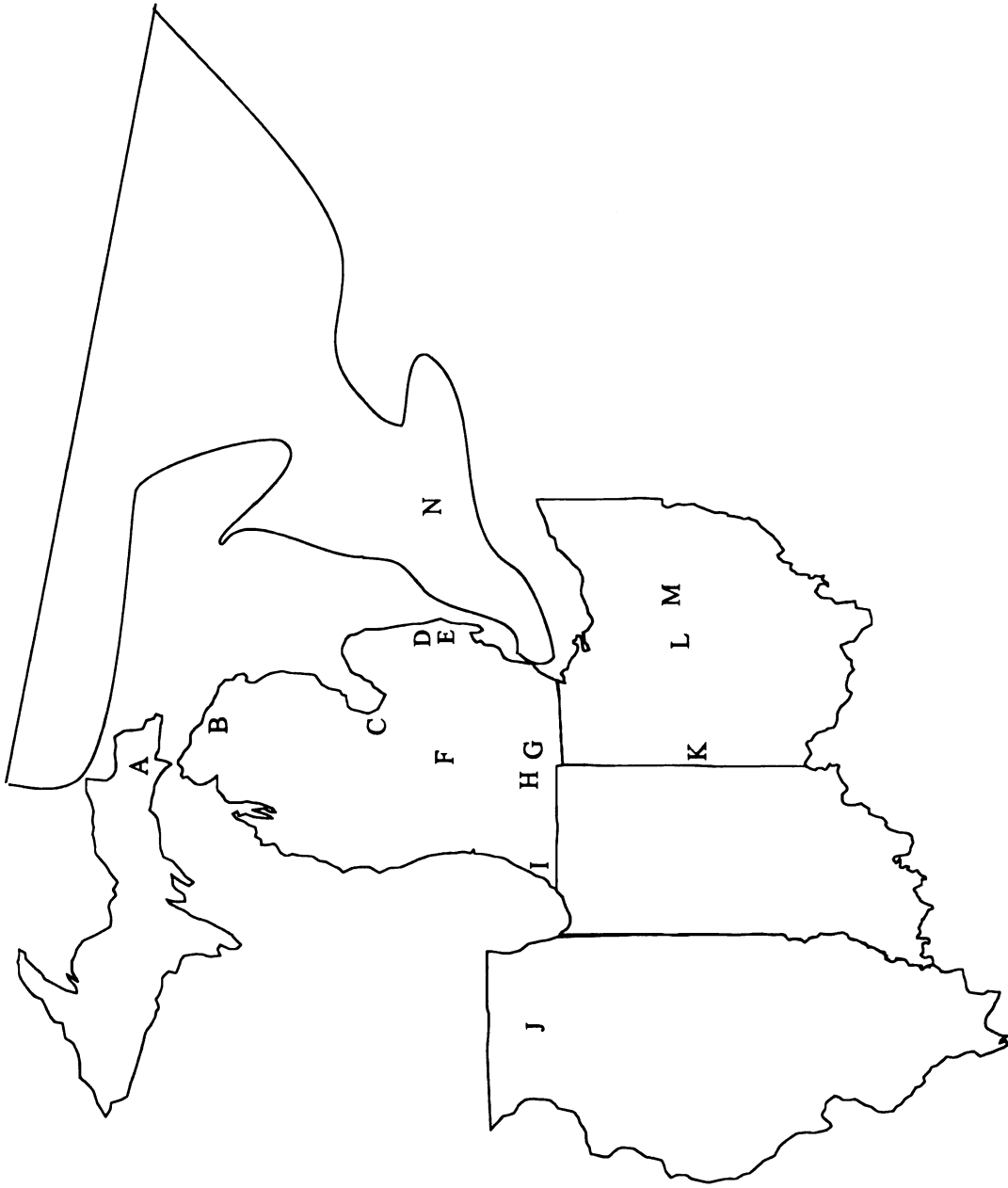
<sup>a</sup>Evaluated 28 DAT.

<sup>b</sup>Value is at LSD (0.10).

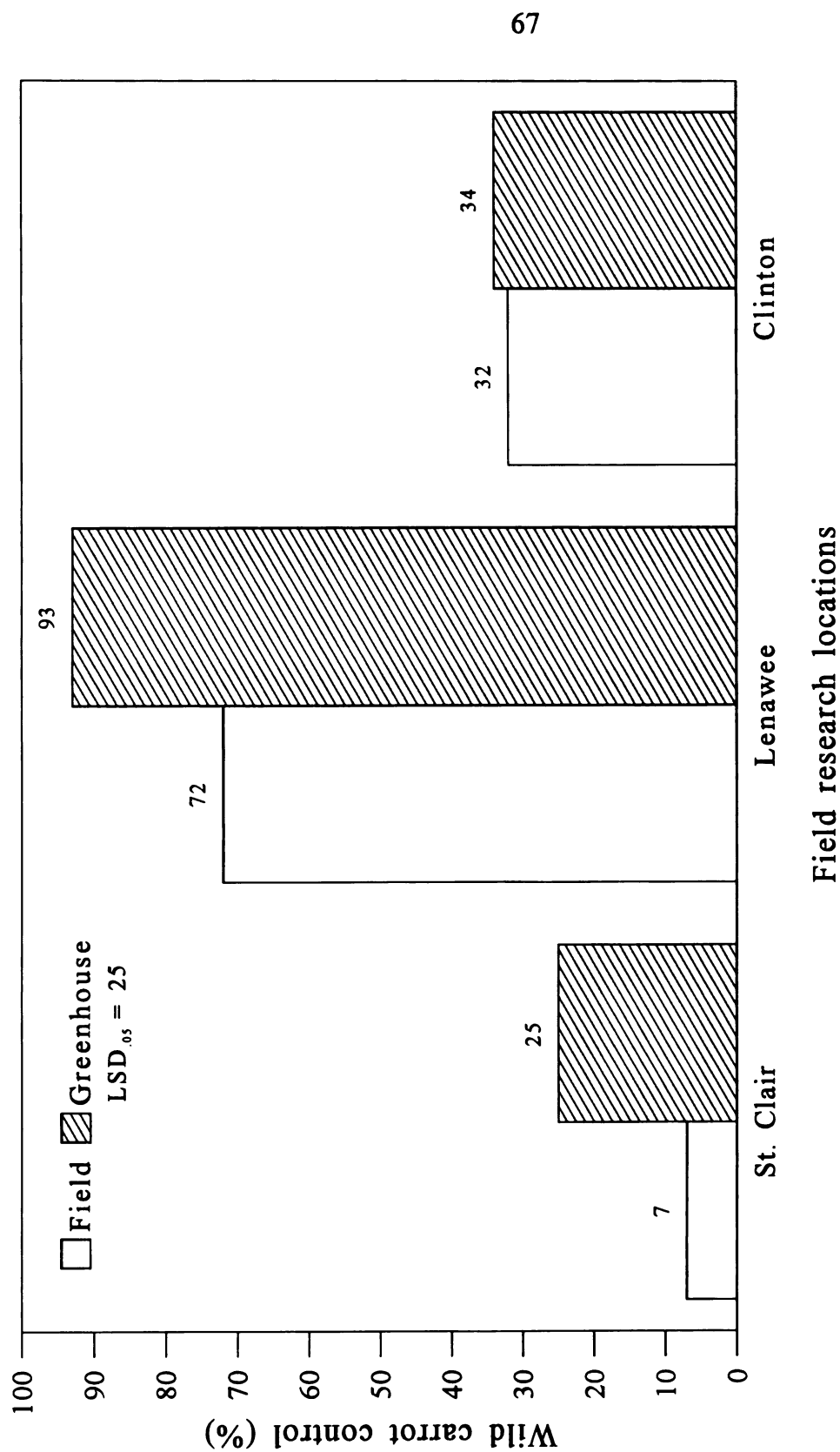
*Table 5.* The distribution of individual plants into three groups based on control at 28 DAT of umbels within samples D (resistant), F (intermediate), and G (susceptible)<sup>a</sup>.

| Individual<br>umbel <sup>b</sup> | Control | Groups                  |                       |                       |
|----------------------------------|---------|-------------------------|-----------------------|-----------------------|
|                                  | 28DAT   | Resistant (0-25%)       | Intermediate (26-74%) | Susceptible (75-100%) |
|                                  | %       | Individual plants       |                       |                       |
|                                  |         | Sample D (resistant)    |                       |                       |
| 1                                | 42      | 2                       | 4                     | 2                     |
| 2                                | 57      | 2                       | 2                     | 4                     |
| 3                                | 15      | 6                       | 2                     | 0                     |
| 4                                | 42      | 3                       | 2                     | 3                     |
| 5                                | 41      | 4                       | 2                     | 2                     |
| 6                                | 76      | 0                       | 2                     | 6                     |
| 7                                | 41      | 5                       | 0                     | 3                     |
| 8                                | 39      | 3                       | 3                     | 2                     |
|                                  |         | Sample F (intermediate) |                       |                       |
| 1                                | 92      | 0                       | 1                     | 7                     |
| 2                                | 85      | 1                       | 0                     | 7                     |
| 3                                | 62      | 1                       | 5                     | 2                     |
| 4                                | 60      | 3                       | 0                     | 5                     |
| 5                                | 66      | 2                       | 1                     | 5                     |
| 6                                | 39      | 4                       | 2                     | 2                     |
| 7                                | 20      | 5                       | 3                     | 0                     |
| 8                                | 77      | 2                       | 0                     | 6                     |
| 9                                | 88      | 0                       | 0                     | 8                     |
| 10                               | 61      | 2                       | 1                     | 5                     |
|                                  |         | Sample G (susceptible)  |                       |                       |
| 1                                | 87      | 0                       | 1                     | 7                     |
| 2                                | 86      | 0                       | 1                     | 7                     |
| 3                                | 86      | 0                       | 2                     | 6                     |
| 4                                | 86      | 0                       | 1                     | 7                     |

<sup>a</sup>2,4-D amine at 1.1 kg/ha was applied.



*Figure 1.* Location of the samples in the sample study.



*Figure 2.* Wild carrot control with 2,4-D at 1.1 kg/ha in field and greenhouse research. Locations can only be compared within the greenhouse study.



*Figure 3. Wild carrot control with 2,4-D amine at 1.1 kg/ha of samples in the sample study.*

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