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Volunteer potato interference in carrot

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Weed management systems in carrot are limited in part by a lack of fundamental understanding of crop–weed interactions. Irrigated field studies were conducted to quantify the effect of volunteer potato density and duration of interference on carrot yield and to determine relationships among weed density, duration of weed growth, and volunteer potato tuber production. A season-long volunteer potato density of 0.06 plants m^{-2} produced from 150 to 230 g tubers m^{-2} and resulted in an estimated 5% crop yield loss. At two volunteer potato plants m^{-2}, the same level of crop loss was estimated with a duration of interference of 430 growing degree days (GDD), a time at which the weed had already produced 130 g tubers m^{-2}. Volunteer potato height at the time of weed removal predicted carrot yield loss ($R^2 = 0.77$) and may be useful for timing of management strategies such as hand weeding. Functional relationships describing carrot–volunteer potato interactions provide simple information that is useful for developing weed management recommendations for carrot, a crop that relies on multiple tactics for managing weeds, and rotational crops that are negatively affected by persistence of volunteer potato.

Nomenclature: Volunteer potato, *Solanum tuberosum* L. 'Russet Burbank'; carrot, *Daucus carota* L. 'PS-104395'.

Key words: Competition, critical time of weed removal, critical weed-free period, economic threshold, yield loss.

Multiple tools are a necessity for managing weeds in carrot, a crop that was the most sensitive to weed interference of 25 crops reviewed by Van Heemst (1985). Damages inflicted by weeds in carrot include reduced yields, improper root formation, and interference with harvest operations (Bell et al. 2000; Bellinder et al. 1997). Because few herbicides are registered for use in carrot, growers employ a combination of alternate methods including soil fumigation with metham, the stale seedbed technique, mechanical cultivation, and hand weeding (Anonymous 2002). High crop seeding rates and narrow rows limit the use of mechanical cultivation to furrows between beds. Therefore, hand weeding is an important tactic employed after crop emergence to control weeds escaping all other tactics.

Volunteer potato is a weed in potato-growing regions where winter temperatures are not cold enough to kill tubers left in the ground after harvest. Immediately following potato harvest, Thornton et al. (2001) observed 6 to 45 tubers m^{-2} ranging in size from 9 to 99 g $tuber^{-1}$. No herbicides are currently registered for use in carrot that suppress volunteer potato. Wick application of a nonselective herbicide over carrot rows has been found to reduce volunteer potato tuber production by 60%, but a significant number of weeds survived this experimental treatment (Boydston and Seymour 1996). Hand weeding is used to control volunteer potato after crop emergence at an average expense of $200 ha^{-1} in Washington (T. Crosby, personal communication).

Weed management systems in vegetables could be improved with a better understanding of crop–weed interactions. As an example, a quantitative understanding of the effect of weed density on carrot yield would help to determine when hand weeding is cost effective, particularly when few weeds are observed. Similarly, decisions on timing of weed management tactics could be optimized if information was available on the critical time of weed removal in carrot. Volunteer potato tuber production also should be considered because the weed persists and causes losses in crop yield or quality in rotational crops including field corn (Boydston 2001), green peas, onion (Williams et al. 2005), snap beans, and sweet corn. Moreover, volunteer potato is a host to serious potato diseases, influencing disease incidence beyond field borders and into future years (Mojtahedi et al. 2003; Thomas 1983).

Little is known about how weeds influence carrot yield, and the dynamics of volunteer potato tuber production in carrot have not been reported. Field research was conducted to (1) quantify the effect of volunteer potato density on carrot yield, (2) characterize the relationship between weed density and volunteer potato tuber production in carrot, (3) determine the critical time for weed removal, and (4) quantify the temporal dynamics of volunteer potato tuber production when grown in carrot.

Materials and Methods

Field Site

Field experiments were conducted in 2003 and 2004 near Prosser, WA, on a Warden silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids). Experimental sites were moldboard-plowed in the fall, seeded to winter wheat, disked or rototilled in early March, fertilized according to soil-test recommendations, and cultipacked before planting. 'Russet Burbank' whole seed potato tubers (65 ± 8 g) were planted on April 10, 2003, and April 13, 2004, to simulate volunteer potato. Tubers were planted 10 cm deep in two rows spaced 86 cm apart. Carrot cultivar, 'PS-140395',[1] was planted at 704,000 seed ha^{-1} in two seed lines spaced 10 cm apart on beds spaced 56 cm between furrows. Four-bed plots were used, with inside beds centered over potato rows. Dates of carrot planting were April 19, 2003, and April 22, 2004. Crop and weed emergence was assessed by counting emerged plants every other day along 1 m of bed. Production practices used in these studies were typical for sprinkler-irrigated carrot in the inland Pacific Northwest region of the United States.

Weed Density Study

Six weed density treatments were established: 0, 0.5, 1, 2, 4, and 8 potato plants m^{-2}. The experimental design was a randomized complete block with four replications. Experimental units measured 7.6 m in length by 2.2 m in width. Experimental sites were kept free of weeds other than volunteer potato by hand weeding and herbicides. Herbicide applications included a PRE application of 1.1 kg linuron ha^{-1} and a postplant application of 1.1 kg glyphosate ha^{-1} before potato or carrot emergence. POST applications of 0.3 kg sethoxydim ha^{-1} were applied May 24 and June 24, 2004.

Carrots were harvested from the center two beds over 6 m of each plot on August 11 to August 13, 2003, and August 13 to August 17, 2004. Within 1 d of carrot harvest, three (2003) or four (2004) volunteer potato plants per plot were randomly selected and examined for tuber number and fresh tuber biomass. Final volunteer potato tuber number and biomass were calculated on an area basis by multiplying mean individual tuber production (number or mass) by plant density.

Relative yield was calculated within each block as yield at a given volunteer potato plant density (*N*) divided by weed-free yield within the block. Yield loss was calculated as unity minus relative yield. A rectangular hyperbola equation (Cousens 1985) was fit to carrot yield loss in each year:

$$Y_l = \frac{I \times N}{1 + \frac{I \times N}{A}} \qquad [1]$$

where Y_l is percent of yield loss, *I* is percentage yield loss as weed density approaches zero, *N* is weed density (expressed in plants m^{-2}), and *A* is maximum yield loss. Parameter estimates were determined using an iterative least-squares procedure (Sigma Plot 8.0[2]). Lack of fit was assessed by reporting standard errors of parameter estimates, plotting predicted and observed values, and calculating R^2 values. The extra sum of squares principle for nonlinear regression analysis (Ratkowsky 1983) was employed to evaluate the similarity of parameter estimates among years. Comparisons were made by calculating a variance ratio of individual and pooled residual sums of squares and performing an *F* test described by Lindquist et al. (1996). If parameter estimates were constant across years, data were pooled. The significance of all statistical tests was $\alpha = 0.05$. The same analytical approach was used to relate final tuber density and biomass to initial weed density.

Yield loss parameter estimates were used to determine the volunteer potato plant density, hereafter called threshold weed density, needed to result in levels of yield loss of 2.5, 5, and 10%. Model parameter estimates of final tuber density and biomass were then used to calculate volunteer potato tuber production for each threshold weed density.

Time of Weed Removal Study

The experimental design was a randomized complete block with four replications and plots measured 6 m in length and 2.2 m in width. A volunteer potato density of two plants m^{-2} was established and maintained in each plot, and eight durations of interference treatments were tested. Increasing durations of weed interference were accomplished by delaying volunteer potato shoot removal time according to carrot leaf number and was designated as follows: removal at carrot emergence (weed-free), or at 2-, 4-, 6-, 8-, 10-, or 12-leaf. In addition, a treatment was included in which volunteer potato was allowed to grow for the entire season (no removal). Once the end of the interference duration was reached and volunteer potato shoots removed, the treatment was kept weed-free for the rest of the season. Interference was ended by clipping potato shoots 2 cm above the soil surface and injecting 5 ml of a 10% (v/v) solution of glyphosate with a syringe into the stems. Any regrowth was removed by hand on a weekly basis. Three (2003) or four (2004) plants per plot were flagged at the end of interference durations. At carrot harvest, tubers produced by these plants were dug and measured for tuber number and fresh tuber biomass. Experimental site maintenance, crop yield data collection, and tuber production estimates were identical to the preceding study with the exception of carrot harvest on August 11 to August 13, 2003.

Relative yield was calculated within each block as yield at a given duration of weed interference treatment divided by weed-free yield within the block and expressed as a percentage. Growing degree days (GDD) accumulated after 50% carrot and potato emergence were calculated using a base temperature of 7.2 C. Minimum and maximum daily temperatures were obtained from an automated weather station located within 1 km of experiments.

Logistic (Knezevic et al. 2002), rectangular hyperbolic (Cousens 1985), or sigmoidal equations were used to describe relationships between duration of weed interference, weed height, and thermal time to crop yield loss and volunteer potato tuber production. Procedures for fitting data, testing lack of fit, and pooling data across years were the same as described in the preceding study. Model parameter estimates of crop yield loss were used to determine the duration of interference and weed height needed to result in predetermined levels of yield loss of 2.5, 5, and 10%. Model parameter estimates of final tuber density and biomass were then used to calculate volunteer potato tuber production for each duration of interference resulting in a predetermined level of yield loss.

Results and Discussion

Weed Density Study

Typically, weeds that emerge before the crop are controlled with a nonselective herbicide; therefore, weeds found in carrot have primarily emerged with or after the crop. In this study, crop and weed emerged at the same time (data not shown). Weed-free carrot yields were 41.4 and 43.5

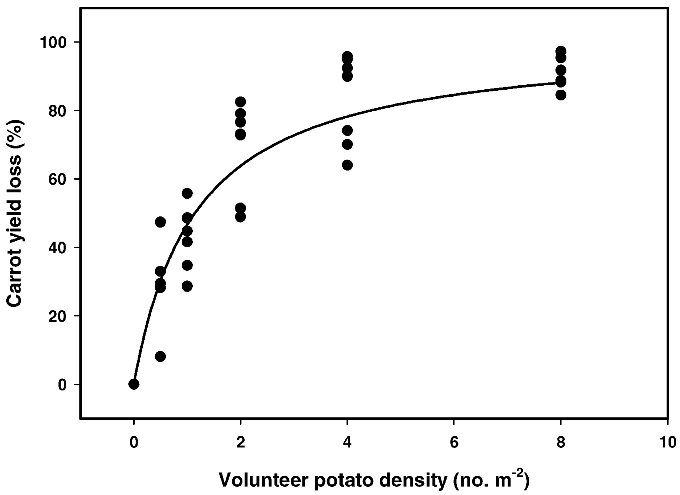

FIGURE 1. Percent carrot yield loss as a function of volunteer potato plant density in 2003 and 2004. The regression equation is yield loss = $(87 \times x)/1 + (87 \times x)/100$ (R^2 = 0.88).

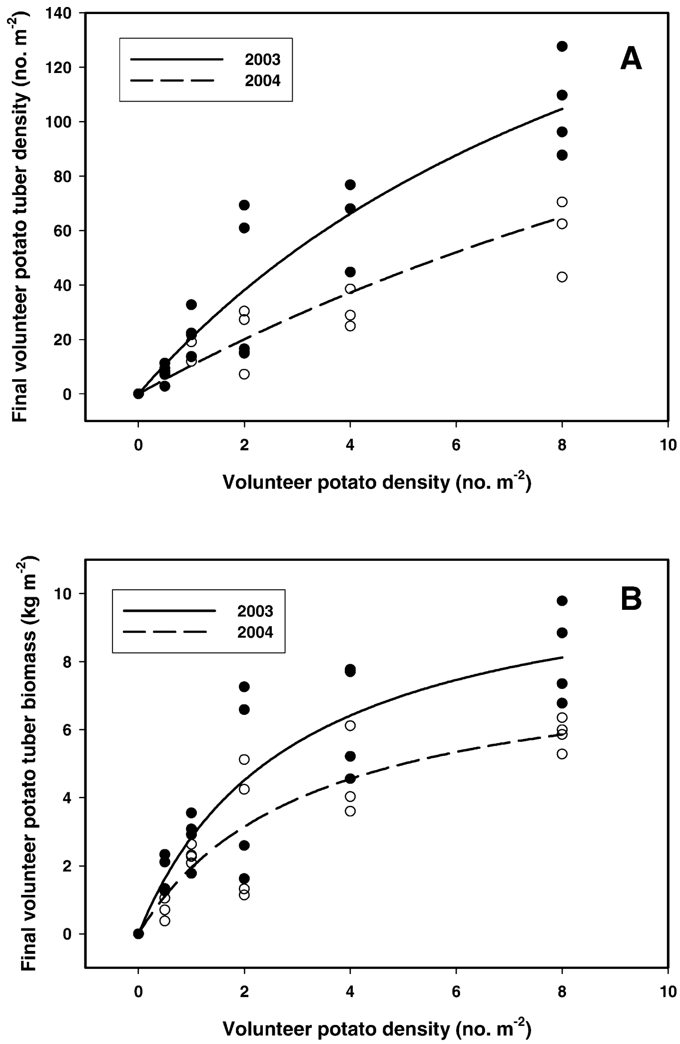

FIGURE 2. Effect of initial volunteer potato plant density in carrot on (A) final tuber density, with regression equations: 2003 final tuber density = $(22 \times x)/1 + (22 \times x)/250$ (R^2 = 0.88); and 2004 final tuber density = $(11 \times x)/1 + (11 \times x)/255$ (R^2 = 0.86); and (B) final tuber biomass, with regression equations: 2003 final tuber biomass = $(3.8 \times x)/1 + (3.8 \times x)/11.1$ (R^2 = 0.82); and 2004 final tuber density = $(2.6 \times x)/1 + (2.6 \times x)/8.2$ (R^2 = 0.84).

megatons (Mt) ha^{-1} in 2003 and 2004, respectively (data not shown).

Volunteer potato competition resulted in almost complete crop loss at relatively low weed densities, and maximum yield loss was 100% (Figure 1). The F test for comparing nonlinear models indicated carrot yield response to weed density was constant between years (P = 0.896); therefore, data were pooled. Typically, carrot suffers complete yield loss when weeds are allowed to compete the entire growing season (Van Heemst 1985). William and Warren (1975) reported from 39 to 50% carrot yield loss due to full-season interference from purple nutsedge (*Cyprus rotundus* L.). The response of carrot yield to weed density has not been reported previously.

Yield losses were observed with relatively few weeds. Volunteer potato plant density at 0.03, 0.06, and 0.13 m^{-2} resulted in estimated yield losses of 2.5, 5, and 10% (Table 1). Densities of volunteer potato emerging in the spring in Washington are as high as 10 plants m^{-2} (Thornton et al. 2001). Effective volunteer potato management systems are essential to carrot production where the species are grown in rotation.

The rectangular hyperbolic model adequately described volunteer potato tuber production as a function of initial weed density, with R^2 ranging from 0.82 to 0.88 (Figures 2A and 2B). The F test for comparing nonlinear models indicated that volunteer potato tuber production was not constant between years; therefore, tuber density (P = 0.001) and biomass (P = 0.001) data are reported by year. At low weed densities, the number of tubers produced was estimated to be twofold higher in 2003 (I = 22) relative to 2004 (I = 11) (Figure 2A). Tuber biomass was also higher in 2003, relative to 2004 (Figure 2B). A large population of Colorado potato beetle (*Leptinotarsa decemlineata* Say)

TABLE 1. Volunteer potato plant density resulting in three levels of carrot yield loss. Volunteer potato tuber production for each threshold weed density is included. Standard errors are reported in parentheses.

Carrot yield loss	Threshold weed density resulting in yield loss	Volunteer potato tuber production as a result of threshold weed density: Tuber density 2003	Tuber density 2004	Tuber biomass 2003	Tuber biomass 2004
%	No. m^{-2}	No. m^{-2}		g m^{-2}	
2.5	0.03 (< 0.01)	0.7 (< 0.1)	0.5 (< 0.1)	110 (10)	80 (4)
5.0	0.06 (0.01)	1.4 (< 0.1)	1.0 (< 0.1)	230 (10)	150 (10)
10	0.13 (0.01)	2.9 (0.1)	2.0 (0.1)	470 (20)	320 (20)

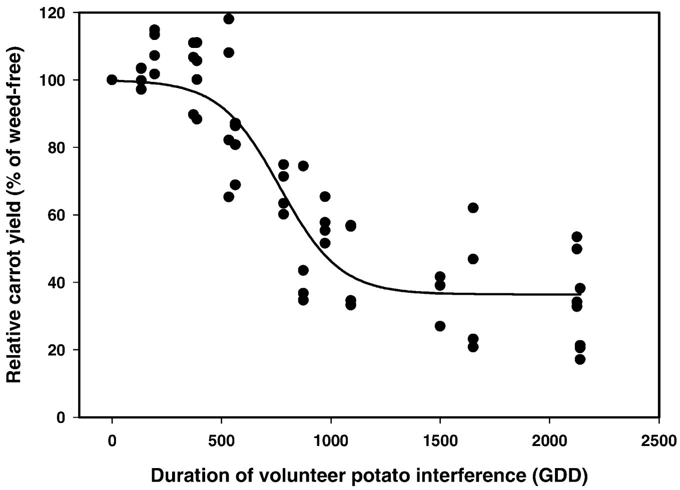

Figure 3. Relative carrot yield as a function of duration of volunteer potato interference in 2003 and 2004. Regression equation is relative yield = 1/exp([0.007 × {x − 705}] + 1.57) +([{1.57 − 1}/1.57] × 100) (R^2 = 0.85). Growing degree day (GDD) base temperature was 7.2 C.

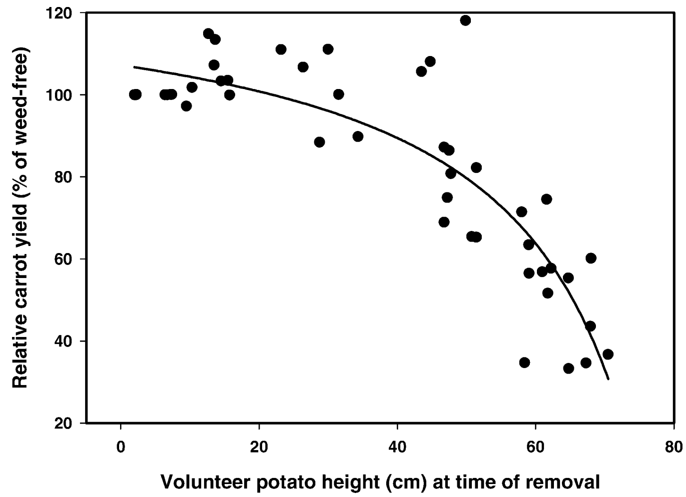

Figure 4. Relative carrot yield as a function of volunteer potato height at the time of weed removal in 2003 and 2004. Regression equation is relative yield = (107 × [{1 − 0.234} × x])/(100 × [{1 + 0.234} × x]/−21.4) (R^2 = 0.77).

moved into the experimental area in 2004 and defoliated many volunteer potato plants. Colorado potato beetle has been previously found to significantly reduce volunteer potato tuber production (Boydston and Williams 2005; Williams et al. 2004b).

Volunteer potato tuber production was high, even at weed densities that resulted in subtle carrot yield losses. For instance, a threshold weed density of 0.06 plants m^{-2} produced from 1.0 to 1.4 tubers m^{-2} and resulted in an estimated 5% yield loss (Table 1). Even a 2.5% yield loss threshold weed density of 0.03 plants m^{-2} resulted in 80 to 110 g m^{-2} of new tubers. Such levels of tuber production are comparable to or less than volunteer potato tuber density and biomass following several herbicide and cultivation treatments in field corn (Boydston 2001), onion (Boydston and Seymour 2002), or noncrop studies (Williams and Boydston 2002). Without supplemental tuber mortality, volunteer potato can persist and remain at levels high enough to cause carrot yield losses even when preceded by crops with relatively effective herbicides and cultivation.

Time of Weed Removal Study

Crop and weed emergence were simultaneous and weed-free yields were 55.0 and 52.4 Mt ha^{-1} in 2003 and 2004, respectively (data not shown). Increasing the duration of volunteer potato interference significantly reduced carrot yield (Figure 3). The *F* test for comparing nonlinear models indicated carrot response to the duration of the volunteer potato interference was consistent between years (P = 0.200); therefore, data were pooled. Carrot tolerated volunteer potato well initially, but tolerance dropped precipitously beyond some 500 GDD after crop emergence. Consequently, the critical time for weed removal of volunteer potato in carrot begins early. Estimated yield losses of 2.5% occurred at 329 GDD when carrot had 3.5 leaves (Table 2). Five percent yield loss occurred at some 430 GDD when carrot had 4.5 leaves, and 10% yield loss was estimated for 6-leaf carrot. This work is the first to report the critical time for weed removal in carrot.

A relationship was observed between volunteer potato height at the time of weed removal and carrot yield (Figure 4). The *F* test for comparing nonlinear models indicated carrot response to volunteer potato height was consistent between years (P = 0.998); therefore, data were pooled. This relationship could provide further information to assist in determining the timing of a weed management tactic. For instance, 5% yield loss was observed when volunteer potato was allowed to reach 32 cm before removal (Table 2). Hand weeding of volunteer potato is most effective when the maternal tuber is removed with the shoot, which improves as hand weeding is delayed. However, new tubers are formed and may remain in the soil when hand weeding is

Table 2. Duration of interference, carrot leaf number, and volunteer potato height for three levels of carrot yield loss. Volunteer potato tuber production for each duration of interference is included. Standard errors are reported in parentheses.

Carrot yield loss	Duration of interference resulting in yield loss	Carrot leaf number at the time of yield loss	Volunteer potato height at the time of yield loss	Volunteer potato tuber production as a result of duration of interference: Tuber density 2003	Tuber density 2004	Tuber biomass
%	GDD[a]	No. $plant^{-1}$	cm	No. m^{-2}	No. m^{-2}	g m^{-2}
2.5	329 (74)	3.5	27 (4)	0.7 (0.3)	2.2 (1.3)	70 (20)
5.0	430 (63)	4.5	32 (3)	2.0 (0.7)	7.1 (2.7)	130 (30)
10	537 (51)	6.0	39 (3)	5.1 (1.3)	15.4 (2.1)	230 (40)

[a] Abbreviations GDD, growing degree day.

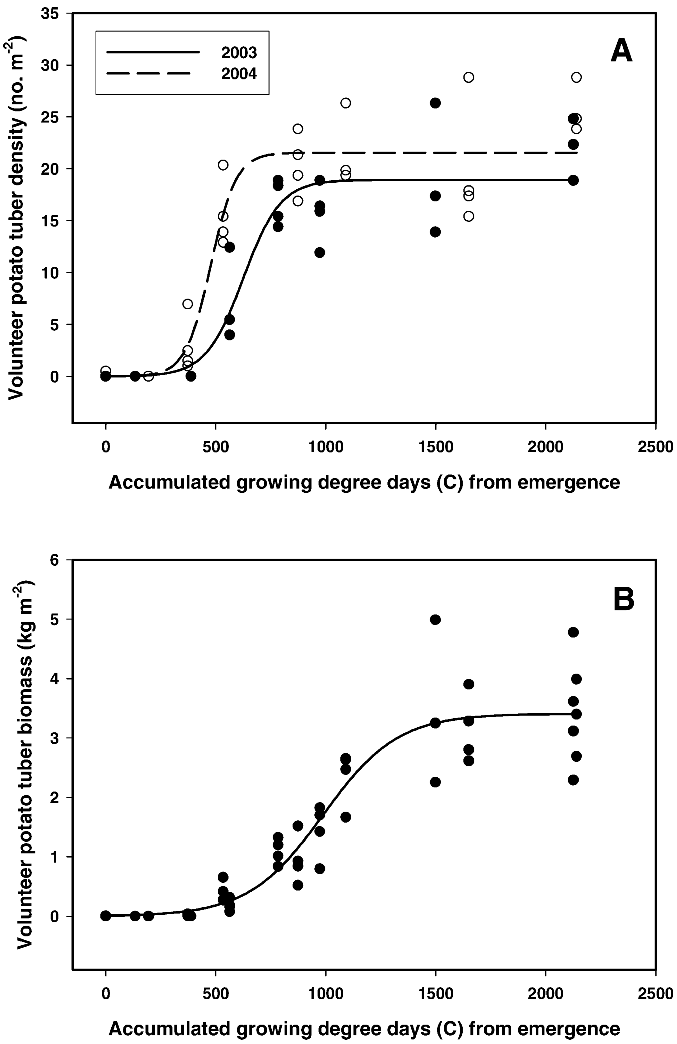

FIGURE 5. Effect of accumulated growing degree days after emergence in carrot on (A) volunteer potato tuber density, with regression equations: 2003 tuber density = 18.9/1 + exp(−[x − 626]/85.0) (R^2 = 0.90); and 2004 tuber density = 20.5/1 + exp(−[x − 478]/57.7) (R^2 = 0.90) and (B) volunteer potato tuber biomass, with regression equation tuber biomass = 3.4/1 + exp(−[x − 988]/[1 + 169]) (R^2 = 0.90). Growing degree day GDD base temperature was 7.2 C.

delayed. Data presented here could be used to develop management guidelines specific to volunteer potato development by estimating how long hand weeding can be delayed before carrot yield loss occurs.

Volunteer potato had significant tuber production while growing in carrot. Regression parameter estimates of final tuber density were not constant between years ($P < 0.001$); therefore, data on tuber number were not pooled. Two volunteer potato plants m^{-2} produced an estimated 9.5 and 10.3 tubers m^{-2} by 626 and 478 GDD, respectively in 2003 and 2004 (Figure 5A). The F test comparing nonlinear models indicated that tuber biomass was consistent between years ($P = 0.763$); therefore, tuber biomass data were pooled. Two volunteer potato plants m^{-2} produced some 3.4 kg of tubers m^{-2} by the time of carrot harvest, with 50% of tuber mass produced by 988 GDD (Figure 5B). The relatively short time necessary for volunteer potato growing in carrot to produce tubers may have implications for deploying weed management tactics after crop emergence. Further research is necessary to determine the maturity and persistence of tubers produced early in the season, particularly as a function of weed management tactic (e.g., shoot removal versus herbicide application).

Despite the poor competitive ability of carrot, the crop appears to have greater crop tolerance and suppressive ability of volunteer potato than onion. Williams et al. (2004a) reported nearly twofold higher onion yield losses at low weed densities compared with carrot yield losses observed here. Crop yield loss due to duration of volunteer potato interference occurs 2 to 3 wk later in carrot, relative to onion (Williams et al. 2005). Finally, volunteer potato tuber production, as influenced by initial weed density and accumulated GDD, was considerably higher in onion (Williams et al. 2004a, 2005) relative to estimates of weed fecundity reported here in carrot. Knowledge of differences in rotational crops' competitive ability is important to recognize when developing integrated weed management (IWM) systems (Cardina et al. 1999).

Implications for IWM

Few herbicides are available to manage weeds in carrot (Jensen et al. 2004), and none suppress volunteer potato in the United States. Leroux et al. (1996) demonstrated the importance of crop rotation in managing weeds when no herbicides are available. Nighttime soil cultivation and intrarow brush weeding has promise in two- to three-leaf carrot (Fogelberg 1999), but the extent to which these tactics suppress volunteer potato is unknown. In the United States, hand weeding remains the only method of controlling emerged volunteer potato in carrot rows.

Future weed management systems in carrot that reduce production costs and dependence on hand weeding will likely require multitactic approaches. Ideally more tubers could be removed during potato harvest to reduce the density of volunteer potatoes emerging in subsequent crops. This research compliments previous research because volunteer potato persists in most crops (Boydston 2001; Boydston and Seymour 2002; Perombelon 1975; Williams et al. 2004a). Williams and Boydston (2005) found ethofumesate and prometryn selectively suppress volunteer potato in carrot. Herbivory from the Colorado potato beetle enhances suppression of sublethal herbicide use (Boydston and Williams 2005; Williams et al. 2004b). Soil fumigation, although primarily used to control nematodes and soil pathogens, greatly reduces the number of viable potato tubers (Boydston and Williams 2003). Given the current state of weed management technology in carrot, improved weed management systems will likely target several aspects of the life cycle of volunteer potato with multiple tactics used during weed growth.

Sources of Materials

[1] Carrot cultivar, 'PS-140395', Singulaire 785, Stanhay Webb Ltd., Houghton Road, Grantham, Lincs, NG31 6JE, U.K.

[2] SigmaPlot 8.0, SigmaPlot 2002 for Windows, Version 8.02. SPSS Inc., 444 North Michigan Avenue, Chicago, IL 60611.

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Literature Cited

Anonymous. 2002. Pacific Northwest Weed Management Handbook. Corvallis, OR: Oregon State University. 420 p.

Bell, C. E., B. E. Boutwell, E. J. Ogbuchiekwe, and M. E. McGiffen, Jr. 2000. Weed control in carrots: the efficacy and economic value of linuron. Hortscience 35:1089–1091.

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 Technol. 11:235–240.

Boydston, R. A. 2001. Volunteer potato (*Solanum tuberosum*) control with herbicides and cultivation in field corn (*Zea mays*). Weed Technol. 15: 461–466.

Boydston, R. A. and M. D. Seymour. 1996. Volunteer potato control in carrots with glyphosate. WSWS Res. Prog. Rep. p. 22.

Boydston, R. A. and M. D. Seymour. 2002. Volunteer potato (*Solanum tuberosum*) control with herbicides and cultivation in onion (*Allium cepa*). Weed Technol. 16:620–626.

Boydston, R. A. and M. M. Williams, II. 2003. Effect of soil fumigation on volunteer potato (*Solanum tuberosum*) tuber viability. Weed Technol. 17:352–357.

Boydston, R. A. and M. M. Williams, II. 2005. Managing volunteer potato (*Solanum tuberosum*) in field corn with mesotrione and arthropod herbivory. Weed Technol. 19:443–450.

Cardina, J., T. M. Webster, C. P. Herms, and E. E. Regnier. 1999. Development of weed IPM: levels of integration for weed management. Pages 239–267 *in* D. D. Buhler, ed. Expanding the Context of Weed Management. New York: Hawthorn Press.

Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. Appl. Biol. 107:239–252.

Fogelberg, F. 1999. Night-time soil cultivation and intra-row brush weeding for weed control in carrots (*Daucus carota* L.). Biol. Agric. Hortic. 17: 31–45.

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

Knezevic, S. Z., S. P. Evans, E. E. Blankenship, R. C. Van Acker, and J. L. Lindquist. 2002. Critical period for weed control: the concept and data analysis. Weed Sci. 50:773–786.

Leroux, G. D., D. L. Benoît, and S. Banville. 1996. Effect of crop rotations on weed control, *Bidens cernua* and *Erigeron canadensis* populations, and carrot yields in organic soils. Crop Protect. 15:171–178.

Lindquist, J. L., D. A. Mortensen, S. A. Clay, R. Schmenk, J. J. Kells, K. Howatt, and P. Westra. 1996. Stability of corn (*Zea mays*)–velvetleaf (*Abutilon theophrasti*) interference relationships. Weed Sci. 44:309–313.

Mojtahedi, H., R. A. Boydston, P. E. Thomas, J. M. Crosslin, G. S. Santo, E. Riga, and T. L. Anderson. 2003. Weed hosts of *Paratrichodorus allius* and tobacco rattle virus in the Pacific Northwest. Am. J. Potato Res. 80:379–385.

Perombelon, M.C.M. 1975. Observations on the survival of potato groundskeepers in Scotland. Potato Res. 18:205–215.

Ratkowsky, D. A. 1983. Nonlinear Regression Modeling: A Unified Practical Approach. New York: Marcel Dekker. Pp. 135–153.

Thomas, P. E. 1983. Sources and dissemination of potato viruses in the Columbia Basin of the Northwestern United States. Plant Dis. 67: 744–747.

Thornton, R. E., G. D. Newberry, D. Joy, G. Hyde, and T. Schotzko. 2001. Potato volunteer project. Pages 189–239 *in* Progress Reports 2001. Moses Lake, WA: Washington State Potato Commission.

Van Heemst, H.D.J. 1985. The influence of weed competition on crop yield. Agric. Syst. 18:81–93.

William, R. D. and G. F. Warren. 1975. Competition between purple nutsedge and vegetables. Weed Sci. 23:317–323.

Williams, M. M., II and R. A. Boydston. 2002. Effect of shoot removal during tuberization on volunteer potato (*Solanum tuberosum*) tuber production. Weed Technol. 16:617–619.

Williams, M. M., II and R. A. Boydston. Alternative to hand weeding volunteer potato (*Solanum tuberosum*) in carrot (*Daucus carota*). Weed Technol. 19:1050–1055.

Williams, M. M., II, C. V. Ransom, and W. M. Thompson. 2004a. Effect of volunteer potato density on bulb onion yield and quality. Weed Sci. 52:754–758.

Williams, M. M., II, C. V. Ransom, and W. M. Thompson. 2005. Duration of volunteer potato (*Solanum tuberosum*) interference in bulb onion. Weed Sci. 53:62–68.

Williams, M. M., II, D. B. Walsh, and R. A. Boydston. 2004b. Integrating arthropod herbivory and reduced herbicide use for weed management. Weed Sci. 52:1018–1025.

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