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ALTERNATIVE METHODS OF WEED CONTROL FOR
CARROT PRODUCTION

presented by

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of the requirements for the

M.S. degree in Horticulture

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Major Professor's Signature

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**ALTERNATIVE METHODS OF WEED CONTROL FOR CARROT
PRODUCTION**

By

Juan Jose Cisneros

A THESIS

**Submitted to
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ABSTRACT

ALTERNATIVE METHODS OF WEED CONTROL FOR CARROT PRODUCTION

By

Juan Jose Cisneros

Experiments were conducted to study alternative methods of weed control in carrot. Several herbicides were tested in Michigan between 2001 and 2003 for preemergence and postemergence weed control in carrot. Preemergence clomazone and flufenacet plus metribuzin (Domain®) were consistently safe on carrot and provided good weed control during the production season. Carrot stand counts and yield in these herbicide treatments were similar to linuron treatment in all sites and years. Oxyfluorfen postemergence was safe on carrot and also gave good weed control.

In another experiment, an air-assisted rotary atomizer sprayer was compared to a conventional boom sprayer. Herbicide application effectiveness did not differ between the conventional sprayer and the rotary atomizer sprayer. However, this sprayer used a fourth of the amount of liquid compared to the conventional sprayer, an advantage of fewer refill trips required.

Flame weeding was studied as an alternative method of weed control. Broadleaf weeds with unprotected growing points were more susceptible to heat than grass weeds with protected growing points. Furthermore, weeds at earlier developmental stages were more susceptible to heat than weeds at older stages. In general, better weed control was obtained when weeds were flamed at the 0-2 leaf stage.

To my wife Carla and my sons Bartolome and Cristobal for their love and unconditional support

To Fausto and Rosa, my loved parents

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CHAPTER I

REVIEW OF LITERATURE

Introduction

Carrot is an important vegetable crop in several states in the US, including California, Colorado, Florida, and Michigan. In 2002, the total carrot harvested area in the US was over 43,000 ha. Michigan ranks fifth nationally in carrot production with a total harvested area of approximately 2,500 ha (U.S. Department of Agriculture, 2002). The main carrot producing counties in Michigan are Muskegon, Montcalm, and Oceana counties on mineral soils, and Newaygo and Lapeer counties on muck soils.

In general carrot production relies heavily on pesticides to increase quality and productivity. In particular, herbicides constitute about 60% of the total tonnage of pesticides applied annually on conventional vegetable production farms (Gianessi and Marcelli, 2000). This substantial use of herbicides may cause several problems such as chemical carryover, residues in the crop, soil, and groundwater, and weed resistance. Herbicide usage is essential for carrot production due to its low competitive capacity with weeds. Carrot emerges slowly preventing carrot from competing efficiently against weeds during the first six weeks of growth. In addition to competition for nutrients, water, and light and the consequent carrot yield reduction, weeds may act as host to insects and pathogens and may interfere with harvesting operations (U.S. Department of Agriculture, 1999; Bell *et al.*, 2000a; Stall, 2003). Bell *et al.* (2000a) reported an 85% reduction in carrot yield when no weed control program was applied.

In Michigan, three herbicides are labeled for preemergence use in carrots: trifluralin, metribuzin, and linuron. Linuron is the most widely used herbicide and has the widest spectrum of weed control (Bellinder *et al.*, 1997; Bell *et al.*, 2000a; Michigan State University, 2000; Stall, 2003; Zandstra, 2004). Linuron is the primary herbicide on 90% of Michigan carrot acreage (Crop Life Foundation, 1997). Linuron is a safe, efficient, and cost effective herbicide for carrot weed control and gives the highest rate of return from incremental investment in weed control (Bell *et al.*, 2000a; Michigan State University, 2000). Nevertheless, linuron is an herbicide that has been in use for several decades. Linuron was first registered in the U.S. in 1966. From 1984 to 1988 linuron was under special review because it exceeded the oncogenicity risk criteria. At present, linuron and all other herbicides labeled for carrots face an uncertain future as a result of the Food Quality Protection Act (FQPA) of 1996, that requires the Environmental Protection Agency (EPA) to reassess all pesticide tolerances by 2006 (Bell *et al.*, 2000b). Therefore, there is a future risk of use restriction, label elimination, or manufacturer voluntary withdrawal of the herbicides labeled for carrots.

The FQPA promotes the development and use of new environmentally friendly pesticides. In the past years many new herbicides have been introduced for use in major crops (Bell *et al.*, 2000b; Haar *et al.*, 2002). Most of these new herbicides are active at very low rates compared to their predecessors, which should result in lower residues in the crop, soil, and groundwater (Putnam, 1990; Haar *et al.*, 2002; Ogbuchiekwe *et al.*, 2004). Unfortunately, there is little economic incentive for chemical companies neither to register new herbicides for minor crops, nor to invest in research to develop herbicides for minor crops (Bell *et al.*, 2000b; Haar *et al.*, 2002).

Dependence on a few herbicides for many years may result in the development of herbicide resistant weeds. Masabni and Zandstra (1999) identified linuron-resistant common purslane (*Portulaca oleracea* L) in Michigan carrots fields. Beuret (1989) reported the discovery of biotypes of common groundsel (*Senecio vulgaris* L) resistant to linuron in carrots in Switzerland. The dependence on linuron for weed control in carrots may lead to the development of additional weed resistance. In addition, linuron requires high rates compared to new low-rate herbicides that in many cases are active at rates of grams per hectare. Herbicides applied at higher rates are more likely to cause problems such as chemical carryover and chemical residues in the crop, soil, and groundwater than new low-rate herbicides (Haar *et al.*, 2002; Ogbuchiekwe *et al.*, 2004). Some Michigan carrot growers produce carrot for the baby food industry, which is greatly concerned with chemical residues in raw product. As a result they demand lower inputs of pesticides in their carrot production. These growers are facing a major challenge to produce carrots with lower residues without the availability of alternative herbicides (Michigan State University, 2000).

A common cultural practice in Michigan carrot production to prevent erosion and seedling damage from wind is planting of a small grain nurse crop, usually rye (*Secale cereale* L.) or barley (*Hordeum vulgare* L.). When the cover crop reaches four inches high it is killed with an herbicide to prevent competition with the carrot crop (U.S. Department of Agriculture, 1999; Michigan State University, 2000). Linuron applied preemergence has limited activity on annual grasses (Kuratle and Rahn, 1968; Michigan

State University, 2000), so in most situations it does not have an adverse effect on the small grain nurse crop.

There are limited choices for alternative weed control programs in carrots. Below-labeled rate may be an alternative for reducing total herbicide usage, reducing off-target crop damage, and increasing profit margins (Putnam, 1990; Zhang *et al.*, 2000). Below-labeled rates have been studied by Putnam (1990), Bellinder *et al.* (1997), Zhang *et al.* (2000), and Ogbuchiekwe *et al.* (2004). A single low-rate application (0.14 kg ai/ha) of linuron postemergence did not control redroot pigweed (*Amaranthus retroflexus* L.) or common lambsquarters (*Chenopodium album* L.), and reduced carrot yield. However, two low-rate postemergence applications (0.14 kg ai/ha) of linuron significantly improved weed control and there was no yield reduction. Similar results were obtained with low-rate metribuzin applications (Bellinder *et al.*, 1997). Few studies have been reported on selectivity of new low-rate herbicides in carrot.

Physical weed control methods have been developed in other vegetable crops, including flaming and mechanical weed control. The use of mechanical methods for weed control and cover crop removal in carrot production is limited. No mechanical weed control is recommended before carrot has reached at least 15 cm to avoid root injury. Moreover, carrots are grown at very high plant densities preventing effective cultivation to control weeds without damaging the crop (Bell *et al.*, 2000).

The objectives of this research were to: evaluate the selectivity of several new herbicides developed for major agronomics crops in carrots; evaluate level of weed control of the same herbicides at rates that were safe for carrots; and gain a better understanding of flame weeding in grass and broadleaf weed control.

Literature Review

Chemical Weed Control in Carrot Crop

Preemergence herbicides labeled for carrot crops in Michigan

Trifluralin was first registered in the US in 1963. It is incorporated preemergence to control annual grasses and broadleaf weeds. Trifluralin belongs to the dinitroaniline chemical family. It is absorbed by plants through developing roots and impedes mitosis and cell elongation. Currently, trifluralin is classified as a Group C carcinogen by the Environmental Protection Agency (EPA). EPA defines C carcinogen as possible human carcinogen for which there is limited animal evidence (United States Environmental Protection Agency, 1996; Bell *et al.*, 2000a; Michigan State University, 2000).

Trifluralin is used on limited carrot acreage in Michigan. It is effective on mineral soil, for control of annual grasses and some broadleaves. It does not control Composite weeds, mustards, or nightshades. It is very safe on carrots, but it kills the small grain cover crops used in carrot production (Michigan State University, 2000; Zandstra, 2004).

Preemergence and postemergence herbicides labeled for carrot crops in Michigan

Linuron was first registered in the US in 1966. In the 1980s, linuron underwent a special review because of potential oncogenicity. However, there was no strong evidence that it causes cancer in humans. EPA decided to classify linuron as an unquantifiable Group C carcinogen (United States Environmental Protection Agency, 1995). Linuron belongs to the substituted urea chemical family and its mode of action is inhibiting

photosynthesis in photosystem II. This herbicide controls a broad spectrum of weeds on organic and mineral soils and is effective preemergence and postemergence.

In Michigan, linuron is the most widely used herbicide for carrot production. Moreover, carrot production without linuron would not be profitable because there is no current substitute for postemergence broadleaf control (Michigan State University, 2000). Preemergence and postemergence applications of linuron are safe on carrots. Linuron appears to be safe early in the season when carrot is in the 1-2 true leaf stage (Kuratle and Rahn, 1968). However, the label does not allow linuron application until the carrot crop reaches 7.6 cm in height, which limits the effectiveness of postemergence weed control (Bellinder *et al.*, 1997; Zandstra, 2004). Crop injury and yield reduction have occurred when linuron was applied postemergence with temperatures above 30 degree Celsius (Kuratle and Rahn, 1968). Linuron is very effective against most broadleaf and annual grass weeds. Fortunately, it does not kill the small grain cover crop needed to protect the soil and carrot from wind erosion and damage respectively (Michigan State University, 2000). Linuron controls redroot pigweed and common lambsquarters, both very common annual broadleaf weeds in Michigan carrot fields. However, at reduced rates, the weed control is variable. Moreover, a single postemergence application of linuron may result in poor weed control and reduced carrot yield (Bellinder *et al.*, 1997). Temperature during postemergence treatment does not affect broadleaf weed control. However, high temperature either before or after postemergence linuron application reduces its effectiveness against annual grasses (Kuratle and Rahn, 1968).

Intensive use of linuron in carrots may result in linuron-resistant weeds. Linuron-resistant common purslane has been found in Michigan carrot fields (Masabni and

Zandstra, 1999). Beuret (1989) reported linuron-resistant biotypes of common groundsel in carrot crops in Switzerland.

Postemergence herbicides labeled for carrot crops in Michigan

Metribuzin was first registered in the US in 1973. In 1991 and 1995, EPA required supplementary information related to metribuzin chemistry, environmental fate and groundwater, and ecological effect (United States Environmental Protection Agency, 1998).

In Michigan, metribuzin is used to substitute for one postemergence linuron application (Bell *et al.*, 2000b) when the carrot has reached at least 5-6 leaves. Metribuzin is registered for postemergence application in carrot; however, Jensen *et al.* (2004) found that carrot tolerance to metribuzin preemergence application was similar to preemergence linuron. Metribuzin does not have as wide a spectrum of weed control as linuron; under certain condition it can injure carrots, and it can only be applied one time per season (Zandstra, 2004). Therefore this herbicide cannot be used as a primary solution for a weed control program in carrot production. Jensen *et al.* (2004) found injury levels from 2 to 42% in carrots when metribuzin was applied to carrots at the 4-5 leaf stage. Carrot injury increased as temperature increased. Injury only occurred to the leaves sprayed, but not to the new leaves.

Thermal Weed Control

Cultivation is the most extensively used mechanical weed control method. However, cultivation stimulates new weed flushes (Rasmussen, 2003). In addition soil disturbance decreases water retention in the soil, which limits the amount of water available for the crop. Other disadvantages of cultivation are that it cannot control intra-row weeds, and cultivation may injure crop roots (Heiniger, 1999).

Thermal weed control may be an alternative to cultivation for physical weed control. There are several techniques of thermal weed control such as flame weeding, infrared radiation, steam and hot water, electric, microwaves, etc. Flame weeding with liquefied petroleum gas (LPG) burners is the oldest and most commonly used technique for thermal weed control (Rahkonen et al., 2003).

During the 1950s and early 1960s flame weeding with propane burners was very common in US agriculture. By the late 1960's improvement in herbicide efficiency and lower cost pushed flame weeding into obsolescence (Heiniger, 1999; Diver, 2002). In recent years there has been increased interest in thermal weeding as an alternative or complement to chemical weed control, especially where problems with herbicide-resistant weeds have occurred (Mojžiš, 2002). Thermal weed control should help prevent development of herbicide resistant weeds, since no weed is resistant to temperatures above the boiling point of water (Heiniger, 1999).

Thermal weed control has several advantages. In organic agricultural production and in crops where herbicides are not available, thermal weed control may decrease labor required for hand weeding. In addition, thermal weed control leaves no chemical

residues that may contaminate soil and water. Thermal weed control also is compatible with no-tillage production techniques. A major limitation of thermal weed control is the non-selectivity, limiting its usage to crop preemergence and to a limited number of heat resistant crops postemergence. In general, thermal methods have a relative low weed-control capacity with a high consumption of fossil fuels (Ascard, 1998).

Weed Susceptibility to Thermal Treatment

The thermal weed control technique consists of exposing weed foliage to high temperatures for a relatively short period of time. This heat exposure denaturizes plant proteins, which results in loss of cell function, causes intracellular water expansion, cell membrane rupture, and finally desiccates and kills the weeds, normally within 2 to 3 days (Heiniger, 1999; Campbell, 2004; Rahkonen, 2003; Diver, 2002). It is not necessary to burn the weeds to cause death. One technique to verify the sufficiency of the flaming treatment is applying pressure to the leaves between thumbs and fingers. An imprint in the foliage indicates cell membrane rupture (Campbell, 2004; Diver, 2002).

The susceptibility of the weeds to thermal weed control is determined by several factors. The developmental stage of the weed is probably the most important factor; seedlings with the shoot apex exposed are more susceptible to flame weeding than older stages where the shoot apex might be protected by surrounding leaves, or where axillary buds may have developed. In addition, older stages have larger surface and larger biomass, which requires a higher flaming dose to heat. Ascard (1994) found a linear relationship between a weed's fresh weight and the effective propane dose for 95% weed reduction. It required doses above 40 kg ha⁻¹ to achieve 95% control of weeds with 0 to 2

true-leaves, whereas it required up to 70 kg ha⁻¹ to achieve the same control level in weeds with 2 to 4 true-leaves. In general, broadleaves are more susceptible to heat than grasses because grasses develop a sheath that in many cases protects the growing point. Weeds with growing points below the soil surface might have the capacity to regrow after flaming treatment, because flaming has a superficial effect. Finally, annual weeds are more susceptible to flame weeding than biennial and perennials (Diver, 2002; Mojžiš, 2002; Ascard, 1995a, 1998).

Measuring temperature

Two methods of plant temperature measurement are used in thermal weed control. One method is by contact sensors, usually using small thermocouples inserted in the leaf. The other method is by infrared meters. Rahkonen (2003) concluded that it is possible to obtain accurate measurements with either method. Quite the opposite, Ascard (1995b) stated that accurate measurement of leaf temperatures during flaming is very difficult as the temperature changes constantly. If a thermocouple is inserted into a leaf, it will itself act as a heat sink and the type and size of the thermocouple will influence the results. An infrared thermometer can be used as a non-contact temperature measurement method. The main advantage of this method is the non-influence on the target temperature, but the main downside of this technique is the slow response time (Ascard, 1995b).

Thermal weed control usually does not involve burning the weeds; this being the case, temperature in the leaf does not exceed 100 degree Celsius as a result of moisture vaporization from the leaf surface. This moisture vaporization creates a cooling layer which prevents temperatures higher than 100 degree Celsius (Ascard, 1995b).

Ascard (1999) recommends measuring temperature in the flame, or vicinity of the plant, or in an environment without plants. However, Ascard advises that the temperatures recorded by the thermocouples are not temperatures of the air nor of the leaf but of the thermocouple itself. Moreover, in a non-stationary situation the temperature registered will depend on the thickness of the thermocouple. Thus a maximum temperature of 700 degree Celsius recorded by a 0.25 mm thermocouple corresponds to 900 degree Celsius in a 0.13 mm thermocouple.

Flame Weeding

Flame weeding is by far the most common thermal weed control method in agriculture (Ascard, 1995b). This technique uses liquefied petroleum gas (LPG) burners to generate combustion temperatures of up to 1900 degree Celsius, raising the temperature of the exposed leaves very rapidly, causing cell membrane rupture and later desiccation and death of the weed. After its almost complete disappearance in the 1970s, flame weeding is starting to regain interest, mainly in Europe for non-selective weed control in organic production (Ascard, 1995b).

As in any other weed control technique flame weeding has advantages and disadvantages. The main advantages of flame weeding are the lack of chemical residues remaining in the crop, soil, or water; the no carry-over effect on the next season, the wide spectrum of weeds controlled, and the non-possibility to develop weed resistance to flaming (Ascard, 1995b; Heiniger, 1999). The main disadvantages of flame weeding are the lack of residual effect, which requires repeated applications, the lack of selectivity for crop safety, low speed of application, human safety issues, and the high total cost

(Ascard, 1995b). The soil surface condition also may be a limitation for effective flame weeding. A rough surface with many soil clods may cause upward flame deflections that reduce the heat effects close to the surface. In addition, soil clods also could act as shields for small weed seedlings (Ascard, 1999).

The major factor influencing flame weeding efficacy is the developmental stage of the weeds at the time of flaming, that determines the weed sensitivity to the treatment. The stage of growth of the weeds establishes the kind and degree of protective layers, the lignification level, and the location of growth points. For most weed species, flaming will be most effective when weeds are in the early growth stage (Ascard, 1995a; Campbell, 2004).

In addition to the growth stage of the weeds, the efficacy of the flaming treatment is determined by the combinations of two additional factors, the amount of heat transferred from the burner and the time of exposure of the weeds to the heat (Heiniger, 1999; Ascard, 1998). The amount of heat transferred by the flamer to the weeds is determined by the number of burners for a given working width, the nozzle size, and the gas pressure. Each burner type has its own optimum fuel pressure, and there is a narrow interval for changing the fuel pressure for a given burner type. The exposure time is determined by the tractor speed. Ascard (1998), found a strong positive correlation ($r^2=99$) between the combination of temperature-exposure (temperature sum) and the weeds killed. The correlation was slightly lower when temperature alone was correlated with weeds killed or exposure time alone was correlated with weeds killed. These two factors combined are commonly cited in the literature as propane consumption per hectare (Mojžiš, 2002) or propane consumption per unit working width (Ascard, 1998).

This propane consumption is determined by gas pressure and the speed of the tractor. Higher propane consumption is obtained by higher pressure and lower tractor speed. The relationship between propane consumption per hectare and weed control is direct; the higher the propane consumption, the better the weed control. Factors that affect flame weeding performance are: burner type, fuel pressure, burner height, treatment speed, and wind (Ascard, 1999).

The relationship of these factors with the efficacy of the flaming treatment is simple. Gas pressure has a direct relationship with heat produced; the higher the pressure, the more heat is produced. For tractor speed there is an inverse relationship; the higher the speed, the lower the heat time exposure. For burner type, there is more complexity because there are different models available in the market. In other words, we can have higher tractor speed by increasing the burner power of the flamer (Ascard, 1995b, 1997). In an experiment combining fuel input and ground speed for weed control, Ascard (1997) found that for a covered flamer with fuel consumption of 34 kg h^{-1} per meter working width at a ground speed of 7.9 km h^{-1} , he was able to achieve 95% weed control. On the other hand, in the same study and for achieving the same level of weed control but with a fuel consumption of 12 kg h^{-1} , it required an effective ground speed of 2.6 km h^{-1} .

Burner Type

Burners are typically classified by the shape of the burner and flame and the presence or absence of a vapor chamber (Ascard, 1995b). The most common burner types are the flat burner and the round burner. The flat burner, also known as the flat

vapor burner, produces a wide, flat flame with temperatures of about 1300 degree Celsius. It is important to mention that the width of the flame can vary depending on the jet nozzle. Round burners produce long and narrow flames with temperatures of about 1400 degree Celsius. For flame weeding, flat burners are more common, because of their wide coverage (Campbell, 2004). The presence of a vapor chamber indicates that the burner is a liquid-phase type; on the other hand the absence of a vapor chamber would indicate a gas-phase burner. According to Ascard (1995b) there are no consistent differences between burner types for weed control.

Burner angles

The burner angle has considerable influence on flame weeding performance. The burner angle determines how the flame reaches the weed and how long the high temperature will last. In open flammers, the burner angle is more critical than in covered flammers because direction of the flame has to be more accurate.

In selective flaming with open high pressure flammers it is generally recommended to use burner angles of 30 to 45 degrees to the ground. In this technique the flames aim at the base of the crop, crossing beneath the canopy and avoiding direct contact with the crop foliage (Diver, 2002; Heiniger, 1999). However, these angles are not necessarily appropriate in other flaming situations, such as with less powerful burners or non-selective flame weeding. There are no conclusive studies of the appropriate burner angle for the different types of flammers and flaming techniques.

Open and Covered Flammers

According to Ascard (1995b), there are basically two different flame weeder designs, the open burner flamer that is usually used in heat-resistant crops such as cotton, sugar cane, and corn; and the covered flamer that concentrates the flames under a shield or insulated cover, commonly used in intra-row treatment in heat-sensitive crops.

Covered flamers are considered more efficient than open flamers, as well as being operationally safer. This difference in efficiency is more obvious in bigger weeds or more heat-tolerant weeds. Bertram (1991, 1992), in his thermodynamic model, proposes that the actual heat transferred to the weeds with an open flamer at a fuel consumption of 50 kg ha⁻¹ is only 15% of the total combustion heat. At the same fuel consumption for a covered flamer, the heat transferred to the weeds is 30%. Moreover, the heat transferred to weeds could be increased to 60% of the total combustion heat by optimizing the cover design (Ascard, 1995b).

Ascard (1995) demonstrated that covered flamers were more efficient than open flamers. On average, open flamers required 40% more fuel than covered flamers to achieve the same level of weed control. These differences varied depending on the developmental stage of the plants. In small, heat-sensitive plants, the difference between open and covered flamers was minor, whereas in larger plants the difference was more obvious.

In a study comparing flaming versus cultivation for weed control in popcorn and soybean, Heiniger (1999) reported that flaming treatment showed consistently better weed control than cultivation. However, crop yields for both popcorn and soybean were not significantly different between the methods. From a cost point of view, fuel cost of flame weeding is similar to the cost of herbicides. However, the total cost of flame

weeding is much higher than herbicide weed control due to the necessity of supplementary hand weeding (Ascard, 1995).

Preemergence Flame Weeding

Preemergence flaming is based on the presumption that the first flush of weeds is the largest group to germinate during the season. If there is no soil disturbance after initial tillage, new weed emergence will be reduced. If flame weeding is applied after tillage and just before crop emergence, most weeds will be killed early in the season.

For fast growing crops, preemergence flame weeding would create favorable conditions for the crop and in many cases allow the formation of full canopy which impedes later weed emergence. Later flushes of weeds, even though in lower quantities, may cause serious competition for slow growing crops.

Diver (2002) refers to two distinct techniques to use preemergence flame weeding, one being the stale seedbed technique and the other the peak emergence technique.

Stale seedbed technique

The stale seedbed technique consists of delaying planting after seedbed preparation. Flame is applied to a field two to three weeks after tillage, when the first flushes of weeds have emerged (Caldwell and Mohler, 2001; Diver, 2002; Rasmussen, 2003). The basic principle is to delay sowing after tillage, kill the early germinated weeds and avoid later soil disturbance that promotes germination of weeds. The crop then is sowed into a weed-free field. Variations on this technique could be irrigating

before flaming to induce more weed germination and punch planting as proposed by Rasmussen (2003) to minimize soil disturbance.

Punch planting is a technique of sowing used in organically grown crops to reduce weeds within rows. A hole is punched in the soil and the seeds are dropped into it without seedbed preparation and soil disturbance beyond the hole. Rasmussen (2003), in an experiment combining stale seedbed technique, punch planting, and flame weeding, found that this combined treatment showed a 30% intra-row weed reduction compared with normal planting with flame weeding.

The efficacy of the stale seedbed technique is influenced by the growth rate of the crop and its critical weed-free period. The critical weed-free period is the minimum amount of time a crop requires to be weed-free to avoid yield reductions or lower quality. In most cases, this critical weed-free period is during the first quarter or third of the growing period, usually for four to five weeks. Weeds emerging later in the season have little or no impact on yield of most crops (Ross & Lembi, 1985; Caldwell and Mohler, 2001).

Peak Emergence Technique

The peak-emergence flaming technique is very similar to the stale seedbed technique; the main difference being that instead of having a delayed sowing, in the peak emergence technique the sowing is done right after seedbed preparation. The flame treatment is applied just before crop seedlings emerge, which kills the first flushes of seedling weeds. This first flush is the most abundant of the season, especially if there are

no later soil disturbances. However, this technique is only applicable to slow-germinating crops such as carrots and parsley.

In general terms, preemergence flame weeding is not sufficient to avoid yield reduction due to weeds. It could work very well for the establishment of the crop but later in the season some form of weed control is required. Flame weeding after crop emergence is known as postemergence flame weeding.

Postemergence Flame Weeding

This technique consists of controlling weeds by flaming after the crop has emerged. Timing of application is important to avoid crop damage (Campbell, 2004). For heat-resistant crops such as cotton, corn, and sugarcane, flame weeding can be applied directly to the bottom of the plant at some growth stages. This technique, called selective flaming, controls intra-row weeds (Diver, 2002). For heat-sensitive crops, postemergence flaming can be applied using a covered flamer to protect the crop from the intense heat (Ascard, 1995). This technique, also known as parallel flaming, controls the weeds between the rows.

Cross Flaming

In cross flaming, also known as selective flaming, the burners are directed down in a 45 degree angle towards both sides of the crop row in an alternate pattern. The flames aim at the base of the crop, crossing beneath the canopy and avoiding direct contact with the crop foliage (Diver, 2002; Heiniger, 1999). Cross flaming targets the small weeds growing in the rows. For cross flaming to be effective, the soil surface must

be relatively smooth; a rough surface causes flame deflection upwards, which may injure the crop.

Parallel Flaming

This technique used in heat-sensitive crops and in early growth stages of heat resistant crops, aims at the weeds growing between rows and close to the rows. In this method, burners are set parallel to the direction of the crop row or a flamer shield is employed to protect the crop (Diver, 2002).

Split vs. Single Application

A split application could be used in any of the techniques described above. A split application is partitioning of the full flaming dose in two half doses applied in subsequent passes separated in time. Ascard (1995) reported no difference between split applications with two half dose treatments one week apart and a single late flame treatment at the same total fuel dose. Despite these results there are some situations where split applications can be advantageous. For example, in crops with long germination periods, it may be possible to kill the early first flush of weeds before they get too big and more heat-resistant; and then the second application could be applied just before crop emergence. It may also be favorable to use split applications in selective flaming to reduce crop injury.

Infrared Weed Control

The infrared weeder is a variation to the covered flamer design characterized by not having a visible flame. Infrared weeders use propane burners that heat a ceramic or steel surface to a red brightness at temperatures around 900 degree Celsius that then irradiates heat towards the weeds (Diver, 2002; Campbell, 2004). Safety is the main advantage of using infrared weeders over flaming due to the lack of an open flame. Disadvantages of infrared weed control are the poor capacity to penetrate dense canopies, the slower speed required for application, and the high cost of the equipment (Ascard, 1998).

Ascard (1998) reported substantially higher temperatures reached under a flamer than under an infrared weeder when temperatures were measured 1 cm above the ground. However, the temperature under the flamer was only slightly higher at 3.5 cm above ground. In the same study, Ascard found that infrared weeders and flammers require the same dose of propane (60 kg per ha) to obtain a 95% weed reduction at a 0 to 2-leaf stage; in other words, both thermal weeders had comparable effects on weeds at the same propane doses. Since flammers have higher consumption capacity than infrared weeders, the effective speed of application is higher in flame weeders.

Literature Cited

- Armel, G. R., H. P. Wilson, R. J. Richardson, and T. E. Hines. 2003. Mesotrione, acetochlor, and atrazine for weed management in corn (*Zea mays*). *Weed Technology* 17:284–290.
- Ascard, J. 1994. Dose-response models for flame weeding in relation to plant size and density. *Weed Research* 34: 337-385.
- Ascard, J. 1995a. Effects of flame weeding on weed species at different developmental stages. *Weed Research* 35: 397-411.
- Ascard, J. 1995b. Thermal weed control by flaming: biological and technical aspects. Dissertation. Swedish University of Agricultural Sciences, Department of Agricultural Engineering, Alnarp.
- Ascard, J. 1997. Flame weeding: effects of fuel pressure and tandem burners. *Weed Research*. 37: 77-86.
- Ascard, J. 1998. Comparison of flaming and infrared radiation techniques for thermal weed control. *Weed Research*. 38 (1), 69-76.
- Ascard, J. 1999. Flame weeding: effects of burner angle on weed control and temperature patterns. *Acta Agriculturae Scandinavica* 48: 248-254.
- Bell, C. E., B. E. Boutwell, E. J. Ogbuchiekwe, and M. E. McGiffen, Jr. 2000a. Weed control in carrots: efficacy and economic value of linuron. *HortScience* 35 (6): 1089-1091.
- Bell, C. E., S. A. Fennimore, M. E. McGiffen, Jr., W. T. Lanini, D. W. Monks, J. B. Masiunas, A. R. Bonanno, B. H. Zandstra, K. Umeda, W. M. Stall, R. R. Bellinder, R. D. William, and R. B. McReynolds. 2000b. My view. *Weed Science* 48:1.
- Bellinder, R. R., J. J. Kirkwyland, and R. W. Wallace. 1997. Carrot (*Daucus carota*) and weed response to linuron and metribuzin applied at different crop stages. *Weed Technology* 11: 235-240.
- Beuret, E. 1989. A new problem of herbicide resistance: *Senecio vulgaris* L. in carrot crops treated with linuron. *Revue-Suisse-de-Viticulture,-d'Arboriculture-et-d'Horticulture* 21 (6): 349-352.

- Brown D. and J. Masiunas. 2002. Evaluation of herbicides for pumpkin (*Cucurbita* spp.). *Weed Technology* 16:282–292.
- Caldwell, B. and C. L. Mohler. 2001. Stale seedbed practices for vegetable production. *HortScience* 36 (4): 703-705.
- Campbell, R. 2004. Flame weeding. Organic Agriculture Centre of Canada.
http://www.organiccentre.ca/ResearchDatabase/ext_thermal_weed.html
- Cavero J., J. Aibar, M. Gutierrez, S. Fernandez-Cavada, J. M. Sopena, A. Pardo, M. L. Suso, and C. Zaragoza. 2001. Tolerance of direct-seeded paprika pepper (*Capsicum annuum*) to clomazone applied preemergence. *Weed Technology* 15:30–35.
- Crop Life Foundation. 1997. National pesticide use database.
<http://cipm.ncsu.edu/croplife>.
- Diehl, H. J. and W. Benz. 1998. FOE 5043 (flufenacet) and mixing partners for use in maize, cereals, and potatoes in Germany. *Pflanzenschutz-Nachrichten Bayer* 51 (2) 129-138.
- Diver, S. 2002. Flame weeding for vegetable crops. ATTRA bulletin.
<http://attra.ncat.org/attra-pub/PDF/flameweedveg.pdf>.
- Ghosheh, H. Z. 2004. Single herbicide treatments for control of broadleaved weeds in onion (*Allium cepa*). *Crop Protection* 23: 539–542.
- Gianessi, L. P. and M. B. Marcelli. 2000. Pesticide use in U.S. crop production: 1997. National Center for Food and Agricultural Policy.
<http://cipm.ncsu.edu/croplife/nationalsummary1997.pdf>
- Grichar W. J., B. A. Besler, K. D. Brewer and D. T. Palrang. 2003. Flufenacet and metribuzin combinations for weed control and corn (*Zea mays*) tolerance. *Weed Technology* 17:346–351.
- Haar, M. J., S. A. Fennimore, M. E. McGiffen, W. T. Lanini, and C. E. Bell. 2002. Evaluation of preemergence herbicides in vegetable crops. *HortTechnology* 12 (1): 95-99.
- Hansson, D. and J. Ascard. 2002. Influence of developmental stage and time of assessment on hot water weed control. *Weed Research* 42: 307–316.
- Heiniger, R. W. 1999. Controlling weeds in organic crops with flame weeders. *Organic*

Farming Research Foundation, Information Bulletin No. 6: 17-19.

Jensen, K. I. N., D. J. Doohan, and E. G. Specht. 2004. Response of processing carrot to metribuzin on mineral soils in Nova Scotia. *Canadian Journal of Plant Science* 84: 669–676.

Johnson B. C. and B. G. Young. 2002. Influence of temperature and relative humidity on the foliar activity of mesotrione. *Weed Science* 50:157–161.

Johnson B. C., B. G. Young, and J. L. Matthew. 2002. Effect of postemergence application rate and timing of mesotrione on corn (*Zea mays*) response and weed control. *Weed Technology* 16:414–420.

Kolberg, R. L. and L. J. Wiles. 2002. Effect of steam application on cropland weeds. *Weed Technology*. 16: 43-49.

Kuratle H. and E. M. Rahn. 1968. Weed control with linuron and prometryne. *Journal American Society for Horticultural Science* 92: 465-472.

Li, B. and A. R. Watkinson. 2000. Competition along a nutrient gradient: a case study with *Daucus carota* and *Chenopodium album*. *Ecological Research* 15: 293-306.

Masabni, J. G. and B. H. Zandstra. 1999. Discovery of a common purslane (*Portulaca oleracea*) biotype resistant to linuron. *Weed Technology* 13 (3): 599–605.

Melander, B., L. Elsgaard, and M. H. Jørgensen. 2004. Band-steaming reduces laborious hand-weeding in vegetables. Newsletter from Danish Research Centre for Organic Farming, No 3. <http://www.darcof.dk/enews/sep04/steam.html>

Michigan State University. 2000. A strategic plan for the Michigan carrot industry. Workshop Summary. <http://pestdata.ncsu.edu/pmsp/pdf/micarrots.pdf>

Mitchell, G., D. W. Bartlett, T. EM. Fraser, T. R. Hawkes, D. C. Holt, J. K. Townson, and R. A. Wichert. 2001. Mesotrione: a new selective herbicide for use in maize. *Pest Management Science* 57:120-128.

Mojžiš, M. 2002. Energetic requirements of flame weed control. *Research in Agricultural Engineering*. 48 (3): 94–97.

Ogbuchiekwe, E. J., M. E. McGiffen, Jr., J. Nuñez, and S. A. Fennimore. 2004. Tolerance of carrot to low-rate preemergent and postemergent herbicides. *HortScience* 39 (2): 291-296.

- Peachey, R. E. and C. Mallory-Smith. Tolerance of processed vegetables to herbicides. Oregon State University. <http://oregonstate.edu/dept/hort/weedrpt/screen2.htm>
- Putnam, A. R. 1990. Vegetable weed control with minimal herbicide input. HortScience 25 (2): 155-159.
- Rahkonen, J. and H. Jokela. 2003. Infrared radiometry for measuring plant leaf temperature during thermal weed control treatment. Biosystems Engineering. 86 (3), 257–266.
- Rasmussen, J. 2003. Punch planting, flame weeding and stale seedbed for weed control in row crops. Weed Research 43, 393–403.
- Ross, M. A. and C. A. Lembi. 1985. Applied weed science. Macmillan Publishing Company.
- Stall, W. M. 2003. Weed control in carrots. University of Florida. Fact Sheet HS-201, <http://edis.ifas.ufl.edu/pdffiles/WG/WG02600.pdf>
- U.S. Department of Agriculture. 1999. Crop profile for carrots in Michigan. <http://www.ipmcenters.org/cropprofiles/docs/micarrots.html>
- U.S. Department of Agriculture. 2002. Census of agriculture. National Agricultural Statistics System.
- United States Environmental Protection Agency. 1995. Linuron. R.E.D. Facts, EPA-738-F-95-003.
- United States Environmental Protection Agency. 1996. Trifluralin. R.E.D. Facts, EPA-738-F-95-035. <http://www.epa.gov/REDs/factsheets/0179fact.pdf>
- United States Environmental Protection Agency. 1998. Metribuzin. R.E.D. Facts, EPA-738-F-96-006. <http://www.epa.gov/oppsrrd1/REDs/factsheets/0181fact.pdf>
- United States Environmental Protection Agency. 2001. Mesotrione. R.E.D. Facts, EPA-738-F-95-003.
- Zandstra, B. 2004. Weed control guide for vegetable crops. East Lansing, Michigan, Michigan State University. Extension Bulletin E 433.
- Zhang, J., S. E. Weaver, and A. S. Hamill. 2000. Risk and reliability of using herbicides at below-labeled rates. Weed Technology 14: 106-115.

CHAPTER II

ALTERNATIVE HERBICIDES FOR WEED CONTROL IN CARROT

Introduction

Good weed control is essential in carrot production. Carrots emerge and grow slowly during the first six weeks of growth, which limits their ability to compete against weeds. Weeds also may act as hosts for insects and diseases and may interfere with harvesting operations (Bell *et al.*, 2000a; Stall, 2003; U.S. Department of Agriculture, 1999). Weeds may reduce carrot yield up to 85% (Bell *et al.*, 2000a).

Only two herbicides are registered for preemergence use in carrot on mineral soil in the United States: linuron and trifluralin. S-metolachlor is registered for use on soils with more than 20% organic matter. Linuron is the most widely used herbicide for carrot and has the broadest weed control spectrum (Bell *et al.*, 2000a; Bellinder *et al.*, 1997; Michigan State University, 2000; Stall, 2003; Zandstra, 2004). Ninety percent of carrot acreage in Michigan is treated with linuron (Crop Life Foundation, 1997). Linuron is a safe, efficient, and cost effective herbicide for weed control in carrot with no alternative with the same characteristics (Bell *et al.*, 2000a; Michigan State University, 2000). Nevertheless, linuron has been used for several decades; linuron was first registered as a pesticide in the U.S. in 1966. From 1984 through 1988 linuron was under special review because it exceeded the oncogenicity risk criteria. At present, linuron and all other labeled herbicides for carrots face an uncertain future as a result of the Food Quality Protection Act (FQPA) of 1996, that requires the Environmental Protection Agency

(EPA) to reassess all pesticide tolerances by 2006 (Bell *et al.*, 2000b). Therefore, there is a future risk of use restriction, label elimination, or voluntary withdrawal of the herbicides labeled for carrot by manufacturers. The continued use of linuron for weed control in carrots may lead to the development of herbicide-resistant weeds. Masabni and Zandstra (1999) reported linuron-resistant *Portulaca oleracea* in carrot fields that had been treated with linuron for over 20 years. Beuret (1989) reported biotypes of *Senecio vulgaris* with resistance to linuron in carrot crops in Switzerland. Another concern regarding linuron is the tendency of baby food processors to require reduced chemical use in carrot suppliers. Growers producing carrot for baby food face a major challenge to produce carrots without the availability of alternative herbicides (Michigan State University, 2000).

Few studies have been conducted to test selectivity of new herbicides in carrot. The objective of this study was to evaluate several new and older herbicides for safety in carrots and the level of weed control at rates safe on carrot.

Materials and Methods

Greenhouse studies

Screening studies were conducted in the MSU Plant Science Greenhouse at Michigan State University in 2001 and 2002 to determine carrot sensitivity to several new herbicides (Tables 1 and 2). Carrot 'Apache' seeds were planted in 30 x 30 cm plastic flats. The seeds were sown in rows at a rate of 75 seeds per flat, 25 seeds per row.

Table 1. Greenhouse preemergence herbicide treatments on carrot in 2001 and 2002

Treatments		Rate
Common name	Trade name	(Kg ai/ha)
Linuron	Lorox 50DF	0.561
Flumioxazin	Valor 51WG	0.0011
Flumioxazin	Valor 51WG	0.0056
Flumioxazin	Valor 51WG	0.0112
Oxyfluorfen	Goal XL 2L	0.112
Oxyfluorfen	Goal XL 2L	0.224
Oxyfluorfen	Goal XL 2L	0.448
Clomazone	Command 3ME	0.280
Clomazone	Command 3ME	0.560
Clomazone	Command 3ME	1.121
Clomazone	Command 3ME	2.242
Sulfentrazone	Spartan 75DF	0.112
Sulfentrazone	Spartan 75DF	0.224
Azafenidin	Milestone 80DF	0.112
Azafenidin	Milestone 80DF	0.224
Flufenacet + metribuzin	Domain 60DF	0.09 + 0.135
Flufenacet + metribuzin	Domain 60DF	0.179 + 0.269
Flufenacet + metribuzin	Domain 60DF	0.359 + 0.538
Flufenacet + metribuzin	Domain 60DF	0.717 + 1.076
Mesotrione	Callisto 4SC	0.022
Mesotrione	Callisto 4SC	0.045
Mesotrione	Callisto 4SC	0.090
Mesotrione	Callisto 4SC	0.179

Table 2. Greenhouse postemergence herbicide treatments on carrot in 2001 and 2002

Treatments		Rate
Common name	Trade name	(Kg ai/ha)
Linuron	Lorox 50DF	0.561
Flumioxazin	Valor 51WG	0.036
Flumioxazin	Valor 51WG	0.053
Flumioxazin	Valor 51WG	0.071
Oxyfluorfen	Goal XL 2L	0.035
Oxyfluorfen	Goal XL 2L	0.070
Oxyfluorfen	Goal XL 2L	0.140
Mesotrione	Callisto 4SC	0.022
Mesotrione	Callisto 4SC	0.045
Mesotrione	Callisto 4SC	0.090
Mesotrione	Callisto 4SC	0.179
Carfentrazone	Aim 40DF	0.011
Carfentrazone	Aim 40DF	0.022
Prometryn	Caparol 4L	1.121
Sulfentrazone	Spartan 75DF	0.112
Sulfentrazone	Spartan 75DF	0.224

The media used was soil collected from the MSU Horticulture Teaching and Research Center for mineral soil and from the MSU Muck Research Farm for organic soil. The soil type from the MSU Horticulture Teaching and Research Center was a Marlette fine sandy loam, pH 6.1, with 2.0% organic matter. The soil type from the MSU Muck Farm was Houghton Muck, pH 6.3, with 80% organic matter. Carrot seedlings were fertilized weekly with a solution of 20N-8.6P-16.6K at the rate of 300 mg/L. Irrigation was applied as needed. Flats were hand weeded as required.

Preemergence and postemergence experiments were conducted to determine carrot tolerance to several new herbicides. Preemergence herbicides were applied three days after seeding. Postemergence herbicides were applied when carrots reached the 4 to 5 leaf stage. Herbicides were applied with a traveling-belt bench sprayer equipped with an 8001E flat-fan nozzle and calibrated at 1.5 km/h, 187 L/ha, and 152 kPa. Stand counts, crop injury, and crop biomass measurements were collected. Crop injury ratings were conducted using a scale of 1 to 10, where 1 represented no injury and 10 represented plant death. Crop injury ratings were converted to percentage for presentation. Visual crop injury ratings were made at 7, 14 and 28 days after treatment (DAT). Stand counts were assessed at 14 and 28 DAT and at harvest. Whole plants were harvested 50 to 60 days after sowing and fresh weight was measured. The carrot plants were dried at 50 C for 7 days and dry weights were recorded. The experimental design was a randomized complete block with four replications; each flat was considered to be replication. The preemergence and postemergence treatments are listed in Table 1; all treatments were compared to an untreated control. These experiments were repeated

three times. Statistical analyses were conducted independently for each experiment due to interaction found between experiment and time of the year.

Field Studies

Field studies were conducted in 2001, 2002 and 2003 to evaluate carrot tolerance to several new herbicides under field conditions (Tables 3 - 8). Sites included commercial fields in Oceana and Newaygo counties in 2001, 2002, and 2003, and at the MSU Muck Research Farm (Muck Farm) in Laingsburg in 2003. These three locations represent two major Michigan carrot production areas and two main soil types. The soil type at the Oceana site was a Spinx-Benona complex with 1.6% organic matter, 83% sand, 11% silt, 6% clay and pH 6.7. Soil type at the Newaygo location was a Pipestone Sand complex with 2.4% organic matter, 88% sand, 7% silt, 5% clay, and pH 6.9. Soil type at the Muck Farm was a Houghton Muck soil with 80% organic matter and pH 6.3. Site details are presented in Table 9.

Cultural practices and carrot cultivars used in these studies were typical for each location. Carrot seeds were sown in three lines per bed with a commercial planter in early May 2001, 2002, and 2003 at the Oceana location, late May 2003 at the Muck Farm, and three triple lines per bed in early May 2001, 2002, and 2003 at the Newaygo location. Plot size was 1.4 m wide (1 bed) by 10 m long. The experimental design was a randomized complete block with three replications in all the studies. Herbicide treatments were applied preemergence and postemergence. The herbicides used in this study are listed in Tables 3 - 8. In 2001 and 2002, all experiments had an untreated control plot. In 2003 all experiments had a hand-weeded control plot. A linuron treated check-plot was

Table 3. List of herbicide treatments and rates applied on carrot in Oceana County during 2001

Preemergence			Postemergence		
Treatment	Trade Name	Rate (kg ai/ha)	Treatment	Trade Name	Rate (kg ai/ha)
Linuron	Lorox 50DF	0.280	Linuron ^a	Lorox 50DF	0.280
Linuron	Lorox 50DF	0.561	Linuron ^a	Lorox 50DF	0.561
Flumioxazin	Valor 51WG	0.001	Flumioxazin ^a	Valor 51WG	0.036
Flumioxazin	Valor 51WG	0.006	Flumioxazin ^a	Valor 51WG	0.053
Flumioxazin	Valor 51WG	0.011	Flumioxazin	Valor 51WG	0.036
S-metolachlor	Dual Magnum 7.62EC	0.561	Flumioxazin	Valor 51WG	0.053
Pendimethalin	Prowl 3.3EC	0.841	Flumioxazin	Valor 51WG	0.070
Sulfentrazone	Spartan 75DF	0.112	Oxyfluorfen	Goal XL 2L	0.035
Flufenacet	Define 60DF	0.336	Mesotrione	Callisto 4SC	0.011
Flufenacet + metribuzin	Domain 60DF	0.134 + 0.202	Flufenacet + metribuzin	Domain 60DF	0.268 + 0.404
			Pelargonic acid	Scythe	3.810

^a Treatment + clethodim 0.112 kg ai/ha + NIS 0.25% V/V

Table 4. List of herbicide treatments and rates applied on carrot in Oceana County during 2002

Preemergence			Postemergence		
Treatment	Trade Name	Rate (kg ai/ha)	Treatment	Trade Name	Rate (kg ai/ha)
Linuron	Lorox 50DF	0.561	Linuron	Lorox 50DF	0.561
Oxyfluorfen	Goal XL 2L	0.112	Flumioxazin	Valor 51WG	0.036
Oxyfluorfen	Goal XL 2L	0.224	Flumioxazin	Valor 51WG	0.053
Flumioxazin	Valor 51WG	0.006	Flumioxazin	Valor 51WG	0.071
Flumioxazin	Valor 51WG	0.011	Oxyfluorfen	Goal XL 2L	0.035
S-metolachlor	Dual Magnum 7.62EC	0.561	Oxyfluorfen	Goal XL 2L	0.070
Pendimethalin	Prowl 3.3EC	0.841	Sulfentrazone	Spartan 75DF	0.056
Sulfentrazone	Spartan 75DF	0.112	Flufenacet + metribuzin	Domain 60DF	0.202 + 0.303
Flufenacet	Define 60DF	0.336	Flufenacet + metribuzin	Domain 60DF	0.269 + 0.404
Flufenacet + metribuzin	Domain 60DF	0.134 + 0.202	Mesotrione	Callisto 4SC	0.022
Clomazone	Command 3ME	0.28	Mesotrione	Callisto 4SC	0.045

Table 5. List of herbicide treatments and rates applied on carrot in Oceana County during 2003

Preemergence			Postemergence		
Treatment	Trade Name	Rate (kg ai/ha)	Treatment	Trade Name	Rate (kg ai/ha)
Linuron	Lorox 50DF	0.561	Linuron ^a	Lorox 50DF	0.561
Clomazone	Command 3ME	0.280	Linuron	Lorox 50DF	1.121
Clomazone	Command 3ME	0.561	Oxyfluorfen	Goal XL 2L	0.035
Clomazone	Command 3ME	1.121	Oxyfluorfen	Goal XL 2L	0.070
Mesotrione	Callisto 4SC	0.112	Oxyfluorfen	Goal XL 2L	0.140
Mesotrione	Callisto 4SC	0.224	Flumioxazin	Valor 51WG	0.036
Mesotrione	Callisto 4SC	0.448	Flumioxazin	Valor 51WG	0.070
Flufenacet + metribuzin	Domain 60DF	0.179 + 0.269	Mesotrione ^b	Callisto 4SC	0.05
Flufenacet + metribuzin	Domain 60DF	0.269 + 0.404	Mesotrione ^b	Callisto 4SC	0.105
Metribuzin	Sencor 75DF	0.420	Mesotrione	Callisto 4SC	0.050
Flufenacet	Define 60DF	0.673	Mesotrione	Callisto 4SC	0.105

^a Treatment + COC 1% V/V

^b Treatment + COC 1% V/V + UAN 2.5% V/V

Table 6. List of herbicide treatments and rates applied on carrot in Newaygo County during 2001 and 2002

Postemergence treatments 2001			Postemergence treatments 2002		
Treatment	Trade Name	Rate (kg ai/ha)	Treatment	Trade Name	Rate (kg ai/ha)
Linuron ^a	Lorox 50DF	0.280	Linuron	Lorox 50DF	0.561
Linuron ^a	Lorox 50DF	0.561	Flumioxazin	Valor 51WG	0.036
Flumioxazin	Valor 51WG	0.036	Flumioxazin	Valor 51WG	0.053
Flumioxazin ^a	Valor 51WG	0.036	Flumioxazin	Valor 51WG	0.070
Flumioxazin	Valor 51WG	0.053	Oxyfluorfen	Goal XL 2L	0.035
Flumioxazin ^a	Valor 51WG	0.053	Oxyfluorfen	Goal XL 2L	0.071
Oxyfluorfen	Goal XL 2L	0.035	Oxyfluorfen	Goal XL 2L	0.140
Fluthiacet	Action 4.75WP	0.0038	Mesotrione	Callisto 4SC	0.045
Flumiclorac	Resource 0.86EC	0.045	Sulfentrazone	Spartan 75DF	0.056
Carfentrazone	Aim 40DF	0.011	Sulfentrazone	Spartan 75DF	0.112

^a Treatment + sethoxydim 0.213 kg ai/ha + NIS 0.25% V/V

Table 7. List of herbicide treatments and rates applied on carrot in Newaygo County location during 2003

Preemergence			Postemergence		
Treatment	Trade Name	Rate kg ai/ha	Treatment	Trade Name	Rate kg ai/ha
Linuron	Lorox 50DF	0.280	Linuron ^a	Lorox 50DF	0.280
Linuron	Lorox 50DF	0.561	Linuron ^a	Lorox 50DF	0.561
Clomazone	Command 3ME	0.280	Linuron	Lorox 50DF	1.121
Clomazone	Command 3ME	0.561	Oxyfluorfen	Goal XL 2L	0.035
Mesotrione	Callisto 4SC	0.112	Oxyfluorfen	Goal XL 2L	0.070
Mesotrione	Callisto 4SC	0.224	Oxyfluorfen	Goal XL 2L	0.140
Flufenacet + metribuzin	Domain 60DF	0.179 + 0.269	Flumioxazin	Valor 51WG	0.036
Flufenacet + metribuzin	Domain 60DF	0.269 + 0.404	Flumioxazin	Valor 51WG	0.070
Metribuzin	Sencor 75DF	0.420	Mesotrione	Callisto 4SC	0.050
Flufenacet	Define 60DF	0.673	Mesotrione	Callisto 4SC	0.105

^a Treatment + COC 1% V/V

Table 8. List of herbicide treatments and rates applied on carrot at the Muck Farm during 2003

Preemergence			Postemergence		
Treatment	Trade Name	Rate kg ai/ha	Treatment	Trade Name	Rate kg ai/ha
Linuron	Lorox 50DF	1.121	Linuron ^a	Lorox 50DF	1.121
S-metolachlor	Dual Magnum 7.62EC	1.900	Trifloxysulfuron	Envoke 75 WDG	0.0075
Pendimethalin	Prowl 3.3EC	2.240	Oxyfluorfen	Goal XL 2L	0.035
Clomazone	Command 3ME	0.280	Oxyfluorfen	Goal XL 2L	0.070
Clomazone	Command 3ME	0.561	Oxyfluorfen	Goal XL 2L	0.140
Mesotrione	Callisto 4SC	0.112	Flumioxazin	Valor 51WG	0.036
Mesotrione	Callisto 4SC	0.224	Flumioxazin	Valor 51WG	0.071
Mesotrione	Callisto 4SC	0.448	Mesotrione	Callisto 4SC	0.050
Flufenacet + metribuzin	Domain 60DF	0.269 + 0.404	Mesotrione	Callisto 4SC	0.105
Metribuzin	Sencor 75DF	0.561	Mesotrione ^b	Callisto 4SC	0.050
Flufenacet	Define 60DF	0.673	Mesotrione ^b	Callisto 4SC	0.105

^a Treatment + COC 1% V/V

^b Treatment + COC 1% V/V + UAN 2.5% V/V

Table 9. Field experiments site details

	Oceana County	Newaygo County	MSU Muck Farm
Cultivar Type			
2001	Goliath (P) ^a	Bergen (P)	Goliath (P)
2002	Canada (P)	Sugarsnax (F)	N/A
2003	Recolleta (P)	Sugarsnax (F)	Apache (F)
Seeding rate	670,000 seeds/ha	2,000,000 seeds/ha	1,350,000 seeds/ha
Soil type	Spinx-Benona	Pipestone Sand	Houghton Muck
Sand	83%	88%	N/A
Silt	11%	7%	N/A
Clay	6%	5%	N/A
Organic matter	1.6%	2.4%	80%
pH	6.7	6.9	6.3

^a P = Processing variety; F = Fresh market variety

included among the treatments in all studies. Herbicides were applied using a CO₂ pressurized backpack sprayer and a 1.2 m boom with four FF8002 nozzles at 187 L/ha volume, pressure of 207 kPa, and a speed of 5.3 km/h.

Stand counts, crop injury, weed control ratings, and yields were collected. Crop injury was rated for all experiments at 7, 14, and 21 DAT. Crop injury and weed control estimates were done on a scale of 1 to 10, where 1 represented no injury and 10 represented complete plant death. The visual rating scale was converted to percentage for analysis. The carrot stands of preemergence studies were assessed in 1 linear meter of bed at 14 DAT. Yields were obtained in mid September by harvesting 1.5 m of all three rows near the center of each plot. Fresh weight of carrot roots was recorded.

Experiments were arranged in a randomized complete block design with three replications. Data from each experiment were subjected to analysis of variance using SAS program (SAS, 1990). Fisher's Protected LSD at $\alpha = 0.05$ significance level was used to detect differences between treatment means.

Results and Discussion

Greenhouse Studies

Greenhouse screening studies were conducted to determine carrot sensitivity to several new herbicides. Herbicides that appeared to be safe on carrot were selected and further studies were conducted under field conditions.

Preemergence herbicides

Flumioxazin preemergence at 0.0011 and 0.0056 kg/ha demonstrated low toxicity to carrot, and did not reduce stand counts or biomass. When flumioxazin rate was

increased to 0.0112 kg/ha results were inconsistent. In one experiment, carrot stand was reduced significantly and biomass tended to decrease but was not significantly different compared to the untreated control. In the other experiment, stand count and biomass did not differ compared to the untreated control (Tables 10, 11, 12, and 13).

Azafenidin at 0.112 kg/ha was highly toxic to carrot. Applied preemergence, azafenidin killed all carrots. Sulfentrazone at 0.112 and 0.224 kg/ha was toxic to carrot, reducing stand count and biomass (Tables 10 and 11).

Clomazone at 0.280, 0.561, and 1.12 kg/ha was safe on carrot. It caused low initial injury, similar to the injury caused by linuron at 0.561 kg/ha. Stand counts and biomass did not decrease. Clomazone at 2.24 kg/ha caused slightly higher injury compared to the lower rates. Stand counts and biomass were not affected (Tables 10, 13, and 14).

Domain (flufenacet 24% plus metribuzin 36%) at 0.224 and 0.448 kg/ha was safe for carrot. Domain at those rates caused minimal initial injury which was not different from linuron at 0.561 kg/ha. Stand counts and biomass were similar to the untreated control. Domain at 0.897 kg/ha caused slightly higher initial crop injury. However, Domain at 1.79 kg/ha was toxic to carrot, causing significant initial injury and stand count and biomass reduction (Tables 10 and 14).

Mesotrione preemergence at 0.022, 0.045, 0.090 and 0.179 kg/ha was safe for carrot. Initial injury was minimal at 0.022 kg/ha and increased slightly at 0.045, 0.090, and 0.179 kg/ha, although it was not significant. Stand count and biomass reduction was not observed (Tables 10 and 14).

Table 10. Summary of the effect of preemergence herbicides on carrot grown in the greenhouse.

Herbicide	Rate (Kg/ha)	Toxicity to carrot	Comments
Flumioxazin	0.0011	Low	
Flumioxazin	0.0056	Low	
Flumioxazin	0.0112	Moderate	Irregular. One time safe, one time moderate
Azafenidin	0.112	High	Completely killed plants
Azafenidin	0.224	High	Completely killed plants
Oxyfluorfen	0.112	Low	
Oxyfluorfen	0.224	Low	Low. Initial crop injury higher than linuron
Oxyfluorfen	0.448	Moderate	Irregular. Two time safe, one time moderate. Initial injury high.
Sulfentrazone	0.112	High	Significant reduction in stand and biomass
Sulfentrazone	0.224	High	Significant reduction in stand and biomass
Clomazone	0.280	Low	
Clomazone	0.561	Low	
Clomazone	1.12	Low	
Clomazone	2.24	Low	Crop injury slightly higher
Domain ^a	0.224	Low	
Domain	0.448	Low	
Domain	0.897	Low	Crop injury slightly higher
Domain	1.79	High	Crop injury higher than linuron. Significant reduction in stand counts and biomass
Mesotrione	0.0224	Low	
Mesotrione	0.0448	Low	
Mesotrione	0.0897	Low	
Mesotrione	0.179	Low	Crop injury slightly higher

^a Flufenacet 24% plus metribuzin 36%

Table 11. Effect of preemergence herbicides on carrot stand and fresh weight applied in the greenhouse on March 2001.

Treatment	Rate (kg ai/ha)	Stand count		Fresh weight
		No. of plants per flat ^a		g/flat
		35 DAT	66 DAT	66 DAT
Flumioxazin	0.0011	73.7 ab	69.7 a	10.0 ab
Flumioxazin	0.0056	57.7 abc	59.3 ab	9.3 ab
Flumioxazin	0.0112	39.0 c	38.0 b	5.8 bc
Azafenidin	0.112	0.0 d	0.0 c	0.0 d
Azafenidin	0.224	0.0 d	0.0 c	0.0 d
Oxyfluorfen	0.224	55.0 abc	53.7 ab	7.7 abc
Oxyfluorfen	0.448	45.0 bc	30.0 b	3.7 cd
Linuron	0.561	74.7 a	68.3 a	12.1 a
Untreated control		57.3 abc	56.0 ab	7.1 bc
LSD _(0.05)		28.805	29.762	4.5

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a 100 seeds were planted per 900 cm² flat

Table 12. Effect of preemergence herbicides applied in the greenhouse on May 2001, on carrot stand and fresh weight.

Treatment	Rate (kg ai/ha)	Stand count		Fresh weight
		No. of plants per flat ^a		g/flat
		35 DAT	66 DAT	66 DAT
Flumioxazin	0.0011	65.3 a	64.3 a	18.9 abc
Flumioxazin	0.0056	64.5 a	60.5 ab	19.0 abc
Flumioxazin	0.0112	54.8 abc	54.8 abc	20.7 ab
Oxyfluorfen	0.224	42.5 de	41.3 de	18.9 abc
Oxyfluorfen	0.448	49.5 cde	48.5 cde	17.9 abc
Sulfentrazone	0.112	47.3 cde	45.8 cde	16.6 c
Sulfentrazone	0.224	40.5 e	37.5 e	17.3 bc
Linuron	0.561	53.3 bcd	51.0 bcd	20.9 a
Untreated control		61.5 ab	60.3 ab	20.5 ab
LSD _(0.05)		10.9	11.2	3.5

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a 75 seeds were planted per 900 cm² flat

Table 13. Effect of preemergence herbicides applied in the greenhouse on April 2002, on carrot stand, injury level, and fresh weight.

Treatment	Rate (kg ai/ha)	Stand count	Crop injury ^b			Fresh weight
		No. of plants per flat ^a	(%)			g/flat
		14 DAT	14 DAT	21 DAT	28 DAT	58 DAT
linuron	0.561	57.3 b	8.9 cde	11.1 bc	11.1 b	16.2 b
flumioxazin	0.0011	62.3 ab	5.5 cde	3.3 cd	3.3 bc	16.1 b
flumioxazin	0.0056	57.0 b	11.1 cd	8.9 bcd	5.5 bc	17.0 ab
oxyfluorfen	0.112	62.3 ab	14.4 bc	11.1 bc	8.9 bc	16.3 ab
oxyfluorfen	0.224	59.8 b	22.2 ab	16.7 b	5.5 bc	16.8 ab
oxyfluorfen	0.448	59.3 b	31.1 a	31.1 a	22.2 a	16.5 ab
clomazone	0.280	59.0 b	5.5 cde	3.3 cd	3.3 bc	19.1 a
clomazone	0.561	67.1 a	1.1 e	0.0 d	0.0 c	19.1 a
Untreated control		62.3 ab	3.3 de	0.0 d	0.0 c	17.7 ab
LSD _(0.05)		6.7	10.0	10.0	10.0	2.8

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a 75 seeds were planted per 900 cm² flat

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

Table 14. Effect of preemergence herbicides applied in the greenhouse on March 2003, on carrot stand, injury level, and fresh weight.

Treatment	Rate (kg ai/ha)	Stand count		Crop injury ^b (%)	Fresh weight
		No. of plants per flat ^a			g/flat
		19 DAT	60 DAT	19 DAT	60 DAT
Linuron	1.120	64.3 a	56.7a	11.1 bc	14.0 ab
clomazone	0.561	62.3 ab	57.0 a	11.1 bc	13.6 ab
clomazone	1.120	63.0 ab	50.3 ab	11.1 bc	10.2 bc
clomazone	2.240	60.7 ab	53.0 ab	25.5 abc	11.2 ab
Domain ^c	0.224	58.7 ab	48.3 ab	7.8 bc	12.3 ab
Domain	0.448	62.3 ab	57.7 a	11.1 bc	12.4 ab
Domain	0.897	56.7 ab	51.0 ab	22.2 abc	11.0 ab
Domain	1.790	40.7 c	34.0 c	36.7 a	6.7 c
mesotrione	0.022	59.7 ab	57.3 a	3.3 c	12.1 ab
mesotrione	0.045	54.3 abc	48.0 abc	18.9 abc	11.7 ab
mesotrione	0.090	49.3 bc	47.0 abc	18.9 abc	11.8 ab
mesotrione	0.179	51.3 abc	49.3 ab	30.0 ab	11.8 ab
Untreated control		58.3 ab	50.0 ab	7.8 bc	14.5 a
LSD _(0.05)		14.0	14.0	24.4	3.8

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a 75 seeds were planted per 900 cm² flat

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

^c Flufenacet 24% plus metribuzin 36%

Postemergence herbicides

Flumioxazin postemergence at 0.022 kg/ha demonstrated low toxicity to carrot. Stand counts and biomass of carrot treated with flumioxazin at 0.022 were similar to the untreated control. When flumioxazin rate was increased to 0.036, 0.044, and 0.053 kg/ha, stand counts were not different from the untreated control and biomass was not statistically different compared to untreated control. However, there was a trend of decreasing weight (Tables 15, 16, 17, and 18). Results of flumioxazin at 0.067 kg/ha were variable. In one experiment, stand counts were reduced and biomass was significantly different compared to the untreated control. In another experiment, there was no reduction in stand counts and biomass. Flumioxazin at 0.071 kg/ha caused stunting in carrot but there was no effect on stand counts. Biomass was reduced and statistically different compared to untreated control but it was not significantly different when compared to linuron at 0.561 kg/ha.

Oxyfluorfen postemergence at 0.035, 0.070, and 0.140 kg/ha was safe on carrot. There was no significant stand count or biomass reduction. However, initial injury was higher at all rates of oxyfluorfen when compared to linuron at 0.561 kg/ha (Tables 15, 16, 17, 18, and 19).

Carfentrazone postemergence at 0.011 kg/ha was moderately toxic to carrot. In one experiment there was no stand reduction but biomass was significantly reduced compared to the untreated control. In another experiment, both stand and biomass were significantly reduced compared to the untreated control. Carfentrazone at 0.022 kg/ha was highly toxic to carrot significantly reducing both stand counts and biomass compared to the untreated control (Tables 15, 16, and 17).

Table 15. The effect of postemergence herbicides on carrot grown in the greenhouse – summary of results.

Herbicide	Rate (Kg/ha)	Toxicity to carrot	Comments
flumioxazin	0.022	Low	
flumioxazin	0.036	Low	Initial crop injury high. Slight fresh weight reduction
flumioxazin	0.045	Low	Slight biomass reduction
flumioxazin	0.053	Low	Slight biomass reduction
flumioxazin	0.067	Moderate to high	Variable results. Stand and fresh weight sometimes reduced
flumioxazin	0.070	Moderate	Initial crop injury high. Fresh weight reduced but no significant difference compared to linuron
oxyfluorfen	0.035	Low	Initial crop injury slightly high
oxyfluorfen	0.070	Low	Initial crop injury slightly high
oxyfluorfen	0.140	Low	Initial crop injury slightly high. Slight fresh weight reduction (variable)
carfentrazone	0.011	Moderate to high	Fresh weight reduction, occasional stand reduction
carfentrazone	0.022	High	Stand reduction and significant biomass reduction
mesotrione	0.022	Low	
mesotrione	0.045	Low	
mesotrione	0.090	Low	Tendency to reduce fresh weight
mesotrione	0.179	Moderate	Fresh weight reduction

Table 16. Effect of postemergence herbicides applied in the greenhouse on March 2001, on carrot stand and fresh weight.

Treatment	Rate (kg ai/ha)	Stand count		Fresh weight
		No. of plants per flat ^a		g/flat
		0 DAT	24 DAT	24 DAT
flumioxazin	0.022	85.3 a	79.0 a	19.3 ab
flumioxazin	0.045	86.5 a	80.5 a	15.2 bcd
flumioxazin	0.067	82.3 ab	57.5 b	11.1 de
oxyfluorfen	0.035	73.3 ab	72.5 ab	17.6 abc
oxyfluorfen	0.070	73.3 ab	73.5 ab	20.9 ab
oxyfluorfen	0.140	82.8 ab	81.3 a	15.7 bcd
carfentrazone	0.011	73.3 ab	70.8 ab	12.6 cde
carfentrazone	0.022	69.0 b	57.8 b	7.2 e
linuron	0.561	80.3 ab	79.8 a	21.9 a
Untreated control		74.5 ab	74.0 ab	17.5 abc
LSD _(0.05)		15.4	16.6	5.8

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a 100 seeds were planted per 900 cm² flat

Table 17. Effect of postemergence herbicides applied in the greenhouse on May 2001, on carrot stand and fresh weight.

Treatment	Rate (kg ai/ha)	Stand count		Fresh weight
		No. of plants per flat ^a		g/flat
		0 DAT	32 DAT	32 DAT
flumioxazin	0.022	62.3 a	62.3 ab	20.6 ab
flumioxazin	0.045	63.3 a	60.5 abc	18.6 b
flumioxazin	0.067	63.8 a	59.5 abc	18.5 b
oxyfluorfen	0.035	60.0 a	59.8 abc	21.4 ab
oxyfluorfen	0.070	61.5 a	56.0 bc	18.4 b
oxyfluorfen	0.140	60.0 a	57.5 abc	19.5 b
carfentrazone	0.011	59.5 a	53.3 c	13.4 c
carfentrazone	0.022	65.3 a	44.0 d	7.5 d
linuron	0.561	62.5 a	62.0 ab	23.9 a
Untreated control		64.3 a	64.0 a	21.7 ab
LSD (0.05)		NS ^b	7.9	3.8

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a 75 seeds were planted per 900 cm² flat

^b No significant difference

Table 18. Effect of postemergence herbicides applied in the greenhouse on April 2002, on carrot stand, injury level, and fresh weight.

Treatment	Rate (kg ai/ha)	Stand count		Crop injury ^b (%)		Fresh weight
		No. of plants per flat ^a				g/flat
		0 DAT	28 DAT	7 DAT	14 DAT	60 DAT
linuron	0.561	61.3 a	59.5 a	8.9 d	0.0 b	15.2 bc
flumioxazin	0.035	60.0 a	58.8 a	27.8 ab	14.4 a	13.9 c
flumioxazin	0.053	62.3 a	60.8 a	22.2 c	20.0 a	14.7 bc
flumioxazin	0.070	63.5 a	62.5 a	22.2 c	16.7 a	14.0 c
oxyfluorfen	0.035	64.0 a	62.8 a	25.5 bc	5.5 b	15.8 abc
oxyfluorfen	0.070	63.8 a	61.8 a	22.2 c	3.3 b	15.3 bc
oxyfluorfen	0.140	60.0 a	59.3 a	31.1 a	0.0 b	16.7 abc
mesotrione	0.022	59.3 a	56.8 a	11.1 d	0.0 b	19.0 a
mesotrione	0.044	63.8 a	61.3 a	11.1 d	3.3 b	17.3 abc
Untreated control		59.8 a	60.5 a	0.0 e	0.0 b	17.8 ab
LSD _(0.05)		NS ^c	NS	5.6	7.8	3.6

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a 75 seeds were planted per 900 cm² flat

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

^c No significant difference

Table 19. Effect of postemergence herbicides applied in the greenhouse on March 2003, on carrot stand, injury level, and fresh weight.

Treatment	Rate (kg ai/ha)	Stand count	Crop injury ^b	Fresh weight
		No. of plants per flat ^a	(%)	g/flat
		48 DAT	7 DAT	48 DAT
Linuron	0.561	55.7 ab	14.4 cd	18.2 ab
Linuron	1.121	50.3 ab	14.4 cd	16.7 bc
oxyfluorfen	0.035	55.7 ab	41.1 b	20.2 ab
oxyfluorfen	0.070	52.0 ab	52.2 a	16.2 bc
oxyfluorfen	0.106	56.3 ab	44.4 ab	19.7 ab
oxyfluorfen	0.142	49.0 ab	52.2 a	17.0 bc
mesotrione	0.022	62.7 a	14.4 cd	18.4 ab
mesotrione	0.044	57.3 ab	11.1 d	18.3 ab
mesotrione	0.090	51.3 ab	18.9 cd	16.6 bc
mesotrione	0.179	46.7 b	22.2 c	13.4 c
Untreated control		47.0 b	0.0 e	22.4 a
LSD _(0.05)		14.7	8.9	4.5

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a 75 seeds were planted per 900 cm² flat

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

Mesotrione postemergence at 0.022 and 0.044 kg/ha had low toxicity to carrot. Initial injury level, stand counts, and biomass were similar to linuron at 0.561 kg/ha. Mesotrione at 0.090 kg/ha had a tendency to reduce carrot biomass. Biomass was not different compared to linuron at 0.561 kg but was significantly different when compared to the untreated control. Mesotrione at 0.179 kg/ha reduced biomass significantly compared to linuron and the untreated control (Tables 15, 18, and 19).

Field Studies

Flumioxazin preemergence:

Flumioxazin preemergence at 0.0011 kg/ha in mineral soil at Oceana County in 2001 was safe on carrot with no significant difference compared to linuron at 0.56 kg/ha for stand count, injury, and yield (Table 20). When the flumioxazin rate was increased to 0.0056 and 0.011 kg/ha in 2001 and 2002, a significant decrease of stand and a higher level of injury appeared. Visual injury was rated at 22.2% 35 DAT for both flumioxazin rates in 2001 and 36.7% 42 DAT in 2002. Carrot yield with flumioxazin at 0.0056 kg/ha was not different from linuron at 0.561 kg/ha in 2001; however, yield decreased significantly in 2002. With flumioxazin at 0.011, carrot yield decreased significantly in 2001 and 2002 (Table 20).

Flumioxazin at 0.0011 had fair control (67%) of common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.), and poor control (< 30%) of shepherd's-purse (*Capsella bursa-pastoris* L.) at Oceana County in 2001 (Appendix 5). At the same rate, control of eastern black nightshade (*Solanum ptycanthum* Dun.) was 83%. Weed control improved at 0.0056 and 0.011 kg/ha. For

Table 20. The effect of preemergence flumioxazin on carrot stand, injury, and yield in the field.

Treatment	Rate (kg ai/ha)	<u>Stand count</u> (plants/1m of bed) ^a		<u>Crop injury</u> ^b (%)		<u>Yield</u> (kg/1.5m of bed)	
		Oceana	Oceana	Oceana	Oceana	Oceana	Oceana
		2001 35 DAT	2002 127 DAT	2001 35 DAT	2002 42 DAT	2001 125 DAT	2002 127DAT
Linuron	0.280	26.7 a		0.0 b		14.6 a	
Linuron	0.561	22.0 b	69.5 ab	0.0 b	14.4 ab	14.2 ab	7.0 b
Flumioxazin	0.001	22.7 ab		7.8 b		13.9 ab	
Flumioxazin	0.006	16.7 c	36.0 bc	22.2 a	36.7 a	11.8 bc	1.0 c
Flumioxazin	0.011	15.0 c	17.3 c	22.2 a	36.7 a	10.4 c	0.6 c
Untreated		24.3 ab	97.3 a	7.8 b	0.0 b	10.0 c	9.9 a
LSD _(0.05)		4.1	35.3	13.3	24.4	2.7	2.6

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

common lambsquarters and redroot pigweed, control was 93% at both rates, and for shepherd's-purse control was 73% with 0.0056 kg/ha of flumioxazin and 90% with 0.011 kg/ha of flumioxazin. With both rates, control of eastern black nightshade was 100% (Appendix 5). However, in 2002 at Oceana County, weed control with flumioxazin at 0.0056 and 0.011 kg/ha was lower than in 2001. Control of redroot pigweed was of 53% at a rate of 0.0056 kg/ha and 93% at a rate of 0.011 kg/ha. Control of ladysthumb (*Polygonum persicaria* L.) was marginal (< 20%) at both rates and common lambsquarters was controlled 70% at 0.0056 kg/ha and 37% at 0.011 kg/ha. Common ragweed (*Ambrosia artemisiifolia* L.) control was 30% at 0.0056 kg/ha and 53% at 0.011 kg/ha in 2002, black medic (*Medicago lupulina* L.) with less than 45% control at both rates, and common chickweed (*Stellaria media* L.) with 70% control at both rates. Control of those weeds decreased considerably 11 weeks after treatment (Appendixes 10 and 13).

Flumioxazin postemergence:

Carrot had moderate tolerance to postemergence flumioxazin at 0.053 kg/ha in 2001 and 2002 at Newaygo and Oceana County. Stand count and yield were not significantly different from linuron at 0.561 kg/ha (Tables 21 and 23). Crop injury caused by flumioxazin at 0.053 kg/ha 7 DAT was not different from linuron in 2001 at Oceana County (Table 22). However, flumioxazin crop injury was significantly higher in Newaygo in 2001 and 2003 and Oceana in 2002 and 2003 compared to linuron (Table 22). Flumioxazin at 0.070 kg/ha injured carrot seven DAT but did not reduce stand counts and yield at Oceana in 2001 and 2003, and at Newaygo 2003. Results in 2002

Table 21. The effect of postemergence flumioxazin on carrot stand, 2001 and 2002.

Treatment	Rate (kg ai/ha)	Stand count (Plants/m of bed) ^a		
		Newaygo 2001 99 DAT	Oceana 2001 99 DAT	Oceana 2002 84 DAT
Linuron	0.280	65.0 a	25.3 a	
Linuron	0.561	63.0 a	24.7 a	92.3 a
Flumioxazin	0.035	56.3 a	21.3 a	79.3 a
Flumioxazin	0.053	60.0 a	24.0 a	89.7 a
Flumioxazin	0.070		23.0 a	90.0 a
Untreated		59.0 a	23.0 a	101.0 a
LSD _(0.05)		NS ^b	NS	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

Table 22. The effect of postemergence flumioxazin on carrot injury, 2001, 2002, and 2003.

Treatment	Rate (kg ai/ha)	Carrot injury (%) ^a					
		Newaygo	Oceana	Oceana	Newaygo	Oceana	Muck Farm
		2001 7 DAT	2001 7 DAT	2002 7 DAT	2003 14 DAT	2003 14 DAT	2003 14 DAT
Linuron	0.280	0.0 b	3.3 c		3.3 d		
Linuron	0.561	7.8 b	3.3 c	3.3 b	14.4 c	7.8 bc	
Linuron	1.121				25.5 b	14.4 b	3.3 bc
Flumioxazin	0.035	66.7 a	14.4 ab	18.9 a	44.4 a	30.0 a	11.1 ab
Flumioxazin	0.053	74.4 a	7.8 bc	22.2 a			
Flumioxazin	0.070		22.2 a	22.2 a	44.4 a	33.3 a	18.9 a
Untreated		0.0 b	0.0 c	0.0 b	0.0 d	0.0 c	0.0 c
LSD _(0.05)		13.3	8.9	14.4	10.0	10.0	8.9

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

Table 23. The effect of postemergence flumioxazin on carrot yield, 2001, 2002, and 2003.

Treatment	Rate (kg ai/ha)	Yield (kg/1.5m of bed) ^a				
		Newaygo	Oceana	Oceana	Newaygo	Oceana
		2001 99 DAT	2001 99 DAT	2002 84 DAT	2003 91 DAT	2003 105 DAT
Linuron	0.280	11.9 a	11.6 a		14.9 a	
Linuron	0.561	10.6 ab	11.9 a	10.4 a	15.1 a	14.2 a
Linuron	1.121				16.5 a	14.8 a
Flumioxazin	0.035	8.7 b	11.0 a	4.9 b	15.6 a	16.6 a
Flumioxazin	0.053	8.9 b	10.9 a	5.7 b		
Flumioxazin	0.071		11.6 a	3.7 b	13.0 a	17.2 a
Untreated		6.1 c	9.7 a	11.9 a	15.5 a	13.9 a
LSD _(0.05)		2.2	NS ^b	4.7	NS	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

were considerably different; flumioxazin significantly reduced yield at Oceana. Even at a low flumioxazin rate of 0.035 kg/ha, yield was reduced to half compared to linuron 0.56 kg/ha. However, stand was not significantly different compared to linuron and hand weeded treatments. It is probable that crop yield reduction in 2002 was more influenced by weed competition than by the effect of the herbicide itself. During 2002 there was high precipitation and higher weed pressure. Crop injury at Oceana was also higher in 2002 and 2003 than in 2001 at 7 DAT (Table 22). Carrot injury with flumioxazin at 0.035 kg/ha in muck soil was not different from linuron at 1.121 kg/ha. However, flumioxazin at 0.070 kg/ha increased injury in muck soil at the MSU Muck Farm in 2003 (Table 22)

Flumioxazin postemergence at 0.053 kg/ha had good control (> 95%) during the season of redroot pigweed, ladythumb, common purslane (*Portulaca oleracea* L.), and common chickweed. Early in the season, flumioxazin at 0.053 kg/ha gave good control (> 77%) of large crabgrass (*Digitaria sanguinalis* L.) and common lambsquarters at Newaygo in 2001 (Appendix 2). However, three weeks later control of large crabgrass and common lambsquarters fell to less than 30% (Appendix 3). In 2003, flumioxazin at 0.070 had good control (73%) of redroot pigweed and 83% control of common lambsquarters at Newaygo County (Appendix 22). Flumioxazin at 0.035 kg/ha had a fair control (> 60%) of large crabgrass and common lambsquarters 7 DAT and no control three weeks after treatment. The addition of NIS 0.25% to flumioxazin at 0.035 and 0.053 kg/ha in Newaygo County during 2001 increased weed control to above 95% for all weeds described above (Appendix 2).

At the Oceana site, flumioxazin at 0.035, 0.053 and 0.070 kg/ha had good control (> 90%) of redroot pigweed during all the season in all three years (Appendixes 7, 15, 16, 17, 18, and 19). In 2001, flumioxazin at 0.035, 0.053 and 0.070 kg/ha had good control (> 90%) of shepherd's-purse, eastern black nightshade, common chickweed and common lambsquarters; and 80% control of ladysthumb (Appendix 8). In 2002, flumioxazin at 0.035, 0.053 and 0.070 kg/ha had fair to good control (< 80%) of common ragweed, ladysthumb, and common lambsquarters; and good control of black medic. Control of common ragweed and ladysthumb decreased during the season reaching a level of less than 67% for common ragweed and less than 50% for ladysthumb (Appendixes 15, 16, 17, and 18). In 2003, flumioxazin at 0.035 and 0.070 kg/ha had fair to good control (< 80%) of common lambsquarters and hairy nightshade (*Solanum sarrachoides* Sendtner) and fair control (< 67%) of redroot pigweed.

At the MSU Muck Farm on organic soil, flumioxazin at 0.035 and 0.070 kg/ha had poor control of yellow nutsedge (*Cyperus esculentus* L.), ladysthumb, redroot pigweed, common purslane, and common lambsquarters. Flumioxazin at 0.071 kg/ha increased moderately control of redroot pigweed and common purslane (Appendix 30).

Flufenacet 24% plus metribuzin 36% (Domain DF) preemergence:

Carrot was tolerant of Domain (flufenacet 24% plus metribuzin 36%) preemergence at 0.336, 0.448, and 0.673 kg/ha in mineral soils in 2001, 2002, and 2003 at Newaygo and Oceana County (Tables 24, 25, and 26). At 0.336 kg/ha, crop injury, stand counts, and yield did not differ from linuron in 2001 and 2002 at Newaygo and

Table 24. The effect of preemergence flufenacet plus metribuzin on carrot stand, 2001, 2002, and 2003

Treatment	Rate (kg ai/ha)	Stand count (plants/1m of bed) ^b			
		Oceana 2001 35 DAT	Oceana 2002 127 DAT	Newaygo 2003 35 DAT	Oceana 2003 35 DAT
Linuron	0.280	26.7 a		257.0 a	
Linuron	0.561	22.0 a	69.5 a	258.0 a	41.7 a
Domain ^a	0.336	23.0 a	64.7 a		
Domain	0.448			109.0 b	30.3 b
Domain	0.673			73.0 b	30.0 b
Untreated		24.3 a	97.3 a	207.3 a	42.0 a
LSD _(0.05)		NS ^c	NS	94.3	10.1

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Domain: flufenacet 24% plus metribuzin 36%

^b Carrots were planted on beds. Each bed had 3 rows

^c No significant difference

Table 25. The effect of preemergence flufenacet plus metribuzin on carrot injury, 2001, 2002, and 2003

Treatment	Rate (kg ai/ha)	Carrot injury (%) ^b				
		Oceana	Oceana	Newaygo	Oceana	Muck Farm
		2001 35 DAT	2002 42 DAT	2003 21 DAT	2003 21 DAT	2003 14 DAT
Linuron	0.280	0.0 a		3.3 b		
Linuron	0.561	0.0 a	14.4 a	3.3 b	25.5 b	
Linuron	1.121					18.9 b
Domain ^a	0.336	7.8 a	18.9 a			
Domain	0.448			55.5 a	47.8 a	
Domain	0.673			70 a	52.2 a	63.3 a
Untreated		7.8 a	0.0 a	14.4 b	0.0 c	11.1 b
LSD _(0.05)		NS ^c	NS	25.6	17.8	20.0

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Domain: flufenacet 24% plus metribuzin 36%

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

^c No significant difference

Table 26. The effect of preemergence flufenacet plus metribuzin on carrot yield, 2001, 2002, and 2003.

Treatment	Rate (kg ai/ha)	Yield (kg/1.5m of bed) ^b			
		Oceana	Oceana	Newaygo	Oceana
		2001 125 DAT	2002 127 DAT	2003 128 DAT	2003 142 DAT
Linuron	0.280	14.6 a		19.1 a	
Linuron	0.561	14.2 ab	7.0 b	18.5 a	16.5 a
Domain ^a	0.336	11.8 bc	6.2 b		
Domain	0.448			14.6 a	14.1 a
Domain	0.673			15.1 a	12.8 a
Untreated		10.0 c	9.9 a	19.1 a	15.1 a
LSD _(0.05)		2.7	2.6	NS ^c	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Domain: flufenacet 24% plus metribuzin 36%

^b Carrots were planted on beds. Each bed had 3 rows

^c No significant difference

Oceana County. In 2003, at rates of 0.448 and 0.673 kg/ha, crop injury was higher than linuron and stand count was lower than linuron in mineral and organic soils in all sites. However, yield was not reduced and was not different from linuron application (Tables 24, 25, and 26).

Weed control with Domain at 0.336, 0.448, and 0.673 kg/ha was over 90% in all sites and all years for common lambsquarters, redroot pigweed, shepherd's-purse, common ragweed, ladythumb, black medic, common chickweed, annual bluegrass (*Poa annua* L.), common purslane, and mayweed chamomile (*Anthemis cotula* L.); with the exception of ladythumb with 83% control in 2002 at Oceana County and eastern black nightshade with 87% in 2001 at Oceana County (Appendixes 8, 10, 20, 24, and 27). In organic soil, control of yellow nutsedge was only 40% in 2003 at MSU Muck Farm (Appendix 27).

Clomazone preemergence:

Carrot was tolerant of clomazone at 0.28 and 0.561 kg/ha. Crop injury, stand counts and yield were not different from linuron at 0.561 kg/ha in mineral soil in 2002 and 2003 at Oceana and Newaygo counties (Tables 27, 28, and 29). In organic soil, crop injury was not significantly different from linuron in 2003 at MSU Muck Farm (Table 28). In mineral soil, clomazone at 1.121 kg/ha increased crop injury slightly but was not significantly different from linuron. However, yield was significantly reduced compared to linuron at 0.561 kg/ha but not significantly different from the untreated control (Table 29).

Table 27. The effect of preemergence clomazone on carrot stand, 2002 and 2003.

Treatment	Rate (kg ai/ha)	Stand count (plants/1 m of bed) ^a		
		Oceana	Oceana	Newaygo
		2002 127 DAT	2003 35 DAT	2003 35 DAT
Linuron	0.280			257.0 a
Linuron	0.561	69.5 a	41.7 a	258.0 a
Clomazone	0.280	77.0 a	35.3 a	222.7 a
Clomazone	0.561		36.0 a	250.0 a
Clomazone	1.121		33.3 a	
Untreated		97.3 a	42.0 a	207.3 a
LSD _(0.05)		NS ^b	NS	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

Table 28. The effect of preemergence clomazone on carrot injury, 2002 and 2003.

Treatment	Rate (kg ai/ha)	Carrot injury (%) ^a			
		Oceana	Oceana	Newaygo	Muck Farm
		2002 42 DAT	2003 21 DAT	2003 21 DAT	2003 14 DAT
Linuron	0.280			3.3 a	
Linuron	0.561	14.4 a	25.5 a	3.3 a	
Linuron	1.121				18.9 a
Clomazone	0.280	7.8 a	18.9 a	25.5 a	7.8 a
Clomazone	0.561		22.2 a	22.2 a	7.8 a
Clomazone	1.121		36.7 a		
Untreated		0.0 a	0.0 b	14.4 a	11.1 a
LSD _(0.05)		NS ^b	17.8	NS	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

^b No significant difference

Table 29. The effect of preemergence clomazone on carrot yield.

Treatment	Rate (kg ai/ha)	Yield (Kg/1.5m of bed) ^a		
		Oceana	Oceana	Newaygo
		2002 127 DAT	2003 142 DAT	2003 128 DAT
Linuron	0.280			19.1 a
Linuron	0.561	7.0 b	16.5 a	18.5 a
Clomazone	0.280	5.3 b	14.1 ab	18.3 a
Clomazone	0.561		14.2 ab	20.8 a
Clomazone	1.121		12.4 b	
Untreated		9.9 a	15.1 ab	19.1 a
LSD _(0.05)		2.6	4.0	NS ^b

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

Clomazone at 0.28 kg/ha controlled over 95% of ladythumb, common lambsquarters, common chickweed, annual bluegrass, and common purslane in all years and all sites (Appendixes 10, 20, 24, and 27). In 2002, control of common ragweed and black medic was less than 75% at Oceana County (Appendix 10). At an increased rate of 0.561 kg/ha, clomazone had a tendency to improve weed control but was not statistically different.

Oxyfluorfen postemergence:

Carrot demonstrated moderate tolerance to postemergence oxyfluorfen at 0.035 and 0.071 kg/ha in 2001, 2002, and 2003 in mineral soil in Newaygo and Oceana County (Tables 30, 31, and 32). In 2003, an additional rate of 0.14 kg/ha was included in the studies increasing slightly the initial crop injury but not affecting yield. Yield and stand count was not significantly different compared to linuron 0.56 kg/ha in 2001 at Oceana and Newaygo County. In 2002 in Oceana County, yield was significantly reduced, probably explained by weed competition more than an effect of oxyfluorfen activity because initial visual crop injury was 14.4% and 11.1% for 0.035 and 0.070 kg/ha respectively and stand counts were not different compared to linuron application. The plots were not weeded after application and there was considerable weed pressure later in the season. In 2003, yield was slightly reduced in Newaygo County at oxyfluorfen rates of 0.035 and 0.070 kg/ha but yield was similar to linuron when oxyfluorfen was applied at 0.140 kg/ha. This better yield can be explained by better weed control with the higher oxyfluorfen rate. The same year in Oceana county yield was not different from linuron at

Table 30. The effect of postemergence oxyfluorfen on carrot stand, 2001 and 2002.

Treatment	Rate (kg ai/ha)	Stand count (plants/1m of bed) ^a		
		Newaygo 2001 99 DAT	Oceana 2001 99 DAT	Oceana 2002 84 DAT
Linuron	0.280	65.0 a	25.3 a	
Linuron	0.561	63.0 a	24.7 a	92.3 a
Oxyfluorfen	0.035	73.7 a	24.7 a	89.7 a
Oxyfluorfen	0.071			82.3 a
Oxyfluorfen	0.140			
Untreated		59.0 a	23.0 a	101.0 a
LSD _(0.05)		NS ^b	NS	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

Table 31. The effect of postemergence oxyfluorfen on carrot injury, 2001, 2002, and 2003

Treatment	Rate (kg ai/ha)	Carrot injury (%) ^a					
		Newaygo	Oceana	Oceana	Newaygo	Oceana	Muck Farm
		2001 7 DAT	2001 7 DAT	2002 7 DAT	2003 14 DAT	2003 14 DAT	2003 14 DAT
Linuron	0.280	0.0 b	3.3 ab		3.3 d		
Linuron	0.561	7.8 b	3.3 ab	3.3 ab	14.4 c	7.8 cd	
Linuron	1.121				25.5 b	14.4 bc	3.3 ab
Oxyfluorfen	0.035	47.8 a	11.1 a	14.4 a	25.5 b	22.2 ab	0.0 b
Oxyfluorfen	0.071			11.1 ab	30.0 ab	14.4 bc	0.0 b
Oxyfluorfen	0.14				36.7 a	30.0 a	11.1 a
Untreated		0.0 b	0.0 b	0.0 b	0.0 d	0.0 d	0.0 b
LSD _(0.05)		13.3	8.9	14.4	11.1	11.1	8.9

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

Table 32. The effect of postemergence oxyfluorfen on carrot yield, 2001, 2002, and 2003

Treatment	Rate (kg ai/ha)	Yield (kg/1.5m of bed) ^a				
		Newaygo	Oceana	Oceana	Newaygo	Oceana
		2001 99 DAT	2001 99 DAT	2002 84 DAT	2003 91 DAT	2003 105 DAT
Linuron	0.280	11.9 a	11.6 a		14.9 a	
Linuron	0.561	10.6 a	11.9 a	10.4 a	15.1 a	14.2 a
Linuron	1.121				16.5 a	14.8 a
Oxyfluorfen	0.035	10.4 a	12.0 a	3.2 b	8.5 bc	15.5 a
Oxyfluorfen	0.071			3.3 b	7.9 c	15.7 a
Oxyfluorfen	0.14				12.0 ab	16.8 a
Untreated		6.1 b	9.7 a	11.9 a	15.5 a	13.9 a
LSD _(0.05)		2.0	NS ^b	4.7	3.7	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

all oxyfluorfen rates (0.035, 0.070, and 0.140 kg/ha). For all experiments in mineral soil, oxyfluorfen caused slightly more injury than regular application of linuron at 0.561 kg/ha (Table 31). In organic soil, oxyfluorfen caused initially no carrot injury, similar to linuron in 2003 at MSU Muck Farm (Table 31).

Oxyfluorfen provided good weed control in general as reported by Ghosheh in 2004. Oxyfluorfen at 0.035 kg/ha had good control (> 90%) of common lambsquarters, redroot pigweed, ladysthumb, and common purslane in 2001 at Oceana and Newaygo County (Appendixes 2, 3, 7 and 8). Results in 2002 were inconsistent; in Oceana County, control of redroot pigweed was 70% at 0.035 kg/ha and 97% at 0.070 kg/ha; control of common ragweed and ladysthumb was less than 65%, control of common lambsquarters was around 75%, and had good control (> 97%) of black medic and common purslane (Appendixes 15 and 16). Weed control results in 2003 at Newaygo County was less effective compared to the other years and sites. Control of redroot pigweed and common lambsquarters went from a low 37% at 0.070 kg/ha to a high of 67% for redroot pigweed and 80% for common lambsquarters at 0.140 kg/ha of oxyfluorfen (Appendix 22). The same year 2003, in Oceana County redroot pigweed control was over 90% (Appendix 25). In organic soil at the MSU Muck Farm in 2003, control of yellow nutsedge was poor, less than 37% for all three oxyfluorfen rates. For the lower rate of 0.035 kg/ha control of ladysthumb, common purslane, and common lambsquarters was partial between 53% and 87%. However, control of those weeds was better at higher rates of oxyfluorfen (Appendix 30).

Mesotrione postemergence:

Carrot tolerance to mesotrione postemergence was inconsistent across different sites and years. This disparity in results could be explained by the effect of temperature and humidity on the activity of mesotrione on plants (Armél *et. al.*, 2003 and Johnson *et. al.*, 2002a). Carrot stand count, visual injury and yield with mesotrione postemergence treatment at 0.011 kg/ha was not different from linuron in 2001 at Oceana County (Tables 33, 34, and 35). In 2002, mesotrione postemergence rates were increased to 0.022 and 0.045 kg/ha at Oceana County. At both rates initial crop injury was higher than linuron but 21 DAT there was minimal injury (Appendix 14). Stand counts for both rates were not significantly different from linuron. Carrot yield from mesotrione 0.045 kg/ha was not different from linuron 0.561 kg/ha. However, carrot treated with mesotrione 0.022 kg/ha showed decreased yield, probably as a result of higher weed competition at the end of the season (Table 35). Mesotrione at 0.022 kg/ha is far below the recommended rate of 0.07 to 0.15 kg/ha for postemergence weed control (Grichar *et. al.* 2003); this could explain the higher weed pressure at 0.022 kg/ha. In Oceana County in 2003, crop injury was considerably higher than regular linuron treatment. Mesotrione at 0.05 kg/ha caused 57% visual injury and mesotrione at 0.105 caused 67% visual injury compared to linuron visual injury of 17% (Table 34). However, crop yield with mesotrione at 0.05 kg/ha was not statistically different from linuron yield. Mesotrione at 0.105 kg/ha reduced yield significantly (Table 35). A similar result of initial high level of injury but with no effect on yield was reported on corn (Johnson *et. al.*, 2002b). In Newaygo County in 2003, mesotrione postemergence at 0.05 and 0.105 kg/ha caused high crop injury and reduced crop yield significantly (Tables 34 and 35). In

Table 33. The effect of postemergence mesotrione on carrot stand, 2001 and 2002

Treatment	Rate (kg ai/ha)	Stand count (plants/1 m of bed) ^a	
		Oceana 2001 99 DAT	Oceana 2002 84 DAT
Linuron	0.280	25.3 a	
Linuron	0.561	24.7 a	92.3 a
Linuron	1.121		
Mesotrione	0.011	22.3 a	
Mesotrione	0.022		83.7 a
Mesotrione	0.045		93.0 a
Mesotrione	0.050		
Mesotrione	0.105		
Untreated		23.0 a	101.0 a
LSD _(0.05)		NS ^b	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

Table 34. The effect of postemergence mesotrione on carrot injury, 2001 , 2002, and 2003.

Treatment	Rate (kg ai/ha)	Carrot injury (%) ^a				
		Oceana	Oceana	Newaygo	Oceana	Muck Farm
		2001 7 DAT	2002 7 DAT	2003 14 DAT	2003 14 DAT	2003 14 DAT
Linuron	0.280	3.3 a		3.3 d		
Linuron	0.561	3.3 a	3.3 b	14.4 c	7.8 cd	
Linuron	1.121			25.5 b	14.4 c	3.3 c
Mesotrione	0.011	7.8 a				
Mesotrione	0.022		25.5 a			
Mesotrione	0.045		30.0 a			
Mesotrione	0.050			70.0 a	52.2 b	74.4 b
Mesotrione	0.105			66.7 a	63.3 a	88.9 a
Untreated		0.0 a	0.0 b	0.0 d	0.0 d	0.0 c
LSD _(0.05)		NS ^b	14.4	11.1	11.1	8.9

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

^b No significant difference

Table 35. The effect of postemergence mesotrione on carrot yield, 2001, 2002, and 2003.

Treatment	Rate (kg ai/ha)	Yield (Kg/1.5m of bed) ^a			
		Oceana 2001 99 DAT	Oceana 2002 84 DAT	Newaygo 2003 91 DAT	Oceana 2003 105 DAT
Linuron	0.280	11.6 a		14.9 a	
Linuron	0.561	11.9 a	10.4 ab	15.1 a	14.2 ab
Linuron	1.121			16.5 a	14.8 a
Mesotrione	0.011	11.2 a			
Mesotrione	0.022		4.2 c		
Mesotrione	0.045		6.2 bc		
Mesotrione	0.050			5.6 b	11.0 bc
Mesotrione	0.105			7.2 b	10.5 c
Untreated		9.7 a	11.9 a	15.5 a	13.9 abc
LSD _(0.05)		NS ^b	4.7	3.7	3.7

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

organic soil in 2003 at MSU Muck Farm, the crop injury was high reaching a visual rating of 88.9% or more compared to 3.3% from linuron application (Table 34).

Flufenacet preemergence:

Carrot demonstrated tolerance to flufenacet preemergence at 0.336 and 0.673 kg/ha, although injury was higher at 0.673 kg/ha. Crop yield was not different from regular linuron treatment in 2001 and 2003 in Oceana and Newaygo County (Table 38). However, crop yield was lower than linuron in 2002. Initial crop injury was not significantly different from linuron but flufenacet injury continued during the season whereas linuron injury almost disappeared by the end of the season (Appendix 23). In addition, this reduced yield can also be explained by a higher weed competition due to the poor control of ladysthumb (27%) and redroot pigweed with 37% control (Appendixes 9 and 10).

Metribuzin preemergence:

Metribuzin preemergence was only studied in 2003 in the three sites. Metribuzin at 0.42 kg/ha demonstrated partial safety for carrot. Initial visual injury at Newaygo County was 77% and at Oceana was 40% whereas linuron at 0.561 kg/ha was 13% and 33% respectively. Crop yields were not statistically different from linuron in both sites but presented a tendency to be lower (Table 39). In organic soil, metribuzin applied at 0.561 kg/ha showed toxicity for carrot with a visual rate of 60%. For all three sites, metribuzin had a good weed control (> 90%) comparable with the results obtained by

Table 36. The effect of preemergence flufenacet on carrot stand, 2001, 2002, and 2003.

Treatment	Rate (kg ai/ha)	Stand count (plants/1m of bed) ^a			
		Oceana	Oceana	Newaygo	Oceana
		2001 35 DAT	2002 127 DAT	2003 35 DAT	2003 35 DAT
Linuron	0.280	26.7 a		257.0 a	
Linuron	0.561	22.0 b	69.5 ab	258.0 a	41.7 a
Flufenacet	0.336	24.0 ab	51.0 b		
Flufenacet	0.673			148.3 b	30.7 b
Untreated		24.3 ab	97.3 a	207.3 ab	42.0 a
LSD _(0.05)		4.1	35.3	94.3	10.1

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

Table 37. The effect of preemergence flufenacet on carrot injury, 2001, 2002, and 2003.

Treatment	Rate (kg ai/ha)	Carrot injury (%) ^a				
		Oceana	Oceana	Newaygo	Oceana	Muck Farm
		2001 35 DAT	2002 42 DAT	2003 21 DAT	2003 21 DAT	2003 14 DAT
Linuron	0.280	0.0 b		3.3 a		
Linuron	0.561	0.0 b	14.4 a	3.3 a	25.5 a	
Linuron	1.121					18.9 a
Flufenacet	0.336	14.4 a	7.8 a			
Flufenacet	0.673			25.5 a	33.3 a	25.5 a
Untreated		7.8 ab	0.0 a	14.4 a	0.0 b	11.1 a
LSD _(0.05)		13.3	NS ^b	NS	17.8	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

^b No significant difference

Table 38. The effect of preemergence flufenacet on carrot yield, 2001, 2002, and 2003.

Treatment	Rate (kg ai/ha)	Yield (Kg/1.5m of bed) ^a			
		Oceana	Oceana	Newaygo	Oceana
		2001 125 DAT	2002 127 DAT	2003 128 DAT	2003 142 DAT
Linuron	0.280	14.6 a		19.1 a	
Linuron	0.561	14.2 a	7.0 b	18.5 a	16.5 a
Linuron	1.121				
Flufenacet	0.336	12.7 ab	1.0 c		
Flufenacet	0.673			17.4 a	13.8 a
Untreated		10.0 b	9.9 a	19.1 a	15.1 a
LSD _(0.05)		2.7	2.6	NS ^b	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b No significant difference

Table 39. The effect of preemergence metribuzin on carrot stand, injury, and yield.

Treatment	Rate (kg ai/ha)	Stand count		Crop injury ^b			Yield	
		plants/1m of bed ^a		(%)			kg/1.5m of bed	
		Newaygo	Oceana	Newaygo	Oceana	Muck Farm	Newaygo	Oceana
		2003	2003	2003	2003	2003	2003	2003
Linuron	0.280	257.0 a		3.3 b			19.1 a	
Linuron	0.561	258.0 a	41.7 a	3.3 b	25.5 a		18.5 a	16.5 a
Linuron	1.121					18.9 b		
Metribuzin	0.420	66.3 b	38.3 a	74.4 a	33.3 a		15.0 a	14.9 a
Metribuzin	0.561					55.5 a		
Untreated		207.3 a	42.0 a	14.4 b	0.0 b	11.1 b	19.1 a	15.1 a
LSD _(0.05)		94.3	NS ^c	24.4	17.8	22.2	NS	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

^c No significant difference

Table 40. The effect of preemergence s-metolachlor, pendimethalin, and sulfentrazone on carrot stand, injury, and yield.

Treatment	Rate kg ai/ha	Stand count		Carrot injury ^b			Yield	
		plants/1m of bed ^a		(%)			kg/1.5m of bed	
		Oceana 2001	Oceana 2002	Oceana 2001	Oceana 2002	Muck 2003	Oceana 2001	Oceana 2002
Linuron	0.280	26.7 a		0.0 b			14.6 a	
Linuron	0.561	22.0 b	69.5 ab	0.0 b	14.4 b		14.2 ab	7.0 b
Linuron	1.121					18.9 a		
S-metolachlor	0.561	24.3 ab	43.3 bc	7.8 b	3.3 b		11.8 bc	2.2 c
S-metolachlor	1.9					11.1 a		
Pendimethalin	0.841	23.7 ab	52.3 bc	11.1 b	3.3 b		12.3 abc	0.9 c
Pendimethalin	2.24					11.1 a		
Sulfentrazone	0.112	17.0 c	27.0 c	33.3 a	52.2 a		11.9 abc	0.7 c
Untreated		24.3 a	97.3 a	7.8 b	0.0 b	11.1 a	10.0 c	9.9 a
LSD _(0.05)		4.1	35.3	13.3	24.4	NS ^c	2.7	2.6

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death.

^c No significant difference

Table 41. The effect of preemergence mesotrione on carrot stand, injury, and yield.

Treatment	Rate kg ai/ha	Stand count		Carrot injury ^b			Yield	
		plants/1m of bed ^a		(%)			kg/1.5m of bed	
		Newaygo	Oceana	Newaygo	Oceana	Muck	Newaygo	Oceana
		2003	2003	2003	2003	2003	2003	2003
Linuron	0.280	257.0 a		3.3 b	25.5 b		19.1 a	16.5 a
Linuron	0.561	258.0 a	41.7 a	3.3 b			18.5 a	
Linuron	1.121					18.9 b		
Mesotrione	0.112	0.0 b	1.0 b	100.0 a	100.0 a	88.9 a	0.0 b	5.0 b
Mesotrione	0.224	0.0 b	0.0 b	100.0 a	100.0 a	96.7 a	0.0 b	1.0 c
Mesotrione	0.448		0.0 b		100.0 a	100.0 a		0.0 c
Untreated		207.3 a	42.0 a	14.4 b	0.0 c	11.1 b	19.1 a	15.1 a
LSD _(0.05)		94.3	10.1	24.4	17.8	22.2	4.8	4.0

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Carrots were planted on beds. Each bed had 3 rows

^b Visually assessed crop injury at scale of 0 to 100%; 0= no injury and 100% = plant death..

Ghosheh (2004) with the exception of yellow nutsedge in organic soil that reached a control of only 57%.

Other results:

S-metolachlor preemergence at 0.561 kg/ha did not reduce carrot emergence in 2001 but did reduce carrot emergence in 2002 at Oceana County. Crop injury was similar to linuron in mineral and organic soil. Yield was not different from linuron at 0.561 kg/ha in 2001. However, yield was significantly lower than linuron in 2002 at Oceana County (Table 40). Pendimethalin preemergence at 0.841 kg/ha gave results similar to linuron in stand counts and initial crop injury in 2001 and 2002 at Oceana County. Carrot yield was similar to linuron in 2001 but was significantly reduced in 2002; however, weed pressure was higher in 2002 than in 2001. Pendimethalin at 2.24 kg/ha in organic soil caused the same level of crop injury as linuron at 1.121 kg/ha (Table 40). Mesotrione preemergence at 0.112, 0.224, and 0.448 killed the carrot in organic and mineral soil (Table 41).

In preemergence weed control, Domain (flufenacet 24% plus metribuzin 36%) and clomazone did not injure carrot. Domain at 0.336, 0.448, and 0.673 kg/ha did not injure carrot and had good control of common lambsquarters, redroot pigweed, shepherd's-purse, common ragweed, ladysthumb, black medic, common chickweed, annual bluegrass, common purslane, mayweed chamomile, and eastern black nightshade. Clomazone at 0.28 and 0.561 kg/ha did not injure carrot and had good control of ladysthumb, common lambsquarters, common chickweed, annual bluegrass, and common purslane. In postemergence weed control, oxyfluorfen at 0.035, 0.070 and 0.140 kg/ha

caused some foliar injury, but did not reduce yield of carrot. Oxyfluorfen gave good postemergence weed control but did not have residual activity, so weeds re-grew quickly and carrot yield were reduced.

Literature Cited

- Armel, G. R., H. P. Wilson, R. J. Richardson, and T. E. Hines. 2003. Mesotrione, acetochlor, and atrazine for weed management in corn (*Zea mays*). *Weed Technology* 17:284–290
- Bell, C. E., B. E. Boutwell, E. J. Ogbuchiekwe, and M. E. McGiffen, Jr. 2000a. Weed control in carrots: efficacy and economic value of linuron. *HortScience* 35 (6): 1089-1091
- Bell, C. E., S. A. Fennimore, M. E. McGiffen, Jr., W. T. Lanini, D. W. Monks, J. B. Masiunas, A. R. Bonanno, B. H. Zandstra, K. Umeda, W. M. Stall, R. R. Bellinder, R. D. William, and R. B. McReynolds. 2000b. My view. *Weed Science* 48:1
- Bellinder, R. R., J. J. Kirkwyland, and R. W. Wallace. 1997. Carrot (*Daucus carota*) and Weed response to linuron and metribuzin applied at different crop stages. *Weed Technology* 11: 235-240
- Beuret, E. 1989. A new problem of herbicide resistance: *Senecio vulgaris* L. in carrot crops treated with linuron. *Revue-Suisse-de-Viticulture,-d'Arboriculture-et-d'Horticulture* 21 (6): 349-352
- Brown D. and J. Masiunas. 2002. Evaluation of herbicides for pumpkin (*Cucurbita* spp.). *Weed Technology* 16:282–292
- Cavero J., J. Aibar, M. Gutierrez, S. Fernandez-Cavada, J. M. Sopena, A. Pardo, M. L. Suso, and C. Zaragoza. 2001. Tolerance of direct-seeded paprika pepper (*Capsicum annuum*) to clomazone applied preemergence. *Weed Technology* 15:30–35
- Crop Life Foundation. 1997. National pesticide use database.
<http://cipm.ncsu.edu/croplife>
- Diehl, H. J. and W. Benz. 1998. FOE 5043 (flufenacet) and mixing partners for use in maize, cereals, and potatoes in Germany. *Pflanzenschutz-Nachrichten Bayer* 51 (2) 129-138
- Ghosheh, H. Z. 2004. Single herbicide treatments for control of broadleaved weeds in onion (*Allium cepa*). *Crop Protection* 23: 539–542

- Gianessi, L. P. and M. B. Marcelli. 2000. Pesticide use in U.S. crop production: 1997. National Center for Food and Agricultural Policy.
<http://cipm.ncsu.edu/croplife/nationalsummary1997.pdf>
- Grichar W. J., B. A. Besler, K. D. Brewer and D. T. Palrang. 2003. Flufenacet and metribuzin combinations for weed control and corn (*Zea mays*) tolerance. *Weed Technology* 17:346–351
- Haar, M. J., S. A. Fennimore, M. E. McGiffen, W. T. Lanini, and C. E. Bell. 2002. Evaluation of preemergence herbicides in vegetables crops. *HortTechnology* 12 (1): 95-99
- Jensen, K. I. N., D. J. Doohan, and E. G. Specht. 2004. Response of processing carrot to metribuzin on mineral soils in Nova Scotia. *Canadian Journal of Plant Science* 84: 669–676
- Johnson B. C. and B. G. Young. 2002a. Influence of temperature and relative humidity on the foliar activity of mesotrione. *Weed Science* 50:157–161
- Johnson B. C., B. G. Young, and J. L. Matthew. 2002b. effect of postemergence application rate and timing of mesotrione on corn (*Zea mays*) response and weed control. *Weed Technology* 16:414–420
- Kuratle H. and E. M. Rahn. 1968. Weed control with linuron and prometryne. *Journal American Society for Horticultural Science* 92: 465-472
- Li, B. and A. R. Watkinson. 2000. Competition along a nutrient gradient: a case study with *Daucus carota* and *Chenopodium album*. *Ecological Research* 15: 293-306
- Masabni, J. G. and B. H. Zandstra. 1999. Discovery of a common purslane (*Portulaca oleracea*) biotype resistant to linuron. *Weed Technology* 13 (3): 599–605.
- Michigan State University. 2000. A strategic plan for the Michigan carrot industry. Workshop Summary. <http://pestdata.ncsu.edu/pmsp/pdf/micarrots.pdf>
- Mitchell, G., D. W. Bartlett, T. EM. Fraser, T. R. Hawkes, D. C. Holt, J. K. Townson, and R. A. Wichert. 2001. Mesotrione: a new selective herbicide for use in maize. *Pest Management Science* 57:120-128
- Ogbuchiekwe, E. J., M. E. McGiffen, Jr., J. Nuñez, and S. A. Fennimore. 2004. Tolerance of carrot to low-rate preemergent and postemergent herbicides. *HortScience* 39 (2): 291-296

- Peachey, R. E. and C. Mallory-Smith. Tolerance of processed vegetables to herbicides. Oregon State University. <http://oregonstate.edu/dept/hort/weedrpt/screen2.htm>
- Putnam, A. R. 1990. Vegetable weed control with minimal herbicide input. HortScience 25 (2): 155-159
- Ross, M. A. and C. A. Lembi. 1985. Applied weed science. Macmillan Publishing Company. New York. 340 p.
- Stall, W. M. 2003. Weed control in carrots. University of Florida. Fact Sheet HS-201, <http://edis.ifas.ufl.edu/pdf/FILES/WG/WG02600.pdf>
- U.S. Department of Agriculture. 1999. Crop profile for carrots in michigan. <http://www.ipmcenters.org/cropprofiles/docs/micarrots.html>
- U.S. Department of Agriculture. 2002. Census of agriculture. National Agricultural Statistics System
- United States Environmental Protection Agency. 1995. Linuron. R.E.D. Facts, EPA-738-F-95-003
- United States Environmental Protection Agency. 1998. Metribuzin. R.E.D. Facts, EPA-738-F-96-006. <http://www.epa.gov/oppsrrd1/REDs/factsheets/0181fact.pdf>
- United States Environmental Protection Agency. 2001. Mesotrione. R.E.D. Facts, EPA-738-F-95-003
- Zandstra, B. 2005. Weed control guide for vegetable crops. East Lansing, Michigan, Michigan State University. Extension Bulletin E 433
- Zhang, J., S. E. Weaver, and A. S. Hamill. 2000. Risk and reliability of using herbicides at below-labeled rates. Weed Technology 14: 106-115

CHAPTER III

COMPARISON OF A ROTARY ATOMIZER “PROPTEC” AND CONVENTIONAL SPRAYER FOR HERBICIDE APPLICATION IN CARROTS.

Introduction

Applying linuron at reduced rates may be an alternative method to reduce total pesticide application and still maintain good weed control. Zhang *et al* (2000) reported variable results in weed control when below-labeled rates were used. Weed control efficacy for below-labeled rates in several studies was lower than for labeled rates when below-labeled rates were not used in conjunction with other weed control methods such as cultivation. However, Zhang found that weed control was 80% or higher in 50% of the studies. In general terms, weed control tended to be lower and more variable at reduced rates than at labeled rates but always remained within the 60 to 100% range. In a study using linuron at below-label rates, Bellinder *et al* (1997) reported that linuron postemergence at 0.14 and 0.28 kg/ha did not adequately control redroot pigweed (*Amaranthus retroflexus* L.) and common lambsquarters (*Chenopodium album* L.). In general terms, Bellinder found that below-label rate linuron resulted in 35% less control than linuron at labeled rates. Putnam (1990) indicated that herbicide label rates are based on averages produced by scientists' research, where the herbicide is expected to be effective most of the time. There is a window of opportunity for below-labeled rates depending on the weed pressure and the application efficiency.

Zhang *et al* (2000) indicated that the use of adjuvants is not sufficiently reliable to improve efficacy of below-label rate herbicides. However, more uniform coverage through a more efficient sprayer may improve herbicide foliar absorption and effectiveness.

It may be possible to increase the effectiveness of postemergence herbicides applied at reduced rates by increasing the herbicide contact area on the leaf surface. Droplets from conventional nozzles tend to be large and variable in size (Ledebuhr *et al*, 1985). This variability in droplet size creates an inefficient deposition and runoff of the pesticide, especially when large droplets are present. Small droplets tend to stick more easily to the leaf surface (Landers *et al*, 2000). Under normal application conditions, some pesticide solution runs off the leaves and is lost. In other words, the amount of chemical absorbed by the weeds is less than the amount applied. Increasing the efficiency of deposition may allow for decreasing the total amount of herbicide required to obtain good weed control.

A rotary atomizer (Proptec) was developed by engineers in the Michigan State University Agricultural Engineering Department. In a rotary atomizer, liquid is fed into a high-speed rotating screen cage. The impact and centrifugal forces pulverize the drops and produce a very uniform spectrum of small droplets (averaging 60 to 120 microns). Approximately 95% of the droplets are the same size (Van Ee *et al*, 2000). Droplets are directed to the crop by a small propeller producing highly turbulent and high volume airflow while reducing drift (Hanson *et al*, 2000; Landers *et al*, 2000). The airflow is aimed deep into the crop canopy to reach weeds below the crop canopy.

In addition to improved penetration into the plant canopy, the small droplets produced by the Proptec cover more foliage surface than bigger droplets with the same total volume of spray mix. For the same volume of liquid, decreasing in half the diameter of a droplet increases the number of droplets by eight. If the spray droplet diameter decreases to a quarter of the original diameter, then the number of spray droplets increases to 64. The area covered for a fixed volume of liquid is doubled each time the diameter of the droplet is halved (Landers *et al*, 2001).

The use of an air-assisted rotary atomizer applicator may improve the application of postemergence herbicide in carrot fields. This experiment was conducted to compare an air-assisted rotary atomizer sprayer with a conventional boom sprayer for low volume and reduced rate application of linuron on carrot.

Materials and Methods

A field study was conducted at the MSU Muck Research Farm (Muck Farm) in Laingsburg in 2001 to evaluate carrot tolerance and weed control with below-labeled rates of linuron applied with a conventional boom sprayer and an air-assisted rotary atomizer applicator. Soil type at the Muck Farm was a Houghton Muck soil with 80% organic matter and soil pH of 6.3.

Field preparation, seed density, and fertilization, used in this study were typical commercial practices. Carrot seeds of the cultivar 'Premium' were sown in three lines per bed with a commercial carrot planter on June 13, 2001. Plot size was 3.2 m wide (2 beds) by 15 m long. Three factors were considered in this study: one, the effect of the

linuron postemergence rate; two, the effect of using an adjuvant; and three, the effect of the type of sprayer. The treatments applied in this study are listed in detail in Table 42.

The spraying equipment consisted of a conventional boom sprayer and an air-assisted rotary atomizer (Proptec) designed and constructed by Michigan State University Agricultural Engineering Department. Both applicators were mounted on the same tractor, one on each side. The conventional sprayer was a CO₂ pressurized boom sprayer equipped with eight FF11002 nozzles delivering 187 L/ha at a pressure of 207 kPa; 75 cm height, and a speed of 5.5 km/h. The air-assisted applicator was a rotary atomizer with two sets of propellers delivering 46.7 L/ha and a ground speed of 5.5 km/h. Treatments were applied postemergence on July 10 when carrots were 15 to 20 cm high. Weeds present at the time of application were few large crabgrass (*Digitaria sanguinalis* L.), few common purslane (*Portulaca oleracea* L.), and moderate yellow nutsedge (*Cyperus esculentus* L.).

Visual crop injury and weed control were rated on July 30. Visual crop injury and weed control estimates were done in a scale of 1 to 10, where 1 represented no injury and 10 represented complete plant death. Yields were collected on October 2 by harvesting 1.5 m of the center section of each plot. Fresh weight of carrot roots was recorded. The experiment was repeated in 2002, but improper adjustment of the air-assisted sprayer resulted in inadequate results.

Experiments were arranged in a split-block randomized complete block design with four replications. Linuron rate were establish as the main blocks, and the subplots were the sprayer type and the usage or not of adjuvant. Data from each experiment were subjected to analysis of variance using SAS program (SAS, 1990).

Table 42. List of treatments applied at the MSU Muck Farm during 2001

Factors	Rate (kg ai/ha)
Linuron rate	
Linuron	0.11
Linuron	0.22
Linuron	0.45
Sprayer	
Conventional boom	
Proptec	
Adjuvant	
Sylgard 309	+ 0.5%
No Sylgard 309	

Results and Discussion

The three-factor interaction effect, linuron rate, adjuvant application, and sprayer type, was not significant for any of the parameters assessed (Tables 43, 44, 45). The two factor interactions: linuron rate x adjuvant, adjuvant x sprayer, and linuron rate x sprayer, also were not significant. No interaction was found in any combination of the three factors studied when assessing the effect of the treatments on carrot injury, carrot yield, and yellow nutsedge control.

The main effect of linuron rate on carrot injury, carrot yield, and yellow nutsedge was not significant (Table 46). Linuron at 0.11, 0.22, and 0.45 kg/ha alone or mixed with Sylgard 309 (0.5%) gave similar low level of injury to carrots. These results are similar to results obtained by Bellinder *et al* (1997) and Kuratle *et al* (1968), where they found carrot tolerance to linuron up to 3.9 kg/ha. No difference was found when evaluating the main effect of the adjuvant. The air-assisted rotary atomizer gave similar result to the conventional boom.

Carrot yield was reduced only in the treatment with linuron at 0.22 kg/ha applied with Proptec (Table 47). No other treatment had significant yield reduction. This may be explained by an uneven distribution of the weed population. Weed control analysis was limited because of the general low weed population. Yellow nutsedge was the only weed present at densities where weed control could be evaluated. The lowest yellow nutsedge control was obtained by linuron at 0.22 kg/ha mixed with Sylgard 309, applied by Proptec. However, it is important to mention that the nutsedge population was moderate and with an uneven distribution.

Table 43. Analysis of variance of carrot injury, Proptec experiment

Source of Variation	DF	Sum of Squares	Mean Square	F	Sig.
Total	47	10.479			
Block	3	1.063	0.354		
Linuron	2	0.042	0.021	0.040	NS ^a
Error 1	6	3.125	0.521		
Adjuvant	1	0.188	0.188	0.771	NS
Linuron x adjuvant	2	0.375	0.188	0.771	NS
Error 2	9	2.188	0.243		
Sprayer	1	0.021	0.021	0.130	NS
Linuron x sprayer	2	0.292	0.146	0.913	NS
Adjuvant x sprayer	1	0.021	0.021	0.130	NS
Linuron x adjuvant x sprayer	2	0.292	0.146	0.913	NS
Error 3	18	2.875	0.160		

^a Not Significant at $\alpha = 0.05$

Table 44. Analysis of variance of yellow nutsedge control, Proptec experiment

Source of Variation	DF	Sum of Squares	Mean Square	F	Sig.
Total	47	330.000			
Block	3	216.000	72.000		
Linuron	2	18.500	9.250	1.762	NS ^a
Error 1	6	31.500	5.250		
Adjuvant	1	4.083	4.083	0.717	NS
Linuron x adjuvant	2	2.667	1.333	0.234	NS
Error 2	9	51.250	5.694		
Sprayer	1	0.000	0.000	0.000	NS
Linuron x sprayer	2	0.500	0.250	1.059	NS
Adjuvant x sprayer	1	0.083	0.083	0.353	NS
Linuron x adjuvant x sprayer	2	1.167	0.583	2.471	NS
Error 3	18	4.250	0.236		

^a Not Significant at $\alpha = 0.05$

Table 45. Analysis of variance of carrot fresh weight, Proptec experiment

Source of Variation	DF	Sum of Squares	Mean Square	F	Sig.
Total	47	2084.581			
Block	3	1902.514	634.171		
Linuron	2	13.090	6.545	1.136	NS ^a
Error 1	6	34.571	5.762		
Adjuvant	1	11.175	11.175	1.924	NS
Linuron x adjuvant	2	7.949	3.974	0.684	NS
Error 2	9	52.273	5.808		
Sprayer	1	1.920	1.920	0.693	NS
Linuron x sprayer	2	3.140	1.570	0.567	NS
Adjuvant x sprayer	1	3.183	3.183	1.149	NS
Linuron x adjuvant x sprayer	2	4.885	2.443	0.881	NS
Error 3	18	49.881	2.771		

^a Not Significant at $\alpha = 0.05$

Table 46. AOV main effect of linuron rate, adjuvant use, and sprayer type factors independently of each other on carrot injury, yield, and yellow nutsedge control, Proptec experiment.

Treatment	Rate kg ai/ha	Crop injury ^a scale 1-10	Yield kg/1.5m of bed ^b	CYPES control ^c (scale 1-10)
<u>Linuron rate effect</u>				
Linuron	0.11	1.25 a	16.25 a	7.63 a
Linuron	0.22	1.19 a	14.97 a	7.50 a
Linuron	0.45	1.25 a	15.55 a	8.88 a
LSD _(0.05)		0.62	2.08	1.98
<u>Adjuvant effect</u>				
Sylgard 309	0.5%	1.29 a	16.07 a	7.71 a
Sylgard 309	0.0%	1.17 a	15.11 a	8.29 a
LSD _(0.05)		0.32	1.57	1.56
<u>Sprayer effect</u>				
Conventional boom		1.21 a	15.79 a	8.00 a
Proptec		1.25 a	15.39 a	8.00 a
LSD _(0.05)		NS ^d	NS	NS

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed crop injury at scale of 1 to 10; 1= no injury and 10 = plant death.

^b Carrots were planted on beds. Each bed had 3 rows

^c Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = complete control.

^d Not Significant at $\alpha = 0.05$

Table 47. AOV means effect of linuron rate, adjuvant use, and sprayer type factors on carrot injury, yield, and yellow nutsedge control

Treatment	Rate (kg ai/ha)	Sprayer Equipment	Crop injury ^a (scale 1-10)	Yield kg/1.5m of bed ^b	CYPES control ^c (scale 1-10)
Linuron + Sylgard 309	0.11 + 0.5%	Boom	1.25 a	17.11 a	7.25 d
Linuron + Sylgard 309	0.11 + 0.5%	Proptec	1.50 a	16.05 ab	7.75 cd
Linuron	0.11	Boom	1.00 a	15.08 abc	7.75 cd
Linuron	0.11	Proptec	1.25 a	16.78 ab	7.75 cd
Linuron + Sylgard 309	0.22 + 0.5%	Boom	1.25 a	16.30 ab	7.25 d
Linuron + Sylgard 309	0.22 + 0.5%	Proptec	1.00 a	15.73 abc	6.50 e
Linuron	0.22	Boom	1.25 a	14.35 bc	8.00 c
Linuron	0.22	Proptec	1.25 a	13.52 c	8.25 bc
Linuron + Sylgard 309	0.45 + 0.5%	Boom	1.25 a	16.19 ab	8.75 ab
Linuron + Sylgard 309	0.45 + 0.5%	Proptec	1.50 a	15.07 abc	8.75 ab
Linuron	0.45	Boom	1.25 a	15.73 abc	9.00 a
Linuron	0.45	Proptec	1.00 a	15.2 abc	9.00 a
LSD _(0.05)			NS ^d	2.473	0.722

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed crop injury at scale of 1 to 10; 1= no injury and 10 = plant death.

^b Carrots were planted on beds. Each bed had 3 rows

^c Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = complete control.

^d Not Significant at $\alpha = 0.05$

This study was not able to find differences in herbicide application effectiveness between the conventional sprayer and the Proptec. However, it is important to mention that for similar application effectiveness, the Proptec uses a fourth of the amount of liquid compared to the conventional sprayer. This lower requirement of water carrier could be an advantage of less frequent refill trips required.

Literature Cited

- Bellinder, R. R., J. J. Kirkwyland, and R. W. Wallace. 1997. Carrot (*Daucus carota*) and weed response to linuron and metribuzin applied at different crop stages. *Weed Technology* 11: 235-240
- Hanson, E., J. Hancock, D. Ramsdell, A. Schilder, G. Van Ee, and R. Ledebuhr. 2000. Sprayer type and pruning affect the incidence of blueberry fruit rots. *HortScience* 35 (2): 235-238.
- Kuratle H. and E. M. Rahn. 1968. Weed control with linuron and prometryne. *Journal American Society for Horticultural Science* 92: 465-472
- Landers, A. and W. Wilcox. 2001. The effect of spray application in vineyards. *Mark Chien's Viticulture Newsletter*, Penn State University (5/4/01).
- Landers, A., W. Wilcox, G. English-Loeb, T. Martinson, and R. Dunst. 2000. Evaluation of a controlled droplet sprayer to control disease and insects on grapes in New York. A report to the Viticultural Consortium, Cornell University (1/21/00)
- Ledebuhr, R., G. Van Ee, R. Resmer, T. Forbush, and H. Potter. 1985. Field comparison of the effectiveness of air assisted rotary atomizers vs. conventional hydraulic nozzles for disease control and vine kill in potatoes. *American Society of Agricultural Engineers*. Paper No. 85-1076
- Putnam, A. R. 1990. Vegetable weed control with minimal herbicide inputs. *HortScience* 25(2): 155-158
- Van Ee, G., R. Ledebuhr, E. Hanson, J. Hancock, and D.C. Ramsdell. 2000. Canopy development and spray deposition in highbush blueberry. *HortTechnology* 10:353-359.
- Zhang, J., S. E. Weaver, and A. S. Hamill. 2000. Risk and reliability of using herbicides at below-labeled rates. *Weed Technology* 14: 106-115

CHAPTER IV

FLAME WEEDING EFFECTS ON SEVERAL WEED SPECIES

Introduction

Flame weeding is the most common thermal weed control method in agriculture (Ascard, 1995b). This technique uses liquefied petroleum gas (LPG) burners to generate combustion temperatures of up to 1900 degrees Celsius, raising the temperature of the exposed leaves very rapidly without requiring burning the weeds to cause death (Ascard, 1995b). This heat exposure denaturizes plant proteins, which results in loss of cell function, causes intracellular water expansion, cell membrane rupture, and finally desiccates and kills the weeds, normally within 2 to 3 days (Campbell, 2004; Diver, 2002; Heiniger, 1999; Rahkonen, 2003;). After its almost complete disappearance in the 1970s, flame weeding is starting to regain interest, mainly in Europe for non-selective weed control in organic production (Ascard, 1995b).

The main advantages of flame weeding are the lack of chemical residues remaining in the crop, soil, or water; the lack of carry-over effect in the next season, the wide spectrum of weeds controlled, no possibility of developing weed resistance to flaming, and compatibility with no-tillage production techniques (Ascard, 1995b, 1998; Heiniger, 1999, Mojžiš, 2002). The main disadvantages of flame weeding are the lack of residual effect, which requires repeated applications, the lack of selectivity for crop safety, low speed of application, and human safety issues, (Ascard, 1995b).

The major factor influencing flame weeding efficacy is the developmental stage of the weeds at the time of flaming that determines the weed sensitivity to heat. The stage of growth of the weeds establishes the kind and degree of protective layers, the lignification level, and the location of growth points. For most weed species, flaming will be most effective when weeds are in an early growth stage (Ascard, 1995a, 1998; Campbell, 2004; Diver, 2002; Mojžiš, 2002)

In addition to the growth stage of the weeds, the efficacy of the flaming treatment is determined by the combinations of two additional factors, the amount of heat transferred from the burner and the time of exposure of the weeds to the heat (Ascard, 1998 and Heiniger, 1999). The amount of heat transferred by the flamer to the weeds is determined by the number of burners for a given working width, the nozzle size, and the gas pressure. The exposure time is determined by the tractor speed. Ascard (1998), found a strong positive correlation ($r^2=99$) between the combination of temperature-exposure (temperature sum) and the weeds killed. These two factors combined are commonly cited in the literature as propane consumption per hectare (Mojžiš, 2002) or propane consumption per unit working width (Ascard, 1998).

Flame weeding is usually classified as preemergence flaming or postemergence flaming. Preemergence flaming is based on the presumption that the first flush of weeds is the largest group to germinate during the season. If there is no soil disturbance after initial tillage, new weed emergence will be reduced. If flame weeding is applied after tillage and just before crop emergence, most weeds will be killed early in the season.

For fast growing crops, preemergence flame weeding would create favorable conditions for the crop and in many cases allow the formation of full canopy which

impedes later weed emergence. Later flushes of weeds, even though in lower quantities, may cause serious competition for slow growing crops. In general terms, preemergence flame weeding is not sufficient to avoid yield reduction due to weeds. It could work very well for the establishment of the crop but later in the season some form of weed control is required.

Postemergence flaming consists of controlling weeds after the crop has emerged. Timing of application is important to avoid crop damage (Campbell, 2004). For heat-resistant crops such as cotton, corn, and sugarcane, flame weeding can be applied directly to the bottom of the plant at some growth stages. This technique, called selective flaming, controls intra-row weeds (Diver, 2002). For heat-sensitive crops, postemergence flaming can be applied using a covered flamer to protect the crop from the intense heat (Ascard, 1995b). This technique, also known as parallel flaming, controls the weeds between the rows.

The susceptibility of weeds to thermal weed control is determined by several factors. The developmental stage of the weed is probably the most important factor; seedlings with the shoot apex exposed are more susceptible to flame weeding than older seedlings where the shoot apex might be protected by surrounding leaves, or where axillary buds may have developed. In addition, older seedlings have larger surface area and larger biomass, which requires a higher flaming dose to heat to a toxic temperature. In general, broadleaves are more susceptible to heat than grasses because grasses develop a sheath that in many cases protects the growing point. Weeds with growing points below the soil surface might have the capacity to regrow after flaming treatment, because

flaming has a superficial effect. Furthermore, annual weeds are more susceptible to flame weeding than biennials and perennials (Ascard, 1995a, 1998; Diver, 2002; Mojžiš, 2002).

The objective of this study was to determine the temperature and application speed required for a covered flamer to control several weed species. A second objective was to determine the developmental stage at which several common carrot weed species were most sensitive to flaming.

Material and Methods

Experiments were conducted to determine the influence of weed developmental stage and flamer technical factors on weed control efficacy. The weeds tested in this experiment were common weeds found in Michigan carrot fields. Weeds were moved at different speeds through a variable speed conveyer stationary flamer that was built in the Department of Agricultural Engineering at Michigan State University. The experiments were conducted at the MSU Horticulture Teaching and Research Center.

Six weeds were chosen for this study, three grass species and three broadleaf species (Table 48). 500 weed seeds were planted in 30 x 30 cm plastic flats, spread in 4 rows. The media used was a peat-based potting mix (Baccto Professional Planting Mix, Houston, Texas) and irrigation was applied as needed. The weeds were grown in the greenhouse until flaming experiments were initiated.

Table 48. Weeds species studied.

Monocotyledons		
Common name	Latin name	Bayer Code
Green foxtail	<i>Setaria viridis</i> L.	SETVI
Barnyardgrass	<i>Echinochloa crus-galli</i> L.	ECHCG
Large crabgrass	<i>Digitaria sanguinalis</i> L.	DIGSA
Dicotyledons		
Redroot pigweed	<i>Amaranthus retroflexus</i> L.	AMARE
Common ragweed	<i>Ambrosia artemisiifolia</i> L.	AMBEL
Common lambsquarters	<i>Chenopodium album</i> L.	CHEAL

Flamer Design

A covered flamer was designed to have better control of the flame, increase heat efficiency and to protect the crop from the heat (Ascard, 1995b, 1997, 1999). The flamer was designed taking into account future use on a carrot field. The flamer shield dimensions were two meter long, 35 centimeter wide, 20 cm high in the front and 10 cm high in the back. The shield was built from a 1.4 mm stainless steel sheet with no insulation. Two V-shaped liquid phase burners (model LT 1½ x 8 D Liquid Torch from Flame Engineering, Inc) with a maximum capacity of 500,000 kilojoules were installed in the front of the cover directed backwards at an angle of 67 degrees. The flamer had a medium capacity regulator (model 567 RD from Flame Engineering, Inc) and a 12 volt D. C. Solenoid valve (model S122 from Flame Engineering, Inc) for security reasons. A constant fuel pressure of 0.20 MPa was used and fuel consumption was estimated at 42.4 kg/h/m. Fuel consumption is defined as the propane consumption, measured in kilograms per hour, per unit working width measured in meters (Ascard, 1998).

Weed Control Experiments

Studies consisted of four treatments per weed species at two different developmental stages plus an untreated control. The treatments were set as speed of flame application (time exposure). The four treatments or speeds were 2, 4, 6, and 8 km/h. Two different sets of weeds were established, one flamed when weeds reached the 0-2 leaf stage and another when weeds reached the 2-4 leaf stage. All experiments were repeated.

Temperature inside the covered flamer was measured with a 4-channel type K thermometer (Omega HH501DK, Omega Engineering, Inc., Stamford, Connecticut). The flamer generated temperatures inside the cover of 800 to 900 degrees Celsius in the first quarter of the cover where the burners were located, 600 to 800 degrees Celsius in the second quarter, 500 to 700 degrees Celsius in the third quarter, and 200 to 600 degrees Celsius in the fourth quarter. The amount of fuel consumption was kept constant, temperature sums (treatments) were determined by the time exposure through regulating the conveyer speed. The results showed the combination of temperature and exposure time required to obtain a certain level of weed control.

Stand counts and biomass measurements were collected. Two stand counts were taken, one before the treatment application to determine the number of weeds before flaming and a second count 14 days after treatment (DAT) to determine the number of weeds killed. Fresh weight was recorded 14 DAT in order to measure vigor of the remaining weeds after flaming. The experimental layout was arranged in a randomized complete block design with four replications. Data from the two sets of experiments were pooled because there was no significant set by treatment interaction. Data from each experiment were subjected to analysis of variance. Fisher's Protected LSD at $\alpha = 0.05$ significance level was used to detect differences between treatment means.

Results and Discussion

Grasses

Grass control by flaming was variable depending on the species and the developmental stage. Barnyardgrass at the 0-2 leaf stage, when flamed at speed of 2, 4,

and 6 km/h showed no differences in stand counts 14 DAT compared to the untreated control. However, at 8 km/h there was an increased number of live plants compared to the untreated control (Table 49). This could be explained by an increase in germination stimulated by heat produced during the treatment. Ascard (1995b) found in his flaming studies an increased emergence of several weed species. Ascard suggested that flaming may increase germination by breaking seed dormancy on the soil surface. Even though the number of barnyardgrass 14 DAT was similar to the untreated plot, fresh weight was significantly reduced for all application speeds compared to the untreated control (Table 49). Fresh weight of treated barnyardgrass at 0-2 leaf stage was reduced by 84% or more for all speeds compared to the untreated plants. There was no significant difference in barnyardgrass fresh weight between treatments. Although flaming reduced barnyardgrass fresh weight, it failed to control the number of live plants.

For barnyardgrass flamed at the 2-4 leaf stage, stand counts 14 DAT were not different from the untreated control with the exception of barnyardgrass flamed at 6 km/h where the number of plants was higher than the control. Fresh weight was significantly lower in the treated flats than the untreated one. Fresh weight reduction in treated plots was 80% or more compared to the control. However, there was no significant difference in fresh weight between speed treatments. On the other hand, there was a clear tendency of greater fresh weight reduction at slower speeds; 92% weight reduction at 2 km/h compared to 80% at 8 km/h (Table 49). However, none of the heat treatments was effective in killing barnyardgrass.

Table 49. Results from flaming barnyardgrass at 0-2 and 2-4 leaves. Five hundred seeds were planted per flat

Conveyer Speed	0-2 leaves			2-4 leaves		
	Stand counts	Stand counts	Fresh weight	Stand counts	Stand counts	Fresh weight
	# plants/flat	# plants/flat	g/flat	# plants/flat	# plants/flat	g/flat
	0 DAT	14 DAT	14 DAT	0 DAT	14 DAT	14 DAT
2 km/h	16.0 a	20.4 c	2.45 b	24.9 a	43.3 ab	6.85 b
4 km/h	17.6 a	34.1 b	4.21 b	25.6 a	49.9 ab	10.63 b
6 km/h	15.8 a	32.5 b	3.65 b	25.3 a	52.8 a	15.01 b
8 km/h	20.1 a	43.4 a	4.57 b	23.1 a	47.6 ab	16.15 b
Untreated	20.5 a	26.8 bc	28.22 a	23.9 a	38.9 b	84.36 a
LSD _(0.05)	7.5	8.7	11.0	8.3	11.0	11.2
CV	40.5	27.0	33.8	32.9	23.2	17.8

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

Green foxtail control by flaming at the 0-2 leaf stage was effective (Table 50). Stand counts 14 DAT of green foxtail flamed at the 0-2 leaf stage demonstrated significant differences compared to the untreated control for all treatments. Although there was no significant difference between treatments, a clear trend was observed: the slower the speed of application the better the weed control. At 2 km/h weed stand counts were reduced by almost 100%, at 4 km/h green foxtail population was reduced 96.5%; at 6 km/h weed count reduction was 94%, and weed count reduction was 78% at 8 km/h. Green foxtail fresh weight 14 DAT was significantly lower in all treatments compared to the untreated control. Weight reduction was greater than 96.6% for all treatments but there was no significant difference between treatments. Fresh weight reduction followed the same trend as stand counts: the slower the speed the greater the weight reduction (Table 50). Green foxtail fresh weight reduction at 2 km/h and 4 km/h was almost 100%, at 6 km/h weight reduction was 99.4%, and at 8 km/ha was 96.6%.

Different results were obtained when green foxtail was flamed at the 2-4 leaf stage. Stand counts 14 DAT were significantly lower than the untreated control, similar to the earlier stage treatment but the reduction was not as great as in the 0-2 leaf stage (Table 50). At 2-4 leaf stage differences between treatments were found. At 8 km, stand counts were reduced by 33% which was significantly less compared to 79% reduction of the 2 km/h and 63% of the 4 km/h treatments. At 6 km/h, stand counts were reduced by 51%, which was significantly different compared to 79% reduction of the treatment at 2 km/h. At 4 km/h stand counts were reduced by 62.6% and at 2 km/h stand count reduction was 78.8% (Table 50). Only the treatment at 2 km/h had a significant reduction in fresh weight compared to the untreated control. All other treatments were

Table 50. Results from flaming green foxtail at 0-2 and 2-4 leaves. Five hundred seeds were planted per flat

Conveyer speed	0-2 leaves			2-4 leaves		
	Stand counts	Stand counts	Fresh weight	Stand counts	Stand counts	Fresh weight
	# plants/flat	# plants/flat	g/flat	# plants/flat	# plants/flat	g/flat
	0 DAT	14 DAT	14 DAT	0 DAT	14 DAT	14 DAT
2 km/h	103.0 a	0.2 b	0.02 b	61.3 a	13.8 d	3.21 b
4 km/h	99.8 a	4.5 b	0.15 b	57.3 a	24.3 cd	11.03 ab
6 km/h	90.5 a	7.8 b	0.45 b	61.3 a	31.8 bc	22.17 a
8 km/h	92.8 a	28.3 b	2.45 b	50.3 a	43.3 b	18.76 a
Untreated	95.8 a	129.7 a	71.04 a	55.3 a	65.0 a	24.23 a
LSD _(0.05)	NS ^a	60.8	29.8	NS	17.1	14.7
CV	26.1	32.3	30.3	15.0	14.6	60.0

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Not Significant at $\alpha = 0.05$

similar in fresh weight to the control; however, it was still possible to see the inverse trend in fresh weight reduction to treatment speed with the exception of treatment 6 km/h that fresh weight reduction was lower than treatment 8 km/h. The lower fresh weight reduction at 6 km/h than at 8 km/h could be explained by a larger number of emerged large crabgrass present at the time of flaming in the 6 km/h treatment flats compared to the 8 km/h treatment flats. Green foxtail (2-4 leaves) fresh weight reduction at 2 km/h was 86.8%, at 4 km/h was 54.5%, at 6 km/h weight reduction was 8.5%, and at 8 km/h was 22.6%. Flame weed control for green foxtail at a developmental stage of 2-4 leaves was only acceptable when flamed at 2 km/h.

Large crabgrass at the 0-2 leaf stage was more resistant to flame weeding than barnyardgrass and green foxtail (Table 51). Significant stand count reduction was only achieved at 2 km/h with a 51% reduction. At 4 km/h stand count reduction was 33.8% but was not statistically different compared to untreated control. Treatments at 6 and 8 km/h demonstrated no reduction in stand counts 14 DAT. Large crabgrass fresh weight 14 DAT was significantly reduced by all treatments compared to the untreated control. Fresh weight reduction at 2 km/h was 89%, at 4 km/h was 74%, at 6 km/h weight reduction was 37%, and at 8 km/h was 59.4%. The lower fresh weight reduction at 6 km/h than at 8 km/h could be explained by a larger number of emerged large crabgrass present at the time of flaming in the 6 km/h treatment flats compared to the 8 km/h treatment flats. Flame weed control for large crabgrass at a developmental stage of 0-2 leaves was not effective at any application speed, only obtaining marginal control when flamed at 2 km/h. Although fresh weight was reduced in all speed treatments, large crabgrass plants were still alive.

Table 51. Results from flaming large crabgrass at 0-2 and 2-4 leaves. Five hundred seeds were planted per flat

Conveyer speed	0-2 leaves			2-4 leaves		
	Stand counts	Stand counts	Fresh weight	Stand counts	Stand counts	Fresh weight
	# plants/flat	# plants/flat	g/flat	# plants/flat	# plants/flat	g/flat
	0 DAT	14 DAT	14 DAT	0 DAT	14 DAT	14DAT
2 km/h	35.5 a	18.0 c	6.33 d	34.3 a	23.3 b	9.89 b
4 km/h	31.8 a	24.5 bc	15.17 cd	39.3 a	41.5 a	16.10 ab
6 km/h	42.0 a	44.0 a	36.75 b	43.0 a	44.0 a	26.62 a
8 km/h	36.8 a	38.5 ab	23.65 bc	40.5 a	34.0 ab	19.79 ab
Untreated	33.5 a	37.0 ab	58.32 a	43.5 a	41.8 a	21.01 ab
LSD _(0.05)	NS ^a	18.1	16.1	NS	15.4	15.4
CV	31.6	36.2	37.3	15.4	26.4	32.4

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Not Significant at $\alpha = 0.05$

When large crabgrass was flamed at the developmental stage of 2-4 leaves, only treatment at 2 km/h had reduced stand counts 14 DAT compared to the untreated control (Table 51). There was no significant difference for fresh weight for any of the treatments; however, there was a decrease of fresh weight of 53% for treatment at 2 km/h. Flame weed control was ineffective at any speed for large crabgrass at 2-4 leaves.

Broadleaves

As mentioned in the literature, flame weed control is more effective on broadleaves than grasses. Weed control over all broadleaf species tested was effective for all treatment speeds and at all developmental stages.

Flame control of redroot pigweed at the 0-2 leaf stage was very effective at 2, 4, and 6 km/h with control equal or higher than 94%. At 8 km/h redroot pigweed control was moderately reduced to 83.8% or higher (Table 52).

Flame control of common ragweed was slightly less effective than redroot pigweed at the 2-4 leaf stage but still effective, controlling 88% or more of common ragweed at 2-4 leaf stage for all treatments. Control was reduced when flaming was done at 0-2 leaves but was never less than 77.7% (Table 53). There is not a clear explanation for this having a better control at a late developmental stage of common ragweed than an earlier stage. Probably there was more germination after treatment in the common ragweed 0-2 leaf stage experiment.

Common lambsquarters experiments had the same pattern as common ragweed (Table 54). The late flaming was more effective than the earlier flaming. Common

Table 52. Results from flaming redroot pigweed at 0-2 and 2-4 leaves. Five hundred seeds were planted per flat

Conveyer speed	0-2 leaves			2-4 leaves		
	Stand counts	Stand counts	Fresh weight	Stand counts	Stand counts	Fresh weight
	# plants/flat	# plants/flat	g/flat	# plants/flat	# plants/flat	g/flat
	0 DAT	14 DAT	14 DAT	0 DAT	14 DAT	14 DAT
2 km/h	63.3 a	2.0 b	0.17 b	74.00 a	1.63 b	0.144 b
4 km/h	63.8 a	4.0 b	0.65 b	70.00 a	2.75 b	0.345 b
6 km/h	65.8 a	2.3 b	0.21 b	70.13 a	3.75 b	0.760 b
8 km/h	55.3 a	10.8 b	2.58 b	69.38 a	6.00 b	3.056 b
Untreated	61.0 a	66.8 a	66.17 a	69.38 a	65.75 a	46.065 a
LSD _(0.05)	NS ^a	13.4	9.3	NS	8.3	7.1
CV	19.7	37.6	23.0	18.4	31.8	38.5

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Not Significant at $\alpha = 0.05$

Table 53. Results from flaming common ragweed at 0-2 and 2-4 leaves. Five hundred seeds were planted per flat

Conveyer speed	0-2 leaves			2-4 leaves		
	Stand counts	Stand counts	Fresh weight	Stand counts	Stand counts	Fresh weight
	# plants/flat	# plants/flat	g/flat	# plants/flat	# plants/flat	g/flat
	0 DAT	14 DAT	14 DAT	0 DAT	14 DAT	14 DAT
2 km/h	29.5 a	5.5 b	0.52 b	26.1 ab	0.9 b	0.08 b
4 km/h	30.3 a	5.1 b	0.39 b	22.0 b	0.9 b	0.05 b
6 km/h	33.0 a	5.3 b	0.46 b	29.3 a	2.8 b	0.37 b
8 km/h	33.3 a	6.5 b	0.61 b	25.5 ab	3.0 b	0.30 b
Untreated	29.8 a	29.1 a	17.27 a	25.0 ab	25.9 a	13.55 a
LSD _(0.05)	NS ^a	3.3	4.3	4.4	6.6	1.9
CV	18.1	18.8	18.7	17.0	41.8	34.7

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Not Significant at $\alpha = 0.05$

Table 54. Results from flaming common lambsquarters at 0-2 and 2-4 leaves. Five hundred seeds were planted per flat

Conveyer speed	0-2 leaves			2-4 leaves		
	Stand counts	Stand counts	Fresh weight	Stand counts	Stand counts	Fresh weight
	# plants/flat 0 DAT	# plants/flat 14 DAT	g/flat 14 DAT	# plants/flat 0 DAT	# plants/flat 14 DAT	g/flat 14 DAT
2 km/h	101.4 a	1.3 b	0.024 b	76.3 ab	1.0 b	0.060 b
4 km/h	103.4 a	1.4 b	0.101 b	72.5 b	0.3 b	0.013 b
6 km/h	98.1 a	3.5 b	0.116 b	86.0 ab	0.4 b	0.032 b
8 km/h	94.8 a	4.4 b	0.127 b	107.0 a	0.3 b	0.013 b
Untreated	103.8 a	31.5 a	11.561 a	86.0 ab	80.8 a	26.183 a
LSD _(0.05)	NS ^a	3.3	1.9	32.9	6.5	1.5
CV	12.5	38.6	39.0	24.9	13.0	7.0

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Not Significant at $\alpha = 0.05$

lambsquarters control was 86% or higher for the early flaming and 98.8% or higher for the late flaming, similar to results reported by Ascard (1995b). There may have been more germination after treatment in the 0-2 leaf stage experiment than in the 2-4 leaf stage experiment because the weed seeds of the 2-4 leaf stage had more time to germinate.

It seems that the heat tolerance of the broadleaf species were similarly susceptible in both developmental stages. The difference between earlier developmental stage and the later developmental stage could be explained not as re-growth but new germination due to the shorter time that earlier developmental stage weed seeds were allowed to germinate.

Ascard (1995a, 1998), Diver (2002), and Mojžiš (2002) reported that older developmental stages are more heat resistant than earlier stages. This can be explained because older stages have larger surface and larger biomass, which require a higher flaming dose to heat. Ascard (1994) found a linear relationship between weed fresh weight and the effective propane dose for 95% weed reduction. These results seem incongruent with the findings in this study; however, the developmental stages used in this study could be considered as an earlier developmental stage in the cited researcher's experiments. An additional consideration is that most of the literature cited is based on field experiments. These researchers also reported that grasses were more heat resistant than broadleaves because the grass sheath protects the growing point.

Literature Cited

- Ascard, J. 1994. Dose-response models for flame weeding in relation to plant size and density. *Weed Research* 34: 337-385
- Ascard, J. 1995a. Effects of flame weeding on weed species at different developmental stages. *Weed Research* 35: 397-411
- Ascard, J. 1995b. Thermal weed control by flaming: biological and technical aspects. Dissertation. Swedish University of Agricultural Sciences, Department of Agricultural Engineering, Alnarp.
- Ascard, J. 1997. Flame weeding: effects of fuel pressure and tandem burners. *Weed Research*. 37: 77-86
- Ascard, J. 1998. Comparison of flaming and infrared radiation techniques for thermal weed control. *Weed Research*. 38 (1), 69-76.
- Ascard, J. 1999. Flame weeding: effects of burner angle on weed control and temperature patterns. *Acta Agriculturae Scandinavica* 48: 248-254
- Campbell, R. 2004. Flame weeding. Organic Agriculture Centre of Canada. http://www.organicagcentre.ca/ResearchDatabase/ext_thermal_weed.html
- Diver, S. 2002. Flame weeding for vegetable crops. ATTRA bulletin. <http://attra.ncat.org/attra-pub/PDF/flameweedveg.pdf>
- Heiniger, R. W. 1999. Controlling weeds in organic crops with flame weeders. Organic Farming Research Foundation, Information Bulletin No. 6: 17-19
- Mojžiš, M. 2002. Energetic requirements of flame weed control. *Research in Agricultural Engineering*. 48, (3): 94-97
- Rahkonen, J. and H. Jokela. 2003. Infrared radiometry for measuring plant leaf temperature during thermal weed control treatment. *Biosystems Engineering*. 86 (3), 257-266

APPENDICES

Appendix A. List of weed species with their common name, scientific name, and Bayer code.

Common name	Scientific name	Bayer code
Annual bluegrass	<i>Poa annua</i> L.	POAAN
Black medic	<i>Medicago lupulina</i> L.	MEDLU
Common chickweed	<i>Stellaria media</i> L.	STEME
Common lambsquarters	<i>Chenopodium album</i> L.	CHEAL
Common purslane	<i>Portulaca oleracea</i> L.	POROL
Common ragweed	<i>Ambrosia artemisiifolia</i> L.	AMBEL
Eastern black nightshade	<i>Solanum ptycanthum</i> Dun.	SOLPT
Hairy nightshade	<i>Solanum sarrachoides</i> Sendtner	SOLSA
Ladysthumb	<i>Polygonum persicaria</i> L.	POLPE
Large crabgrass	<i>Digitaria sanguinalis</i> L.	DIGSA
Mayweed chamomile	<i>Anthemis cotula</i> L.	ANTCO
Prostrate pigweed	<i>Amaranthus blitoides</i> S. Wats.	AMABL
Redroot pigweed	<i>Amaranthus retroflexus</i> L.	AMARE
Shepherd's-purse	<i>Capsella bursa-pastoris</i> L.	CAPBP
Yellow nutsedge	<i>Cyperus esculentus</i> L.	CYPES

Appendix 1. The effect of postemergence herbicides on carrot stand, injury, and yield. Data from Newaygo County in 2001

Treatment	Rate kg ai/ha	Stand count ^b		Crop injury ^c			Yield kg/1.5m
		7 DAT	99 DAT	7 DAT	21 DAT	49 DAT	99 DAT
Linuron ^a	0.28	79.7 a	65.0 ab	1.0 e	1.0 d	1.0 d	11.9 a
Linuron ^a	0.56	75.3 ab	63.0 ab	1.7 e	1.0 d	1.0 d	10.6 ab
Flumioxazin	0.035	55.3 abc	56.3 b	7.0 b	3.0 b	1.7 bcd	8.7 bcd
Flumioxazin ^a	0.035	48.3 bc	37.7 c	9.0 a	6.0 a	3.3 a	6.7 def
Flumioxazin	0.053	56.3 abc	60.0 ab	7.7 b	2.7 b	1.7 bcd	8.9 bc
Flumioxazin ^a	0.053	41.0 c	34.3 c	9.0 a	6.0 a	2.7 ab	5.6 f
Oxyfluorfen	0.035	63.7 abc	73.7 a	5.3 c	2.0 c	1.3 cd	10.4 ab
Fluthiacet	0.0038	66.0 abc	62.7 ab	3.3 d	2.7 b	2.3 abc	6.3 ef
Flumiclorac	0.045	82.0 a	73.7 a	6.7 b	3.0 b	2.0 bcd	8.2 cde
Carfentrazone	0.011	57.3 abc	74.7 a	6.7 b	3.0 b	2.0 bcd	7.5 c-f
Untreated		79.7 a	59.0 ab	1.0 e	2.0 c	2.7ab	6.1 ef
LSD _(0.05)		31.0	16.05	1.2	0.43	1.09	2.18

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Treatment + sethoxydim 0.213 kg ai/ha + NIS 0.25% V/V

^b Number of plants per meter of row

^c Visually assessed crop injury at scale of 1 to 10; 1 = no injury and 10 = plant death.

Appendix 2. The effect of postemergence herbicides on several weeds. Data from Newaygo County 2001

Treatment	Rate (kg ai/ha)	Weed control assessment one week after treatment ^b					
		DIGSA	CHEAL	AMARE	POLPE	POROL	STEME
Linuron ^a	0.28	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Linuron ^a	0.56	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Flumioxazin	0.035	6.0 bc	6.3 c	10.0 a	10.0 a	10.0 a	10.0 a
Flumioxazin ^a	0.035	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Flumioxazin	0.053	7.7 ab	8.0 abc	10.0 a	10.0 a	10.0 a	10.0 a
Flumioxazin ^a	0.053	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Oxyfluorfen	0.035	8.7 ab	9.0 abc	10.0 a	10.0 a	10.0 a	9.3 a
Fluthiacet	0.0038	3.3 cd	6.7 bc	3.0 b	10.0 a	5.0 b	3.7 b
Flumiclorac	0.045	6.0 bc	9.3 ab	10.0 a	10.0 a	9.3 a	3.7 b
Carfentrazone	0.011	3.7 cd	7.0 bc	10.0 a	9.7 b	5.0 b	1.7 bc
Untreated control		1.7 d	1.3 d	1.0 c	1.0 c	1.0 c	1.0 c
LSD _(0.05)		3.2	2.748	0.889	0.296	2.427	2.618

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Treatment + sethoxydim 0.213 kg ai/ha + NIS 0.25% V/V

^b Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 3. The effect of postemergence herbicides on several weeds. Data from Newaygo County 2001

Treatment	Rate (kg ai/ha)	Weed control assessment three weeks after treatment ^b					
		DIGSA	CHEAL	AMARE	POLPE	POROL	STEME
Linuron ^a	0.28	9.0 a	10.0 a	8.7 a	10.0 a	7.7 b	8.3 ab
Linuron ^a	0.56	8.3 a	10.0 a	10.0 a	10.0 a	8.7 ab	9.0 a
Flumioxazin	0.035	1.3 b	2.3 d	9.3 a	10.0 a	10.0 a	9.7 a
Flumioxazin ^a	0.035	8.7 a	9.3 ab	10.0 a	10.0 a	10.0 a	9.7 a
Flumioxazin	0.053	1.7 b	3.3 cd	10.0 a	10.0 a	10.0 a	9.7 a
Flumioxazin ^a	0.053	8.0 a	9.7 a	10.0 a	10.0 a	9.7 a	9.7 a
Oxyfluorfen	0.035	2.3 b	4.0 cd	3.3 c	7.0 ab	10.0 a	7.7 ab
Fluthiacet	0.0038	3.7 b	1.0 d	1.0 d	4.0 bc	10.0 a	1.7 c
Flumiclorac	0.045	2.3 b	6.3 bc	5.7 b	1.0 c	9.7 a	5.7 b
Carfentrazone	0.011	1.3 b	3.3 cd	3.3 c	3.3 bc	9.3 ab	1.0 c
Untreated control		4.0 b	2.0 d	1.0 d	7.3 ab	8.3 ab	1.0 c
LSD _(0.05)		2.827	3.214	1.915	4.079	1.82	3.204

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Treatment + sethoxydim 0.213 kg ai/ha + NIS 0.25% V/V

^b Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 4. The effect of preemergence herbicides on carrot stand, injury, and biomass. Data from Oceana County in 2001

Treatment	Rate (kg ai/ha)	Stand count ^a	Crop injury ^b		Yield ^c
		35 DAT	35 DAT	63 DAT	125 DAT
Linuron	0.28	26.7 a	1.0 d	1.0 b	14.6 a
Linuron	0.56	22.0 b	1.0 d	1.0 b	14.2 ab
Flumioxazin	0.0011	22.7 ab	1.7 cd	1.7 b	13.9 ab
Flumioxazin	0.0056	16.7 c	3.0 ab	2.7 a	11.8 bc
Flumioxazin	0.011	15.0 c	3.0 ab	2.7 a	10.4 c
S-Metolachlor II	0.56	24.3 ab	1.7 cd	1.0 b	11.8 bc
Pendimethalin	0.84	23.7 ab	2.0 bcd	1.3 b	12.3 abc
Sulfentrazone	0.11	17.0 c	4.0 a	3.3 a	11.9 abc
Flufenacet	0.34	24.0 ab	2.3 bc	1.0 b	12.7 abc
Flufenacet + metribuzin	0.134 + 0.202	23.0 ab	1.7 cd	1.0 b	11.8 bc
Untreated		24.3 ab	1.7 cd	1.3 b	10.0 c
LSD _(0.05)		4.085	1.152	0.904	2.732

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Number of plants per meter of row

^b Visually assessed crop injury at scale of 1 to 10; 1 = no injury and 10 = plant death.

^c Yield in kg from 1.5 m of row.

Appendix 5. The effect of preemergence herbicides on several weeds. Data from Oceana County 2001

Treatment	Rate (kg ai/ha)	Weed control assessment five weeks after treatment ^a			
		CHEAL	AMARE	CAPBP	SOLPT
Linuron	0.28	7.0 ab	8.0 abc	7.7 ab	8.0 a
Linuron	0.56	9.7 ab	7.7 abc	9.7 a	9.3 a
Flumioxazin	0.0011	6.7 b	6.7 bc	3.0 d	8.3 a
Flumioxazin	0.0056	9.3 ab	9.3 a	7.3 ab	10.0 a
Flumioxazin	0.011	9.3 ab	9.3 a	9.0 ab	10.0 a
S-Metolachlor II	0.56	8.7 ab	9.0 ab	6.3 bc	10.0 a
Pendimethalin	0.84	9.7 ab	9.7 a	4.3 cd	10.0 a
Sulfentrazone	0.11	10.0 a	9.7 a	9.3 a	10.0 a
Flufenacet	0.34	7.3 ab	9.7 a	10.0 a	9.3 a
Flufenacet + metribuzin	0.134 + 0.202	9.3 ab	9.3 a	10.0 a	8.7 a
Untreated		7.0 ab	5.7 c	3.7 cd	9.3 a
LSD _(0.05)		3.302	2.398	2.805	2.348

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death

Appendix 6. The effect of postemergence herbicides on carrot stand, injury, and biomass. Data from Oceana County in 2001

Treatment	Rate (kg ai/ha)	Stand count ^b		Crop injury ^c			Yield ^d
		7 DAT	99 DAT	7 DAT	21 DAT	42 DAT	99 DAT
Linuron ^a	0.280	25.7 a	25.3 ab	1.3 de	1.0 d	1.3 ab	11.6 ab
Linuron ^a	0.561	24.3 abc	24.7 ab	1.3 de	1.3 cd	1.0 b	11.9 ab
Flumioxazin ^a	0.035	25.0 ab	24.3 ab	3.7 a	3.0 a	2.0 a	9.6 b
Flumioxazin ^a	0.053	21.3 cd	22.7 ab	3.7 a	2.7 ab	1.7 ab	10.1 ab
Flumioxazin	0.035	22.0 bcd	21.3 b	2.3 bc	1.7 cd	1.3 ab	11.0 ab
Flumioxazin	0.053	24.7 abc	24.0 ab	1.7 cde	1.3 cd	1.3 ab	10.9 ab
Flumioxazin	0.071	22.7 a-d	23.0 ab	3.0 ab	1.7 cd	1.3 ab	11.6 ab
Oxyfluorfen	0.035	23.3 a-d	24.7 ab	2.0 cd	1.0 d	1.0 b	12.0 a
Flufenacet + metribuzin	0.268 + 0.404	24.3 abc	24.0 ab	1.0 e	1.0 d	1.7 ab	11.0 ab
Mesotrione	0.011	20.7 d	22.3 ab	1.7 cde	1.0 d	1.0 b	11.2 ab
Pelargonic acid	10% V/V	25.3 ab	26.3 a	3.0 ab	2.0 bc	1.0 b	9.7 ab
Untreated		24.3 abc	23.0 ab	1.0 e	1.0 d	2.0 a	9.7 ab
LSD _(0.05)		3.567	4.411	0.747	0.803	0.717	2.336

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Treatment + clethodim 0.112 kg ai/ha + NIS 0.25% V/V

^b Number of plants per meter of row

^c Visually assessed crop injury at scale of 1 to 10; 1 = no injury and 10 = plant death.

^d Yield in kg from 1.5 m of row.

Appendix 7. The effect of postemergence herbicides on *Amaranthus retroflexus*. Data from Oceana County 2001

Treatment	Rate (kg ai/ha)	Control of <i>Amaranthus retroflexus</i> ^b			
		7 DAT	21 DAT	28 DAT	42 DAT
Linuron ^a	0.280	7.7 c	5.7 cd	6.7 c	6.7 c
Linuron ^a	0.561	9.0 abc	7.3 abc	8.3 abc	9.0 ab
Flumioxazin ^a	0.035	9.7 ab	9.3 a	9.3 ab	9.7 a
Flumioxazin ^a	0.053	10.0 a	9.3 a	9.7 a	9.3 ab
Flumioxazin	0.035	10.0 a	9.3 a	9.7 a	9.7 a
Flumioxazin	0.053	9.7 ab	9.0 ab	9.7 a	9.3 ab
Flumioxazin	0.071	10.0 a	10.0 a	10.0 a	10.0 a
Oxyfluorfen	0.035	9.3 ab	6.3 bcd	7.7 bc	8.0 bc
Flufenacet + metribuzin	0.268 + 0.404	9.3 ab	7.3 abc	9.3 ab	9.3 ab
Mesotrione	0.011	8.3 bc	4.0 d	6.7 c	7.0 c
Pelargonic acid	10% V/V	9.0 abc	5.0 cd	8.3 abc	7.3 c
Untreated		1.0 d	1.0 e	1.0 d	1.7 d
LSD _(0.05)		1.391	2.708	1.678	1.539

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Treatment + clethodim 0.112 kg ai/ha + NIS 0.25% V/V

^b Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death

Appendix 8. The effect of postemergence herbicides on several weeds. Data from Oceana County 2001

Treatment	Rate (kg ai/ha)	Weed control assessment 7 DAT ^b			Weed control assessment 21 DAT		
		CAPBP	SOLPT	STEME	CHEAL	CAPBP	POLPE
Linuron ^a	0.280	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.0 a
Linuron ^a	0.561	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Flumioxazin ^a	0.035	10.0 a	10.0 a	10.0 a	9.7 a	9.7 a	10.0 a
Flumioxazin ^a	0.053	10.0 a	10.0 a	10.0 a	9.7 a	9.0 ab	8.7 a
Flumioxazin	0.035	10.0 a	10.0 a	10.0 a	9.0 a	8.3 ab	8.3 a
Flumioxazin	0.053	9.7 a	10.0 a	10.0 a	9.0 a	8.3 ab	8.3 a
Flumioxazin	0.071	10.0 a	10.0 a	10.0 a	9.3 a	8.0 abc	8.3 a
Oxyfluorfen	0.035	10.0 a	10.0 a	10.0 a	9.0 a	6.3 bc	9.3 a
Flufenacet + metribuzin	0.268 + 0.404	10.0 a	10.0 a	10.0 a	9.7 a	10.0 a	10.0 a
Mesotrione	0.011	10.0 a	10.0 a	9.7 a	8.0 a	10.0 a	8.3 a
Pelargonic acid	10% V/V	9.7 a	10.0 a	10.0 a	9.3 a	5.0 c	7.0 ab
Untreated		1.3 b	1.0 b	4.7 b	4.3 b	1.0 d	4.3 b
LSD _(0.05)		0.503	0	0.408	2.264	3.157	3.579

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Treatment + clethodim 0.112 kg ai/ha + NIS 0.25% V/V

^b Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 9. The effect of preemergence herbicides on carrot stand, injury, and biomass. Data from Oceana County in 2002

Treatment	Rate (kg ai/ha)	Crop injury ^a				Stand count ^b	Yield ^c
		42 DAT	56 DAT	63 DAT	77 DAT	127 DAT	127 DAT
Linuron	0.561	2.3 b-e	2.0 cde	1.3 cd	1.0 c	69.5 abc	7.0 b
Oxyfluorfen	0.112	3.3 bcd	2.7 bcd	1.3 cd	2.0 bc	64.0 abc	3.3 cd
Oxyfluorfen	0.224	3.7 abc	3.3 abc	2.0 bcd	2.7 abc	58.0 bcd	2.2 de
Flumioxazin	0.0056	4.3 ab	3.7 ab	2.3 a-d	3.7 ab	36.0 cde	1.0 de
Flumioxazin	0.011	4.3 ab	4.0 ab	3.7 a	3.7 ab	17.3 e	0.6 e
S-metolachlor	0.561	1.3 de	2.0 cde	2.7 abc	3.0 ab	43.3 b-e	2.2 de
Pendimethalin	0.841	1.3 de	2.7 bcd	2.7 abc	2.7 abc	52.3 b-e	0.9 de
Sulfentrazone	0.112	5.7 a	4.7 a	3.3 ab	4.3 a	27.0 de	0.7 de
Flufenacet	0.336	1.7 cde	3.3 abc	2.0 bcd	3.0 ab	51.0 b-e	1.0 de
Flufenacet + metribuzin	0.134 + 0.202	2.7 b-e	2.0 cde	1.3 cd	2.0 bc	64.7 abc	6.2 b
Clomazone	0.28	1.7 cde	1.7 de	1.0 d	2.0 bc	77.0 ab	5.3 bc
Untreated		1.0 e	1.0 e	1.0 d	1.0 c	97.3 a	9.9 a
LSD _(0.05)		2.239	1.421	1.522	1.950	35.272	2.596

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed crop injury at scale of 1 to 10; 1= no injury and 10 = plant death.

^b Number of plants per meter of row

^c Yield in kg from 1.5 m of row.

Appendix 10. The effect of preemergence herbicides on several weeds. Data from Oceana County 2002

Treatment	Rate (kg ai/ha)	Weed control assessment 6 weeks after treatment ^a					
		AMBEL	POLPE	MEDLU	AMARE	CHEAL	STEME
Linuron	0.561	9.0 abc	5.3 bcd	10.0 a	10.0 a	10.0 a	10.0 a
Oxyfluorfen	0.112	7.7 a-e	7.7 abc	7.0 abc	9.7 a	7.7 ab	6.3 a
Oxyfluorfen	0.224	8.0 a-d	7.7 abc	8.3 a	9.3 a	6.3 ab	7.7 a
Flumioxazin	0.0056	3.0 fg	1.7 e	4.3 bcd	5.3 b	7.0 ab	7.0 a
Flumioxazin	0.011	5.3 b-g	1.7 e	4.0 cd	9.3 a	3.7 b	7.0 a
S-metolachlor	0.561	3.3 efg	4.7 cde	3.7 cd	10.0 a	7.0 ab	7.0 a
Pendimethalin	0.841	1.0 g	2.3 de	1.3 d	4.3 b	4.7 ab	7.7 a
Sulfentrazone	0.112	4.7 c-g	9.7 a	2.0 d	10.0 a	10.0 a	10.0 a
Flufenacet	0.336	3.7 d-g	2.7 de	8.0 ab	9.3 a	7.0 ab	7.7 a
Flufenacet + metribuzin	0.134 + 0.202	9.3 ab	8.3 ab	10.0 a	10.0 a	10.0 a	10.0 a
Clomazone	0.28	7.3 a-f	10.0 a	7.0 abc	10.0 a	9.7 a	10.0 a
Untreated		10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
LSD _(0.05)		4.416	3.512	3.965	3.430	5.607	5.871

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 11. The effect of preemergence herbicides on several weeds. Data from Oceana County 2002

Treatment	Rate kg ai/ha	Weed control assessment 7 weeks after treatment ^a						
		AMARE	AMBEL	POLPE	CHEAL	MEDLU	POROL	STEME
Linuron	0.561	8.3 abc	9.7 ab	6.3 ab	9.7 a	10.0 a	9.0 ab	10.0 a
Oxyfluorfen	0.112	6.7 bcd	6.3 abc	6.3 ab	7.7 ab	8.7 ab	9.0 ab	7.0 b
Oxyfluorfen	0.224	6.7 bcd	6.0 bcd	5.7 b	5.0 bc	8.0 ab	10.0 a	7.3 b
Flumioxazin	0.0056	5.7 cd	2.7 cde	1.3 c	7.0 abc	6.0 bc	8.3 b	10.0 a
Flumioxazin	0.011	5.0 d	3.7 cde	4.0 bc	3.0 c	4.0 c	9.7 a	10.0 a
S-metolachlor	0.561	9.7 a	2.7 cde	4.3 bc	4.3 bc	4.0 c	10.0 a	10.0 a
Pendimethalin	0.841	7.3 a-d	2.0 e	4.0 bc	5.0 bc	3.0 c	10.0 a	10.0 a
Sulfentrazone	0.112	10.0 a	3.3 cde	10.0 a	10.0 a	3.7 c	10.0 a	10.0 a
Flufenacet	0.336	8.3 abc	2.3 de	4.0 bc	7.0 abc	6.3 abc	10.0 a	10.0 a
Flufenacet + metribuzin	0.134 + 0.202	8.7 ab	9.0 ab	7.7 ab	10.0 a	10.0 a	8.3 b	10.0 a
Clomazone	0.28	8.3 abc	7.7 ab	10.0 a	9.3 a	6.3 abc	10.0 a	10.0 a
Untreated		10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
LSD _(0.05)		2.748	3.734	4.204	4.061	3.778	1.100	2.030

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 12. The effect of preemergence herbicides on several weeds. Data from Oceana County 2002

Treatment	Rate kg ai/ha	Weed control assessment 9 weeks after treatment ^a						
		AMARE	AMBEL	POLPE	CHEAL	MEDLU	POROL	DIGSA
Linuron	0.561	7.3 ab	9.0 ab	4.3 bcd	9.3 a	10.0 a	9.7 a	9.0 ab
Oxyfluorfen	0.112	4.7 bc	6.0 bcd	6.7 abc	8.0 ab	7.0 abc	9.3 a	9.0 ab
Oxyfluorfen	0.224	3.7 c	4.7 cde	4.7 bcd	5.3 bc	8.0 ab	9.7 a	7.7 bc
Flumioxazin	0.0056	5.0 bc	4.0 de	3.7 bcd	5.3 bc	7.0 abc	9.0 a	5.7 c
Flumioxazin	0.011	6.7 bc	3.7 de	3.3 cd	1.7 c	4.3 cd	9.7 a	8.3 ab
S-metolachlor	0.561	10.0 a	3.0 de	4.7 bcd	5.0 bc	5.0 bcd	10.0 a	10.0 a
Pendimethalin	0.841	6.0 bc	1.7 e	4.0 bcd	5.3 bc	3.3 d	10.0 a	9.3 ab
Sulfentrazone	0.112	10.0 a	3.3 de	9.3 a	10.0 a	4.7 cd	9.3 a	8.3 ab
Flufenacet	0.336	5.7 bc	3.0 de	1.7 d	5.3 bc	5.3 bcd	9.0 a	10.0 a
Flufenacet + metribuzin	0.134 + 0.202	7.7 ab	9.0 ab	7.7 ab	10.0 a	10.0 a	9.0 a	9.7 ab
Clomazone	0.28	5.7 bc	8.3 abc	10.0 a	9.3 a	8.0 ab	10.0 a	8.7 ab
Untreated		10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
LSD _(0.05)		3.126	3.713	4.187	3.843	3.321	1.434	2.329

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death

Appendix 13. The effect of preemergence herbicides on several weeds. Data from Oceana County 2002

Treatment	Rate kg ai/ha	Weed control assessment 11 weeks after treatment ^a						
		AMARE	AMBEL	POLPE	CHEAL	MEDLU	POROL	DIGSA
Linuron	0.561	5.3 b-e	7.3 ab	3.3 b	9.0 a	10.0 a	9.3 ab	5.0 bc
Oxyfluorfen	0.112	1.3 e	3.3 cd	1.7 b	6.0 ab	5.7 bc	8.7 b	7.3 abc
Oxyfluorfen	0.224	1.3 e	4.3 bc	1.3 b	3.0 bc	8.0 abc	9.7 ab	4.0 c
Flumioxazin	0.0056	2.3 de	3.0 cd	2.0 b	3.0 bc	5.7 bc	10.0 a	4.3 bc
Flumioxazin	0.011	6.3 a-d	2.3 cd	2.3 b	1.0 c	8.3 ab	9.7 ab	6.7 abc
S-metolachlor	0.561	9.3 ab	2.0 cd	7.3 a	7.3 ab	7.7 abc	10.0 a	9.7 a
Pendimethalin	0.841	7.3 abc	1.0 d	2.7 b	6.3 ab	4.3 bc	10.0 a	10.0 a
Sulfentrazone	0.112	10.0 a	2.0 cd	10.0 a	10.0 a	4.0 c	9.3 ab	6.7 abc
Flufenacet	0.336	7.7 ab	2.0 cd	2.3 b	7.7 a	6.3 abc	9.3 ab	10.0 a
Flufenacet + metribuzin	0.134 + 0.202	3.3 cde	8.7 a	7.3 a	9.0 a	10.0 a	8.7 b	8.3 ab
Clomazone	0.28	6.7 abc	7.3 ab	9.7 a	7.7 a	8.0 abc	10.0 a	7.0 abc
Untreated		10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
LSD _(0.05)		4.124	3.129	3.185	4.422	4.066	1.129	4.130

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 14. The effect of postemergence herbicides on carrot stand, injury, and biomass. Data from Oceana County in 2002

Treatment	Rate (kg ai/ha)	Crop injury ^a				Stand count ^b	Yield ^c
		7 DAT	21 DAT	35 DAT	49 DAT	84 DAT	84 DAT
Linuron	0.561	1.3 de	1.0 a	1.3 ab	1.0 d	92.3 a	10.4 abc
Flumioxazin	0.036	2.7 abc	1.3 a	2.0 ab	2.3 ab	79.3 ab	4.9 d
Flumioxazin	0.053	3.0 abc	1.7 a	2.0 ab	2.0 bc	89.7 a	5.7 cd
Flumioxazin	0.071	3.0 abc	1.0 a	2.3 a	2.7 ab	90.0 a	3.7 d
Oxyfluorfen	0.035	2.3 bcd	1.3 a	2.3 a	3.0 a	89.7 a	3.2 d
Oxyfluorfen	0.071	2.0 cde	1.3 a	2.3 a	2.0 bc	82.3 ab	3.3 d
Sulfentrazone	0.056	3.3 ab	1.3 a	2.0 ab	2.0 bc	63.7 b	3.9 d
Flufenacet + metribuzin	0.202 + 0.303	2.0 cde	1.0 a	1.3 ab	1.0 d	100.3 a	11.3 a
Flufenacet + metribuzin	0.269 + 0.404	2.7 abc	1.0 a	1.7 ab	1.0 d	96.3 a	10.7 ab
Mesotrione	0.022	3.3 ab	1.0 a	1.3 ab	1.3 cd	83.7 ab	4.2 d
Mesotrione	0.045	3.7 a	1.3 a	1.7 ab	1.0 d	93.0 a	6.2 bcd
Untreated		1.0 e	1.0 a	1.0 b	1.0 d	101.0 a	11.9 a
LSD _(0.05)		1.248	0.702	1.194	0.917	22.846	4.683

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed crop injury at scale of 1 to 10; 1 = no injury and 10 = plant death.

^b Number of plants per meter of row

^c Yield in kg from 1.5 m of row

Appendix 15. The effect of postemergence herbicides on several weeds. Data from Oceana County 2002

Treatment	Rate kg ai/ha	Weed control assessment one week after treatment ^a				
		AMARE	AMBEL	POLPE	CHEAL	MEDLU
Linuron	0.561	9.7 ab	9.7 a	9.3 ab	10.0 a	10.0 a
Flumioxazin	0.036	10.0 a	8.0 a-d	7.3 abc	8.3 ab	10.0 a
Flumioxazin	0.053	10.0 a	8.7 abc	6.3 bc	7.3 b	9.7 a
Flumioxazin	0.071	10.0 a	5.7 d	7.0 abc	8.0 ab	10.0 a
Oxyfluorfen	0.035	9.0 b	6.0 cd	6.3 bc	7.7 b	9.7 a
Oxyfluorfen	0.071	9.0 b	6.7 bcd	6.7 bc	9.3 ab	10.0 a
Sulfentrazone	0.056	10.0 a	7.7 a-d	5.0 c	9.0 ab	8.0 b
Flufenacet + metribuzin	0.202 + 0.303	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Mesotrione	0.022	10.0 a	9.0 ab	8.0 abc	9.0 ab	9.3 a
Mesotrione	0.045	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Untreated		10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
LSD _(0.05)		0.717	2.983	3.109	2.199	0.829

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death

Appendix 16. The effect of postemergence herbicides on several weeds. Data from Oceana County 2002

Treatment	Rate kg ai/ha	Weed control assessment 3 weeks after treatment ^a						
		AMARE	AMBEL	POLPE	CHEAL	MEDLU	POROL	DIGSA
Linuron	0.561	9.3 ab	9.7 a	8.0 ab	10.0 a	10.0 a	10.0 a	10.0 a
Flumioxazin	0.036	9.0 ab	7.7 abc	6.7 abc	9.0 a	9.7 a	10.0 a	10.0 a
Flumioxazin	0.053	10.0 a	7.3 a-d	4.7 bc	8.3 ab	9.7 a	10.0 a	10.0 a
Flumioxazin	0.071	9.3 ab	5.3 cd	4.0 bc	5.7 b	10.0 a	10.0 a	10.0 a
Oxyfluorfen	0.035	7.0 b	5.3 cd	4.7 bc	7.3 ab	9.7 a	9.7 a	8.3 b
Oxyfluorfen	0.071	9.7 a	6.3 bcd	5.0 bc	7.7 ab	10.0 a	10.0 a	9.0 ab
Sulfentrazone	0.056	9.0 ab	4.3 d	3.3 c	9.3 a	10.0 a	10.0 a	9.7 a
Flufenacet + metribuzin	0.202 + 0.303	10.0 a	10.0 a	9.7 a	10.0 a	10.0 a	10.0 a	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Mesotrione	0.022	8.3 ab	7.7 abc	3.3 c	7.7 ab	10.0 a	6.7 b	10.0 a
Mesotrione	0.045	9.3 ab	9.0 ab	7.7 ab	10.0 a	10.0 a	7.3 b	9.7 a
Untreated		10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
LSD _(0.05)		2.344	3.073	4.053	2.690	0.442	0.702	1.007

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death

Appendix 17. The effect of postemergence herbicides on several weeds. Data from Oceana County 2002

Treatment	Rate kg ai/ha	Weed control assessment 5 weeks after treatment ^a						
		AMARE	AMBEL	POLPE	CHEAL	MEDLU	POROL	DIGSA
Linuron	0.561	9.3 ab	9.3 ab	8.0 abc	9.7 a	10.0 a	10.0 a	10.0 a
Flumioxazin	0.036	8.7 ab	8.0 ab	7.0 a-d	8.3 ab	9.7 a	10.0 a	10.0 a
Flumioxazin	0.053	9.7 a	8.3 ab	5.0 cd	7.0 ab	10.0 a	10.0 a	10.0 a
Flumioxazin	0.071	9.3 ab	7.0 bc	5.0 cd	6.0 b	10.0 a	10.0 a	10.0 a
Oxyfluorfen	0.035	8.3 ab	7.0 bc	7.0 a-d	7.0 ab	9.7 a	10.0 a	9.3 a
Oxyfluorfen	0.071	9.3 ab	7.0 bc	6.0 bcd	8.3 ab	10.0 a	10.0 a	9.7 a
Sulfentrazone	0.056	9.3 ab	5.3 c	4.7 cd	7.7 ab	10.0 a	10.0 a	9.7 a
Flufenacet + metribuzin	0.202 + 0.303	10.0 a	10.0 a	9.7 ab	10.0 a	10.0 a	10.0 a	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Mesotrione	0.022	8.0 b	8.3 ab	3.7 d	6.3 b	10.0 a	7.3 b	9.7 a
Mesotrione	0.045	9.0 ab	9.0 ab	7.3 a-d	9.8 a	10.0 a	7.0 b	9.3 a
Untreated		10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
LSD _(0.05)		1.553	2.594	3.976	3.384	0.381	1.039	0.928

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

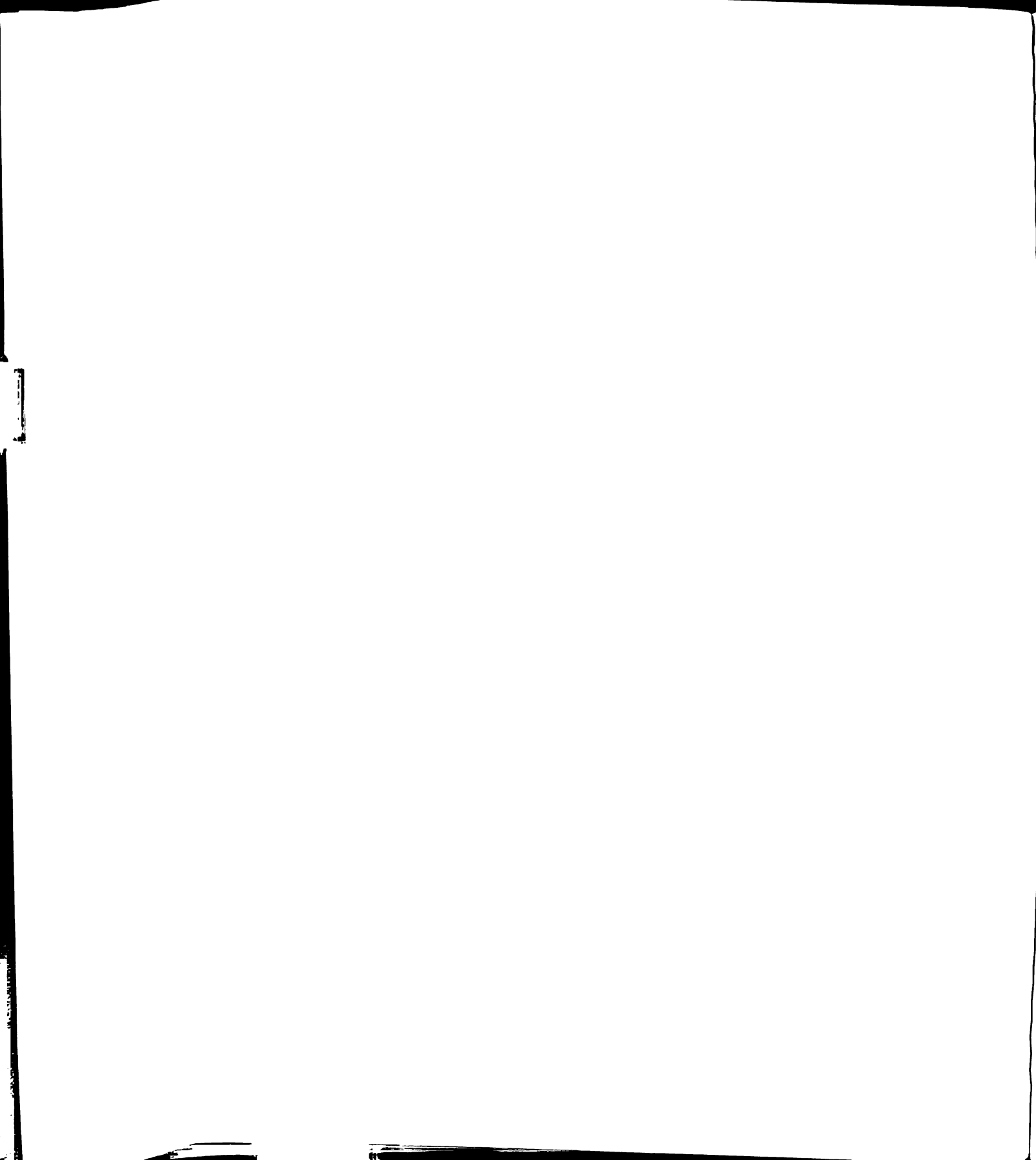
^a Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 18. The effect of postemergence herbicides on several weeds. Data from Oceana County 2002

Treatment	Rate kg ai/ha	Weed control assessment 7 weeks after treatment ^a						
		AMARE	AMBEL	POLPE	CHEAL	MEDLU	POROL	DIGSA
Linuron	0.561	6.7 a	9.0 a	7.0 abc	9.7 a	10.0 a	9.7 ab	9.7 a
Flumioxazin	0.036	8.0 a	6.7 ab	4.7 cde	8.3 ab	10.0 a	10.0 a	9.7 a
Flumioxazin	0.053	10.0 a	6.7 ab	4.0 cde	8.7 ab	9.3 a	10.0 a	10.0 a
Flumioxazin	0.071	9.3 a	4.0 b	3.0 de	3.7 c	9.3 a	10.0 a	7.0 a
Oxyfluorfen	0.035	6.7 a	4.0 b	3.3 cde	4.7 c	10.0 a	10.0 a	6.3 a
Oxyfluorfen	0.071	7.7 a	4.3 b	4.0 cde	6.3 bc	10.0 a	10.0 a	9.3 a
Sulfentrazone	0.056	7.7 a	3.7 b	2.3 de	10.0 a	9.7 a	10.0 a	7.0 a
Flufenacet + metribuzin	0.202 + 0.303	9.3 a	10.0 a	9.7 ab	10.0 a	10.0 a	10.0 a	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	9.7 a	10.0 a	9.7 ab	10.0 a	10.0 a	10.0 a	10.0 a
Mesotrione	0.022	7.7 a	7.3 ab	2.0 e	6.0 bc	10.0 a	9.3 b	9.7 a
Mesotrione	0.045	7.7 a	8.7 a	6.0 bcd	10.0 a	10.0 a	5.7 c	8.0 a
Untreated		10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
LSD _(0.05)		3.474	3.995	3.745	2.954	0.855	0.503	3.899

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death



Appendix 19. The effect of preemergence herbicides on carrot stand, injury, and biomass. Data from Newaygo County in 2003

Treatment	Rate (kg ai/ha)	Crop injury ^a			Stand count ^b	Yield ^c
		21 DAT	35 DAT	49 DAT	35 DAT	128 DAT
Linuron	0.28	1.3 c	1.0 e	1.3 c	257.0 a	19.1 ab
Linuron	0.561	1.3 c	1.0 e	2.0 c	258.0 a	18.5 ab
Clomazone	0.28	3.3 c	1.7 e	2.0 c	222.7 ab	18.3 ab
Clomazone	0.561	3.0 c	3.0 d	2.3 c	250.0 a	20.8 a
Mesotrione	0.112	10.0 a	10.0 a	10.0 a	0.0 d	0.0 c
Mesotrione	0.224	10.0 a	10.0 a	10.0 a	0.0 d	0.0 c
Flufenacet + metribuzin	0.179 + 0.269	6.0 b	6.3 c	5.0 b	109.0 c	14.6 b
Flufenacet + metribuzin	0.269 + 0.404	7.3 b	7.7 b	6.0 b	73.0 cd	15.1 b
Metribuzin	0.42	7.7 b	7.3 bc	5.7 b	66.3 cd	15.0 b
Flufenacet	0.673	3.3 c	3.7 d	2.0 c	148.3 bc	17.4 ab
Untreated		2.3 c	1.0 e	1.0 c	207.3 ab	19.1 ab
LSD _(0.05)		2.246	1.289	1.799	94.291	4.762

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed crop injury at scale of 1 to 10; 1= no injury and 10 = plant death.

^b Number of plants per meter of row

^c Yield in kg from 1.5 m of row.

Appendix 20. The effect of preemergence herbicides on several weeds. Data from Nwaygo County in 2003

Treatment	Rate kg ai/ha	Weed control assessment 5 weeks after treatment ^a			
		AMARE	CHEAL	STEME	POROL
Linuron	0.28	7.7 c	8.7 ab	8.3 b	10.0 a
Linuron	0.561	8.3 bc	8.0 b	10.0 a	10.0 a
Clomazone	0.28	8.3 bc	8.7 ab	10.0 a	10.0 a
Clomazone	0.561	8.7 b	9.7 a	10.0 a	10.0 a
Mesotrione	0.112	10.0 a	10.0 a	10.0 a	10.0 a
Mesotrione	0.224	10.0 a	10.0 a	10.0 a	10.0 a
Flufenacet + metribuzin	0.179 + 0.269	10.0 a	10.0 a	10.0 a	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	10.0 a	10.0 a	10.0 a	10.0 a
Metribuzin	0.42	10.0 a	10.0 a	10.0 a	10.0 a
Flufenacet	0.673	8.0 bc	7.3 b	7.7 b	10.0 a
Untreated		1.0 d	1.0 c	1.0 c	1.0 b
LSD _(0.05)		0.928	1.456	0.864	0.000

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death

Appendix 21. The effect of preemergence herbicides on several weeds. Data from Newaygo County in 2003

Treatment	Rate kg ai/ha	Weed control assessment 7 weeks after treatment ^a		
		AMARE	CHEAL	SOLPT
Linuron	0.28	6.7 d	7.7 ab	8.3 b
Linuron	0.561	8.3 c	8.7 ab	9.7 ab
Clomazone	0.28	8.7 bc	9.3 a	10.0 a
Clomazone	0.561	8.7 bc	9.7 a	10.0 a
Mesotrione	0.112	10.0 a	10.0 a	10.0 a
Mesotrione	0.224	10.0 a	10.0 a	10.0 a
Flufenacet + metribuzin	0.179 + 0.269	9.7 ab	9.7 a	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	9.7 ab	10.0 a	10.0 a
Metribuzin	0.42	10.0 a	10.0 a	10.0 a
Flufenacet	0.673	6.7 d	6.3 b	8.7 ab
Untreated		1.0 e	1.0 c	1.0 c
LSD _(0.05)		1.197	2.363	1.365

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death

Appendix 22. The effect of postemergence herbicides on carrot injury, yield, and weed control. Data from Newaygo County in 2003

Treatment	Rate (kg ai/ha)	Carrot		Weed control ^d		
		Injury ^b	Yield ^c	AMARE	CHEAL	SOLSA
Linuron ^a	0.28	1.3 f	14.9 ab	7.3 bc	8.0 ab	10.0 a
Linuron ^a	0.561	2.3 e	15.1 ab	10.0 a	10.0 a	10.0 a
Linuron	1.121	3.3 d	16.5 a	10.0 a	10.0 a	10.0 a
Oxyfluorfen	0.035	3.3 d	8.5 cd	5.3 cd	3.7 c	8.0 a
Oxyfluorfen	0.071	3.7 cd	7.9 d	3.7 d	3.7 c	8.3 a
Oxyfluorfen	0.14	4.3 bc	12.0 bc	6.7 bc	8.0 ab	8.3 a
Flumioxazin	0.035	5.0 b	15.6 ab	6.0 bcd	7.7 b	8.3 a
Flumioxazin	0.071	5.0 b	13.0 ab	7.3 bc	8.3 ab	10.0 a
Mesotrione	0.05	7.3 a	5.6 d	8.3 ab	10.0 a	10.0 a
Mesotrione	0.105	7.0 a	7.2 d	10.0 a	10.0 a	10.0 a
Untreated control		1.0 f	15.5 ab	1.0 e	1.0 d	1.0 b
LSD _(0.05)		0.992	3.686	2.401	2.050	3.124

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Treatment + COC 1% V/V

^b Visually assessed crop injury at scale of 1 to 10; 1= no injury and 10 = plant death, 14 DAT.

^c Yield in kg from 1.5 m of row, 91 DAT.

^d Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death, 14 DAT.

Appendix 23. The effect of preemergence herbicides on carrot stand, injury, and yield. Data from Oceana County in 2003

Treatment	Rate (kg ai/ha)	Crop injury ^a			Stand count ^b	Yield ^c
		21 DAT	35 DAT	49 DAT	35 DAT	142 DAT
Linuron	0.561	3.3 de	1.7 ef	1.0 f	41.7 a	16.5 a
Clomazone	0.28	2.7 e	1.7 ef	1.3 f	35.3 ab	14.1 ab
Clomazone	0.561	3.0 de	2.7 de	1.3 f	36.0 ab	14.2 ab
Clomazone	1.121	4.3 bcd	4.7 bc	3.7 d	33.3 ab	12.4 b
Mesotrione	0.112	10.0 a	9.0 a	9.0 b	1.0 c	5.0 c
Mesotrione	0.224	10.0 a	9.0 a	9.7 ab	0.0 c	1.0 d
Mesotrione	0.448	10.0 a	10.0 a	10.0 a	0.0 c	0.0 d
Flufenacet + metribuzin	0.179 + 0.269	5.3 bc	4.0 cd	3.0 de	30.3 b	14.1 ab
Flufenacet + metribuzin	0.269 + 0.404	5.7 b	6.0 b	4.7 c	30.0 b	12.8 ab
Metribuzin	0.42	4.0 cde	4.0 cd	3.0 de	38.3 ab	14.9 ab
Flufenacet	0.673	4.0 cde	3.7 cd	2.3 e	30.7 b	13.8 ab
Untreated		1.0 f	1.0 f	1.0 f	42.0 a	15.1 ab
LSD _(0.05)		1.585	1.632	0.978	10.051	3.963

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed crop injury at scale of 1 to 10; 1 = no injury and 10 = plant death.

^b Number of plants per meter of row

^c Yield in kg from 1.5 m of row.

Appendix 24. The effect of preemergence herbicides on several weeds. Data from Oceana County in 2003

Treatment	Rate kg ai/ha	Weed control assessment 35 DAT ^a				Weed control assessment 49 DAT		
		AMARE	ANTCO	POAAN	CHEAL	AMARE	ANTCO	POAAN
Linuron	0.561	8.3 ab	10.0 a	10.0 a	10.0 a	6.7 c	10.0 a	10.0 a
Clomazone	0.28	9.0 ab	8.0 c	10.0 a	10.0 a	8.7 b	8.7 a	10.0 a
Clomazone	0.561	9.7 a	9.0 b	10.0 a	10.0 a	9.7 ab	8.7 a	10.0 a
Clomazone	1.121	10.0 a	10.0 a	10.0 a	10.0 a	9.7 ab	9.7 a	10.0 a
Mesotrione	0.112	10.0 a	10.0 a	5.3 b	10.0 a	9.3 ab	10.0 a	7.0 c
Mesotrione	0.224	10.0 a	10.0 a	7.0 b	10.0 a	10.0 a	10.0 a	7.3 bc
Mesotrione	0.448	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.7 ab
Flufenacet + metribuzin	0.179 + 0.269	10.0 a	10.0 a	10.0 a	9.7 a	9.0 ab	10.0 a	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	10.0 a	10.0 a	10.0 a	10.0 a	9.3 ab	10.0 a	10.0 a
Metribuzin	0.42	9.3 a	10.0 a	10.0 a	10.0 a	9.0 ab	10.0 a	10.0 a
Flufenacet	0.673	7.3 b	9.7 ab	10.0 a	9.7 a	6.3 c	8.7 a	10.0 a
Untreated		1.0 c	1.0 d	1.0 c	1.0 b	1.0 d	1.0 b	1.0 d
LSD _(0.05)		1.678	0.761	2.842	0.408	1.060	1.457	2.574

Values followed by the same letter in the same column are not statistically significant at $\alpha=0.05$

^a Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death

Appendix 25. The effect of postemergence herbicides on carrot injury, yield, and weed control. Data from Oceana County in 2003

Treatment	Rate (kg ai/ha)	Carrot		Weed injury ^d
		Injury ^b	Yield ^c	AMARE
Linuron ^a	0.561	1.7 gh	14.2 abc	8.3 c
Linuron	1.121	2.3 fg	14.8 ab	9.3 abc
Oxyfluorfen	0.035	3.0 ef	15.5 ab	9.0 abc
Oxyfluorfen	0.071	2.3 fg	15.7 ab	9.0 abc
Oxyfluorfen	0.14	3.7 de	16.8 a	9.7 ab
Flumioxazin	0.036	3.7 de	16.6 a	9.0 abc
Flumioxazin	0.071	4.0 d	17.2 a	10.0 a
Mesotrione ^e	0.05	5.0 c	12.1 bcd	9.3 abc
Mesotrione ^e	0.105	6.3 ab	10.5 cd	9.3 abc
Mesotrione	0.05	5.7 bc	11.0 cd	8.7 bc
Mesotrione	0.105	6.7 a	10.5 d	10.0 a
Untreated control		1.0 h	13.9 a-d	1.0 d
LSD _(0.05)		0.974	3.668	1.018

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Treatment + COC 1% V/V

^b Visually assessed crop injury at scale of 1 to 10; 1= no injury and 10 = plant death, 14 DAT.

^c Yield in kg from 1.5 m of row, 105 DAT.

^d Visually assessed weed control at scale of 1 to 10; 1= no control and 10 = plant death, 14 DAT.

^e Treatment + COC 1% V/V + UAN 2.5% V/V

Appendix 26. The effect of preemergence herbicides on carrot injury. Data from MSU Muck Farm in 2003

Treatment	Rate (kg ai/ha)	Carrot injury ^a	
		7 DAT	14 DAT
Linuron	1.121	2.7 cd	2.7 c
S-metolachlor	1.9	1.7 cd	2.0 c
Pendimethalin	2.24	3.0 c	2.0 c
Clomazone	0.28	1.0 d	1.7 c
Clomazone	0.561	3.0 c	1.7 c
Mesotrione	0.112	8.3 ab	9.0 a
Mesotrione	0.224	8.7 ab	9.7 a
Mesotrione	0.448	9.0 a	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	7.0 b	6.7 b
Metribuzin	0.561	7.7 ab	6.0 b
Flufenacet	0.673	2.7 cd	3.3 c
Untreated control		2.0 cd	2.0 c
LSD _(0.05)		1.779	1.954

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed crop injury at scale of 1 to 10; 1 = no injury and 10 = plant death

Appendix 27. The effect of preemergence herbicides on several weeds. Data from MSU Muck Farm in 2003

Treatment	Rate kg ai/ha	Weed control assessment one week after treatment ^a				
		CYPES	POLPE	AMARE	POROL	STEME
Linuron	1.121	7.3 abc	10.0 a	10.0 a	10.0 a	10.0 a
S-metolachlor	1.9	4.0 d	5.0 bc	4.3 cd	9.3 a	3.7 b
Pendimethalin	2.24	5.7 cd	8.3 a	7.0 bc	9.7 a	7.0 a
Clomazone	0.28	7.7 abc	8.0 ab	7.7 ab	9.7 a	9.7 a
Clomazone	0.561	6.7 bc	8.7 a	8.3 ab	10.0 a	10.0 a
Mesotrione	0.112	9.0 a	9.7 a	9.3 ab	10.0 a	10.0 a
Mesotrione	0.224	8.7 ab	9.0 a	8.7 ab	10.0 a	8.7 a
Mesotrione	0.448	8.7 ab	9.7 a	10.0 a	9.7 a	9.7 a
Flufenacet + metribuzin	0.269 + 0.404	4.0 d	10.0 a	10.0 a	10.0 a	10.0 a
Metribuzin	0.561	5.7 cd	10.0 a	10.0 a	10.0 a	10.0 a
Flufenacet	0.673	4.0 d	7.7 ab	8.7 ab	10.0 a	9.0 a
Untreated		1.7 e	4.0 c	3.0 d	3.3 b	3.3 b
LSD _(0.05)		2.250	3.144	2.734	2.165	3.283

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 28. The effect of preemergence herbicides on several weeds. Data from MSU Muck Farm in 2003

Treatment	Rate kg ai/ha	Weed control assessment two weeks after treatment ^a				
		CYPES	POLPE	AMARE	POROL	AMABL
Linuron	1.121	6.0 bc	9.3 a	8.3 ab	8.3 ab	10.0 a
S-metolachlor	1.9	3.0 efg	5.3 b	7.3 b	7.7 ab	9.3 a
Pendimethalin	2.24	4.0 def	8.7 a	9.3 a	10.0 a	8.7 a
Clomazone	0.28	4.7 cd	10.0 a	5.3 c	7.3 abc	6.3 b
Clomazone	0.561	4.3 de	10.0 a	5.3 c	10.0 a	6.3 b
Mesotrione	0.112	7.7 a	9.0 a	8.7 ab	4.0 d	9.3 a
Mesotrione	0.224	7.3 ab	9.0 a	9.7 a	4.7 cd	9.7 a
Mesotrione	0.448	8.0 a	10.0 a	10.0 a	6.3 bcd	10.0 a
Flufenacet + metribuzin	0.269 + 0.404	2.3 gh	9.3 a	10.0 a	10.0 a	10.0 a
Metribuzin	0.561	2.7 fg	9.0 a	9.7 a	9.7 a	10.0 a
Flufenacet	0.673	3.7 d-g	8.7 a	9.3 a	9.0 ab	9.7 a
Untreated		1.0 h	3.3 b	1.0 d	1.0 e	1.0 c
LSD _(0.05)		1.599	2.764	1.905	2.797	2.114

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

Appendix 29. The effect of postemergence herbicides on carrot injury. Data from MSU Muck Farm in 2003

Treatment	Rate (kg ai/ha)	Carrot injury	
		14 DAT	42 DAT
Linuron ^a	1.121	1.3 de	1.0 c
Trifloxysulfuron	0.0075	7.7 b	8.3 a
Oxyfluorfen	0.035	1.0 e	1.0 c
Oxyfluorfen	0.071	1.0 e	1.3 c
Oxyfluorfen	0.14	2.0 cd	2.0 c
Flumioxazin	0.036	2.0 cd	1.7 c
Flumioxazin	0.071	2.7 c	1.0 c
Mesotrione	0.05	7.7 b	6.7 b
Mesotrione	0.105	9.0 a	8.3 a
Mesotrione ^b	0.05	9.0 a	9.3 a
Mesotrione ^b	0.105	9.7 a	9.3 a
Untreated control		1.0 e	1.0 c
LSD _(0.05)		0.821	1.151

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Treatment + COC 1% V/V

^b Treatment + COC 1% V/V + UAN 2.5% V/V

Appendix 30. The effect of postemergence herbicides on several weeds. Data from MSU Muck Farm in 2003

Treatment	Rate kg ai/ha	Weed control assessment two weeks after treatment ^a				
		CYPES	POLPE	AMARE	POROL	CHEAL
Linuron ^b	1.121	8.0 bc	10.0 a	10.0 a	10.0 a	10.0 a
Trifloxysulfuron	0.0075	7.3 c	8.7 ab	8.0 b	2.7 d	7.0 bc
Oxyfluorfen	0.035	1.3 fg	8.7 ab	5.3 c	7.7 b	7.3 bc
Oxyfluorfen	0.071	2.3 ef	7.3 b	8.7 ab	9.7 a	9.0 ab
Oxyfluorfen	0.14	3.7 d	8.3 b	9.3 ab	10.0 a	8.3 abc
Flumioxazin	0.036	2.7 de	2.3 cd	4.7 c	4.3 c	3.7 d
Flumioxazin	0.071	3.0 de	3.7 c	8.7 ab	8.0 b	6.3 c
Mesotrione	0.05	9.0 ab	10.0 a	10.0 a	1.0 e	10.0 a
Mesotrione	0.105	9.0 ab	10.0 a	10.0 a	1.3 de	10.0 a
Mesotrione ^c	0.05	9.0 ab	10.0 a	10.0 a	4.7 c	10.0 a
Mesotrione ^c	0.105	9.3 a	10.0 a	10.0 a	6.7 b	10.0 a
Untreated		1.0 g	1.0 d	1.0 d	1.0 e	1.0 e
LSD _(0.05)		1.039	1.391	1.486	1.383	2.093

Values followed by the same letter in the same column are not statistically significant at $\alpha = 0.05$

^a Visually assessed weed control at scale of 1 to 10; 1 = no control and 10 = plant death

^b Treatment + COC 1% V/V

^c Treatment + COC 1% V/V + UAN 2.5% V/V

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