To Bury or Uproot?

Modelling Selectivity of Physical Weed Control in Sensitive Crops

Noelle A. Connors and Daniel C. Brainard, Michigan State University

Contact us at: brainar9@msu.edu

"To bury or uproot weeds in the style of Matisse" (DALL-E 2)

Introduction

Selectivity– the ability to kill weeds without killing the crop– is a challenge for in-row mechanical cultivation, especially in slow-growing crops like carrots (Fig 1).

Many physical weed control tools kill weeds primarily through uprooting or burial (Fig 2), yet relatively little is known about which mode of action is likely to be most selective for different crop-weed combinations and growth stages.

To gain insight into the optimal tool type and timing for cultivation given different weed-crop combinations, we adapted a model from Kurstjens et al. (2004) to predict "potential efficacy"—the greatest weed mortality attainable at a given level of crop mortality assuming an idealized tool.

Figure 1. Mustard and red amaranth surrogate weeds growing in carrots.

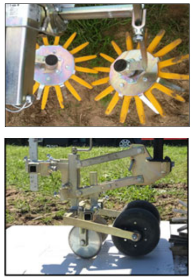

Figure 2. Mechanical cultivation tools that are thought to kill weeds primarily through uprooting or burial include (A) finger weeders and (B) hilling disks.

Objectives

1) Develop a model to predict the potential efficacy of mechanical cultivation tools that uproot or bury weeds.
2) Use the model to generate hypotheses regarding optimal tool type and timing, as well as the impacts of various cultural practices on potential efficacy.

Hypotheses

1) The predicted optimal mode of action (burial vs uprooting) and timing of mechanical cultivation varies with weed species.
2) Cultural practices that increase the relative height or anchorage force of crops relative to weeds impact predicted potential efficacy differently for different weed species.

Methods

Model Description

- Modified version of the 'selectivity model' of Kurstjens et al. (2004).

Key model inputs:

- Probability distributions of anchorage forces and heights of crops and weed as a function of age (e.g. Fig 6)
- Age of crop and weed (GDD; Tb = 5°C)
- Tool mode of action (uproot or burial)

Key model output

- "Potential efficacy" = maximum weed mortality attainable for a given level of acceptable crop mortality assuming idealized tools that can uproot or bury with precision at the optimal level.

Baseline model assumptions

- Plants die if (and only if) they have anchorage forces (or heights) less than the uprooting force (or burial depth) applied by the tool.
- The uprooting force (or burial depth) is set at the level corresponding to 5% carrot mortality.
- Idealized tools apply the uprooting force or burial depth with perfect precision and accuracy.
- Weeds and crops are the same age at the time of cultivation.

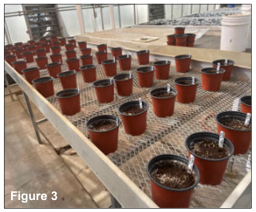

Figure 3

Figure 4

Examples of Model Applications in Carrots

Parameterization

- Heights and Anchorage forces of carrots and 5 weed species were measured at 3-4 day intervals for 3-4 weeks in pot studies in a greenhouse (Fig 3).
- Anchorage force was measured by clipping a force gauge (Alluris FMI-S30) to the plant shoot and recording the force required to uproot (Fig 4).

Plant species included:

- Carrots (*Daucus carota;* 'Bolero')
- Surrogate Weeds
  - Mustard (*Brassica juncea;* 'Mighty Mustard')
  - Amaranthus (*Amaranthus cruentus;* 'Red Spike')
- Weeds
  - Large crabgrass (*Digitaria sanguinalis;* DIGSA)
  - Common lambsquarters (*Chenopodium album;* CHEAL)
  - Giant foxtail (*Setaria faberi;* SETFA)

Modelling examples of impacts of cultural practices

- Stale seedbedding. The predicted impact of stale seedbedding on potential efficacy was modelled by setting the carrot age 100 GDD (approximately 7 days) ahead of the age of weeds.
- Seed quality. The predicted impact of seed-sizing (using only the largest fraction of seeds) on potential efficacy was modelled using anchorage force and height data of large vs small seeds of carrot ('Bolero') from Connors (2022).

Results

Crop and Weed Growth

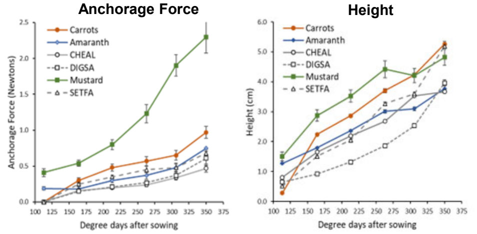

Figure 5. Height and anchorage forces of greenhouse grown carrots and 5 weed species.

Example of Probability Distribution of Anchorage Force and Height

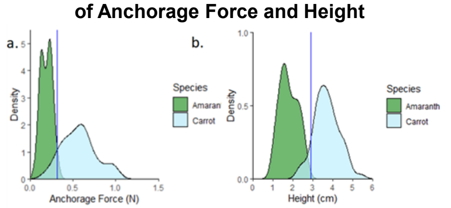

Figure 6. Probability density functions of (a) anchorage force and (b) height of carrot and red amaranth at 213 GDD (~ 2 weeks) after sowing. The vertical line shows the level of uprooting (a) or burial (b) corresponding to 5% carrot mortality.

Predicted Efficacy of Uprooting vs Burial

for 5 weeds in carrots assuming 5% carrot mortality

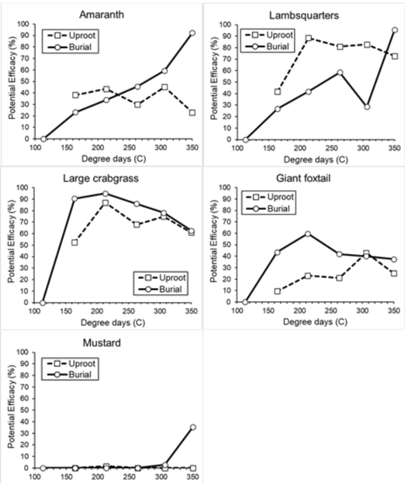

Figure 7. Predicted potential efficacy (weed mortality) of mechanical cultivation in carrots for 5 weed species over time for tools that uproot or bury.

Predicted Impact of Cultural Practices

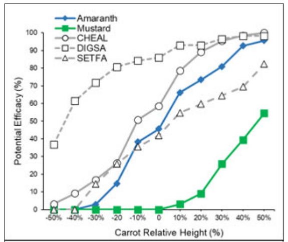

Figure 8. Effect of carrot height on potential efficacy of hilling at 263 GDD (~18 DAS). Heights are expressed as a percentage of the height of carrots ('Bolero') used in the baseline model.

Table 1. Effects of various cultural practices on carrot height and predicted potential efficacy of hilling at 263 GDD, assuming 5% carrot mortality.

		Predicted potential efficacy of hilling				
	Change in Carrot	Weeds			Surrogates	
Cultural Practice	height	CHEAL	DIGSA	SETFA	Amaranth	Mustard
	---%---	% mortality				
A None	0	60	85	42	45	0
B Carrot seed quality[1]	+12	84	92	55	67	4
C Stale seedbed[2]	+50	100	100	95	100	55
D B+C	+62	100	100	98	100	75

[1] Based on observation that large seed fraction of 'Bolero' resulted in 12% increase in height and 20% in anchorage force at 18 DAS (Connors, 2022).

[2] Based on assumption that stale seedbeding results in carrots that are 6 days older than weeds at the time of cultivation.

Summary and Conclusions

- Our model provides a relatively simple method for predicting the optimal mode of action (burial vs uprooting) and timing for mechanical cultivation for different weed-crop combinations.
- The model demonstrates that the optimal mode of action and timing of mechanical cultivation is likely to vary with weed and crop species.
- When applied to carrot-weed combinations, our model predicts that grass species (DIGSA and SETFA) are most effectively managed with hilling (burial) at 150-250 GDD after planting. In contrast, the broadleaf species CHEAL and amaranth are predicted to be most susceptible to uprooting at 150-250 GDD, and burial thereafter.
- The model also provides insight into the likely impact of various cultural practices on the efficacy of mechanical cultivation. For example, in carrots, the use of high quality seeds and stale seed bedding practices was predicted to improve the potential efficacy of hilling from 0-85% to 75-100% depending on weed species.
- The model provides a potentially useful tool for generating hypotheses to facilitate efficient identification of effective approaches for improving selectivity of mechanical cultivation.
- Future research that would improve the usefulness of the model includes: 1) parameterization of different weed-crop combinations under different soil conditions; 2) integration of tool variability into the model; 3) sensitivity analysis to evaluate the potential importance and implications of different assumptions.

References:

- Connors NA. 2022. Addressing Weed and Soil Management Trade-Offs in Vegetables Through Integrated Cultural and Mechanical Strategies (MS Thesis, Michigan State University).
- Kurstjens DAG. 2002. Mechanisms of selective mechanical weed control by harrowing. PhD Dissertation. Wageningen University. 156 p
- Kurstjens DAG, Kropff MJ, Perdock UD. 2004. Method for predicting selective uprooting by mechanical weeders from plant anchorage forces. Weed Sci 52: 123-132

Acknowledgements:

This research was funded primarily through a grant from the USDA-OREI Program (Award # 2018-51300-28426) in collaboration with Dr. Eric Gallandt at the University of Maine. Other sources of funding included the Michigan Carrot Research Committee, NCR-SARE Graduate Student Grant Program and Michigan State University AgBioResearch. We would also like to acknowledge thoughtful input and assistance from Daniel Priddy, Johanna Flies, Brandon Scott and Lily Arriaga.