INTRODUCTION

Carrots are an important fresh market and processing vegetable crop. According to Statistics Canada, fresh market and processing carrots were grown on 8658 hectares in Canada in 2012 (Statistics Canada 2013). A large proportion of these carrots are grown in Ontario with 47% of the national production (Health Canada, 2009).

THE PROBLEM

Weed control in carrots is important as carrots are a poor competitor. Without weed control, yields are often reduced by more than 90 per cent (Swanton et al., 2009). These weeds can act as the host of pests that are important in carrots and can reduce harvest crop quality and harvesting efficiency (Swanton et al., 2009).

Pigweed is one of the most important weeds in carrots. Pigweed and ragweed populations have developed resistance to linuron and prometryne. These herbicides form the foundation of weed management in carrots (Swanton, Chandler, & Callow, 2011).

RESISTANCE

WHAT IS RESISTANCE?

Herbicide Resistance: "Herbicide resistance is the evolved capacity of a previously susceptible weed population to withstand a herbicide and complete its lifecycle when the herbicide is used at normal rates in an agricultural situation" (Heap, 2010).

HOW DOES RESISTANCE DEVELOP?

Genetic diversity - rare resistant mutation within population

+

Selection – the repeated use of the same herbicide, or herbicides with the same site of action

RESISTANCE

Genetic diversity: Through rare random genetic mutations, weed populations naturally contain herbicide-resistant individuals at very low frequencies. These rare, random genetic mutations provide the weed with a mechanism to resist herbicides (Heap, 2010).

Selection: Repeated use of the same herbicide, or herbicide mode of action, eventually enriches the frequency of these rare mutations to a point where they predominate and cause herbicide failure. Herbicide-resistant weeds can then easily spread as contaminants in crop seeds, by machinery, water, animals, wind, and pollen (Heap, 2010).

WHY DO WE HAVE RESISTANCE?

- 1. Human Nature
- 2. Resistance Nature
- 3. Herbicide Nature

4. Weed Nature

HUMAN NATURE

• Continue to repeat successful practices; however, pests including weeds adapt to repeated practices.

RESISTANCE NATURE

 Within a species a few individual plants may have altered genes that allow them to be resistant to the herbicide

HERBICIDE NATURE

- Not all herbicides are alike in their ability to select for herbicide resistant weeds.
 - e.g. Group 4 herbicides: 2,4-D and MCPA have been used successfully for over 50 years with limited selection of resistant weeds
 - e.g. Group 2 herbicides: Glean and Ally were on the market only a few years before there were reports of resistance

WEED NATURE

- Weeds vary in their density in fields. Weeds found in large numbers are more likely to have a resistant individual that can be selected.
- Genetic diversity of weeds weeds that are outcrossers rather than self fertilizing are more variable than others. Outcrossers are more likely to contain an individual with a resistant mutation.

WHY IS HERBICIDE RESISTANCE A CONCERN?

- · Direct loss due to uncontrolled weeds prior to knowing about resistance
- Decreases weed control options
 - Some herbicides are no longer effective
- Increases cost
 - generally growers would be using the cheapest, most effective herbicide, so if they have to change or to supplement with repetitive physical methods (eg. Hand weeding, inter-row cultivation etcetera), then it is likely to increase weed control costs
- Increases the number of herbicides used
 - Often additional herbicides are added to control resistant populations

PIGWEED (DESCRIPTION)

One of the most important weeds in carrot crops is **pigweed**. Pigweed species have an annual life cycle and reproduce only by seeds. Each plant produces hundreds of thousand tiny seeds that can lay dormant for up to 60

years. Pigweed requires high temperatures for germination and germination takes place if soil temperatures exceed 15°C. Pigweed thus continues to germinate throughout the summer if temperatures remain high and soil moisture is adequate. Pigweed can grow in almost any kind of soil but is most abundant on fertile soils. The small and lightweight nature of pigweed seeds makes them easily dispersible and as contaminants of crop seeds and farm equipment.

Some pigweed populations have developed resistance to linuron and prometryne. These herbicides form the foundation of weed management in carrots (Swanton, 2011).

Four different pigweed species are showing resistance to herbicides in Ontario.

- Redroot pigweed (Amaranthus retroflexus)
- Green pigweed (Amaranthus powellii)
- Smooth pigweed (Amaranthus hybridus)
- Common waterhemp (Amaranthus tuberculatus)

Resistance to Group 7 herbicides began in 1999, Group 2 herbicides in 1998 and to Group 5 herbicides in 1977. Multiple resistant populations exist.

Hybridization is known to occur among redroot pigweed, green pigweed and smooth pigweed. Plants which seem to be intermediate or have a mixture of characteristics from any of these species could be hybrids between them (Ontario weeds gallery).

IDENTIFICATION OF PIGWEED

All of the species of pigweed have a pink or red taproot with a green to reddish green stem. The stem can be simple or branched. Pigweeds can reach an average height of 100 cm. The leaves alternate on the stem and range in colour from dull green to shiny green to reddish green. Leaf shape ranges from oval to diamond shaped but is broader at the base of the leaf. The leaf margins are smooth. However, each species of pigweed has individual characteristics that distinguish it from the other pigweed species.

REDROOT PIGWEED (AMARANTHUS RETROFLEXUS)

Caption: Redroot pigweed at the 2-leaf stage.

Leaves are more 'dull green' in colour compared to green pigweed.

Redroot pigweed is often mistaken for green pigweed, smooth pigweed and common waterhemp. It has somewhat dull green leaves, a dense covering of short hair on the upper stem and a thick, coarse, bristly terminal panicle with an uppermost central spike. It has a tall, erect habit of growth and has larger and



broader leaves than tumble and prostrate pigweed. Redroot pigweed is distinguished from smooth pigweed by its coarse, harsh inflorescence (ontarioweeds.com).

Resistance to Group 2, 5, 6 and 7 herbicides exists in Ontario.

GREEN PIGWEED (AMARANTHUS POWELLII)

Caption: Young green pigweed plant

Young green pigweed plants are most easily distinguished from redroot pigweed by their colour. Green pigweed has a shiny green or slightly reddish-green colour. The green pigweed plant has a brighter green, thinner and looser inflorescence than the redroot pigweed. The individual bristly spikes are longer and point upwards in comparison to the redroot pigweed (ontarioweeds.com).

Resistance to Group 2, 5, and 7 herbicides exists in Ontario.

SMOOTH PIGWEED (AMARANTHUS HYBRIDUS)

Caption: Young smooth pigweed plant

Smooth pigweed is less hairy than the redroot pigweed. It has a finer inflorescence and smaller flowers. It differs from green by its more slender, less spiny spikes. (ontarioweeds.com)

Resistance to Group 6 herbicides exists in Ontario.

COMMON WATERHEMP (AMARANTHUS TUBERCULATUS)

Caption: Young common waterhemp plant

Common waterhemp is very similar in appearance to redroot and green pigweed while young. It differs in appearance from redroot and green pigweed by its narrow leaves, wavy leaf margins and almost hairless leaves and stems. Once mature, common waterhemp is more easily distinguished from the other pigweed species as it is much taller. Stem colours range from green to red/purple (ontarioweeds.com).

Resistance to Group 2 and 5 herbicides exists in Ontario.







DO I HAVE HERBICIDE RESISTANT PIGWEED?

SCOUTING

Scouting is the only way to know which weeds you have, in what quantity and why they are present. In this way, scouting is a very important step in determining whether or not you have herbicide resistant weeds.

Scouting should begin between 7 and 14 days after herbicide application. Scouting should then be completed weekly until the crop is harvested. Scouting should be done in a pattern that covers the entire field. Look for and note all weeds that are present, the density in which they are present, growth stage and the herbicide symptomology on the weeds, if any.

Keeping track of all of these identifiers will allow you to determine what effect the applied herbicides have on the weeds, if any, and will allow you to discern any patterns that emerge.

If you find that pigweed is present despite herbicide application, assess the other possible reasons for this presence before looking to herbicide resistance. These other factors include:

Field History - Determine the past mechanical, chemical and cultural weed management practices used on the field. Using the same methods or herbicides with the same mode of action can speed up the development of herbicide resistance.

Weed Biology - Determine whether the herbicide was applied at the right stage (size and age of weed).

Environment - Determine whether the soil and weather conditions were appropriate for herbicide application. Include looking at conditions after herbicide application.

Application Problems - Determine if there were any problems regarding the equipment used, the herbicide used, herbicide rate, herbicide incorporation and soil condition.

Cultural Practices - Determine if there are any problems with the crop selected for the field and the practices used to grow the crop (row spacing etcetera).

CONFIRMATION

If you believe you may have resistant pigweed, do not wait. Confirming resistance when there are only a few weeds present and hand removing them can slow down the spread of herbicide resistant weeds. Have your suspicions checked out.

Confirmation testing of herbicide resistance is confidential and free of charge. Visit <u>http://www.plant.uoguelph.ca/resistant-weeds/</u> or contact the OMAFRA Agricultural Information Contact Centre at 1-877-424-1300. Suspicious weed species will be tested for resistance by the University of Guelph.

BEST MANAGEMENT PRACTICES FOR RESISTANT PIGWEED

INTEGRATED WEED MANAGEMENT

The bottom line - **Integrated Weed Management** (IWM) needs to be used to help control herbicide resistant weeds. Integrated Weed Management can be defined as the use of a range of control techniques. This includes using different mechanical and cultural practices, herbicides and scouting regularly without relying on any single method. The variance in weed management techniques will destabilize the evolution of herbicide resistant weeds.

MECHANICAL SOLUTIONS

CULTIVATION BETWEEN ROWS

Cultivation between rows regularly should be added into weed management practices. This works to control emerged plants and to bury non-germinated seed. Pigweed seeds are small and germinate near the soil surface. Germination is stimulated by light and high temperatures (germination occurs when the average soil temperature exceeds 15°C). Cultivating the soil at night instead of during the day **may reduce** the amount of pigweed germination. This however will not eliminate germination.

HOEING/REMOVING PIGWEED FROM THE FIELD

Hoeing is another practice that can be added back into weed management practices, but in most cases is not economical. This involves using a hoe to remove weeds by cutting them below the soil surface.



Caption: Hoeing

This can involve hand or mechanical removal of the pigweed. Keep in mind that pigweed species have hundreds of thousands of seeds that can lay dormant for up to 60 years. Hoeing and leaving the pigweed in the field may leave behind seeds that can germinate at other times during the summer or the following year.





Caption: Removing pigweed from the field

Removing pigweed from the field will help to decrease the amount of pigweed seed that is returned to the soil seed bank.

WICK WEEDING

This is the process of adding herbicide to the pigweed that is above the crop canopy.



Caption: Wick weeding pigweed in carrots

CULTURAL SOLUTIONS

CROP ROTATION

Crop rotation should be practiced. Rotate your carrot fields to onions and/or other crops that have herbicides with different modes of action registered to control pigweed. For example:

Сгор	Herbicide*	Group
Onions	Chateau, Goal, Aim	14
	Prowl	3
	Pardner	6
	Frontier	15
Beets	Nortron (soil type restrictions)	16
	Upbeet	2

*Please refer to product labels before applying these products.

Each of the herbicides can be classified into a group based on their mode or site of action. Refer to the following table for a description of the classification.

WSSA Group	Site of Action	WSSA Group	Site of Action	
	Inhibitors of acetyl CoA	11	Inhibitors of carotenoid	
1	carboxylase (ACCase)	11	biosynthesis	
	Inhibitors of acetolactate synthase			
2	(ALS) and also called	13	Diterpene synthesis inhibitor	
	acetohydroxyacid synthase (AHAS)			
3	Microtubule assembly inhibitors	14	Inhibitors of protoporphyrinogen oxidase (Protox)	
4	Synthetic auxins	15	Conjugation of acetyl co-enzyme A	
5	Inhibitors of photosynthesis at photosystem II, Site A	19	Inhibitors of auxin transport system	
6	Inhibitors of photosynthesis at	20	Inhibits cell wall synthesis, Site A	
	photosystem II, Site B	20		
7	Inhibitors of photosynthesis at	22	Photosystem I – electron diverters	

	photosystem II, Site B (alternate binding site)		
8	Conjugation of acetyl co-enzyme A	23	Inhibitors of mitosis
9	Inhibitors of 5- enolpyruvylshikimimate-3- phosphate synthase (EPSP)	27	Inhibitors of p-hydroxyphenyl pyruvate dioxygenase (HPPD)
10	Inhibitors of glutamine synthetase		

HERBICIDE SOLUTIONS

HERBICIDE BANDING

Herbicide banding consists of spraying herbicide over the crop rows only. The space between rows is controlled mechanically. The growth of the crop then covers the space between rows which prevents further weed growth. This has many advantages:

Advantages to herbicide banding:

- Reduction by over 60% in quantity of herbicides applied
- Reduced production costs
- Reduced risk of contaminating waterways
- Reduced risk to human and environmental health
- Reduced risk of weeds developing resistance to herbicides

Herbicide banding of contact non selective herbicides can also be applied in between the rows with a hooded sprayer, specifically to kill resistant weeds between rows.

NEW TREATMENT PLANS

Registered solutions:

- Preplant incorporated (PPI) treatment of trifluralin (Treflan). **DO NOT apply** Treflan to carrots grown on muck soils.
- Preemergence (PRE) treatment of s-metolachol (Dual II Magnum) applied after planting, prior to carrot and weed emergence. Make only one application per year. Do not follow a preemergence application with a postemergence spray later in the season.
- Postemergence (POST) treatment of s-metolachlor (Dual II Magnum) applied to the 3-5 leaf stage of carrots and before the 2 leaf stage of weeds
- Postemergence (POST) treatment of metribuzin (Sencor 75 DF) applied when the 4th leaf is partially expanded on most carrot plants, followed by a second application, if necessary, when the fifth leaf is partially expanded (about 6 days after the first application). Use ONLY on carrots previously treated with preemergence application of linuron (1100 g ai/ha). DO NOT apply Sencor to carrots grown on muck soils. Sencor will not control weeds resistant to Group 5 herbicides (triazine resistant weeds).

Possible solutions available in the future:

- Preemergence (PRE) treatment of ethofumesate (Nortron)
- Preemergence (PRE) treatment of pendimethalin (Prowl)

- Preemergence (PRE) treatment of pyroxasulfon
- Postemergence (POST) treatment of oxyfluorfen (Goal)
- Postemergence (POST) treatment of acifluorfen (Blazer)
- Postemergence (POST) treatment of pendimethalin (Prowl)
- Postemergence (POST) treatment of pyroxasulfon

BMP FOR MIXED POPULATIONS OF RESISTANT RAGWEED OR PIGWEED

NON-SELECTIVE MOWING FOR CARROTS GROWN ON FLAT BEDS

Non-selective mowing can be done with a precision cutting weeder. This equipment is made up of a cutting unit based on the principle of a ban saw [an endless belt-like strip of steel, toothed along one or both edges and running uni-directionally between two pulleys]. While in function, the cutting unit is supported by two dead rolls lying over the seedbed in the inter-rows. The cutting height is governed by these dead rolls. It is possible to add or remove weight to the dead rolls by adjusting the tension of springs located on either side of the tractor. The cutting unit works over a 1.8 m wide raised seedbed with 3 rows, one of which is in the middle of the bed and the other two are set at 60 cm apart.



Caption: Precision Cutting unit



Caption: Precision cutting weeder used for non-selective mowing in carrots. A) Side view of precision cutting weeder, B) Cutting of carrot foliage above the growing point, C) dead rolls lying over the seedbed in the interrows, D) Cut carrot foliage at the 3 leaf stage.

This technique can be used only for carrots grown on flat beds and not on raised beds.

This technique cannot be used alone. It should be combined with broadcast preemergence linuron and herbicide banding to be effective.

Non-selective cutting at the 3 leaf stage of carrots will control pigweed and limit ragweed growth without affecting carrot yield.

For mowing to be effective the flat beds should be level and well compacted to ensure that the cutting height is as low as possible (~7cm).

Mowing is best done early in the morning when carrot petioles are turgid and can be cut neatly. If done during a warm spell or later during the day, petioles tend to be under water stress and will bend under the blades making cutting less effective.

Mowing speed should be reduced to avoid twisting of the cutting blade when weed populations have dense foliage.

Non-selective mowing at the 3 leaf stage of carrot should be combined with herbicide banding under a hooded sprayer.

Herbicide banding in between rows is integrated either before or after non-selective mowing depending on the weed population. If AIM is used as a non-selective contact herbicide, only one application per season is permitted.

There are two suggested methods of non-selective mowing for carrots grown on flat beds.

Option A - under high weed pressure

- 1) Broadcast preemergence linuron application after carrot seeding
- 2) At the 2 leaf stage of carrots- apply a non-selective contact herbicide; such as, AIM in between rows with hooded sprayer. At the 3 leaf stage of carrots non-selective mowing with a precision cutting weeder
- 3) 4 days after mowing, if needed, apply a non-selective contact herbicide; such as, AIM in between rows with a hooded sprayer

Option B – under low weed pressure

- 1) Broadcast preemergence linuron application after carrot seeding
- 2) At the 3 leaf stage of carrots non-selective mowing with a precision cutting weeder
- 3) 4 days after mowing apply a non-selective contact herbicide; such as, AIM in between rows with a hooded sprayer

Other options not Included in the above research

Now, there are other preemergence and postemergence herbicide options that have been registered. Please review the NEW TREATMENT PLANS section on page 9.

Commercial standard VS	Carrot yield			
Best management options	Total	Marketable	Cull	
	(T/ha)	(%)	(%)	
Commercial standard				
Linuron preemergence	177 4 ab	65,1 a	34,9 b	
Linuron postemergence	122.4 dD			
Option A - BMP				
Linuron preemergence				
AIM banded in between rows at carrot 2 leaf stage	129.8 a	62,7 a	37,3 ab	
Cutting at carrot 3 leaf stage				
Option B - BMP				
Linuron preemergence				
Cutting at carrot 3 leaf stage	114.3 ab	62,9 a	37,1 ab	
AIM banded in between rows applied 4 days after cutting		·		

Values within a column followed by the same letter are not significantly different

RESOURCES FOR ADDITIONAL HELP

www.weedinfo.ca

http://www.plant.uoguelph.ca/resistant-weeds/

http://www.omafra.gov.on.ca/IPM/english/index.html

http://wssa.net/

http://www.weedscience.org/summary/home.aspx

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