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Volunteer Potato Density Influences Critical Time of Weed Removal in Bulb Onion

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Volunteer potato is highly competitive with onion and few control tactics are effective for removing this weed from an onion crop. Both volunteer potato density and duration of interference reduce onion yield, but the interaction of these factors is unknown. Field trials were conducted in 2003 in Idaho, Oregon, and Washington to determine the influence of volunteer potato density on the critical time of weed removal (CTWR) in onion. Yield losses of 2.5, 5.0, and 10% were estimated to occur at 534, 654, and 830 growing degree days (GDD) after onion emergence, respectively, with a volunteer potato density of 0.5 plants/m^2. At 2.0 volunteer potato plants/m^2, yield losses of 2.5, 5.0, and 10% were estimated to occur at 388, 481, and 598 GDD after onion emergence, respectively. Volunteer potato at 2.0 plants/m^2 had to be removed at least one onion leaf stage sooner, compared to a weed density of 0.5 plants/m^2, to avoid yield loss. Yield loss due to volunteer potato density or duration of interference was greatest among jumbo, colossal, and supercolossal market grades ($P \leq 0.1$). Lowering potato tuber density in crops preceding onion will extend the critical time for weed removal and reduce the risk of crop loss.

Nomenclature: Volunteer potato, *Solanum tuberosum* L. 'Russet Burbank' and 'Ranger Russet'; Onion, *Allium cepa* L. 'Pinnacle' and 'Vaquero'.

Key words: Competition, critical period of weed control, groundkeeper, vegetable.

The critical time of weed removal is defined as the maximum length of time early-season weed interference can be tolerated by the crop before the crop becomes subjected to yield reduction. Knowledge of CTWR can assist practitioners in developing weed management systems by providing useful information on the temporal dynamics of crop susceptibility to weed interference. Highly competitive crops, such as wheat, often have a relatively long CTWR, whereas most small-seeded vegetable crops have a relatively short CTWR (Van Heemst 1985). As the CTWR shortens, timeliness in weed management intervention becomes increasingly important.

Bulb onion, hereafter called *onion*, is an important crop in western United States, where it is often grown in rotation with potato. Onion is highly susceptible to weed interference (Bleasdale 1959; Wicks et al. 1973). The critical timing of weed removal begins between the two- and four-leaf stage of onion for most annual weeds (Dunan et al. 1996; Shadbolt and Holm 1956) and sooner when weed emergence precedes crop emergence (Dunan et al. 1999; Williams et al. 2005). Volunteer potato density also influences onion yield, with complete yield loss observed at 4 plants/m^2 or more (Williams et al. 2004). Dunan et al. (1996) reported an interaction between duration of interference and weed load, where weed load was a function of density of annual weeds and their competitive abilities.

Volunteer potato is highly competitive with bulb onion, is difficult to control with currently registered herbicides (Boydston and Seymour 2002), and serves as a source of inoculum for serious disease, insect, and nematode pests of potato (Ellis 1992; Thomas 1983). Volunteer potato originates from potato tubers remaining in the field following commercial potato harvest, with densities as high as 30 tubers/m^2 (Lumkes 1974; Lutman 1977; Perombelon 1975). Tubers can persist if winter temperatures are mild or if the tubers are buried deep enough to avoid lethal exposure to cold temperatures (Lutman 1977). Tubers surviving overwinter volunteer in subsequent crops and volunteer potato density is affected by interactions among winter temperatures, tillage practices, and tuber depth (Thornton et al. 2001). Growers suppress volunteer potato in onion most commonly with postemergence herbicides (Boydston and Seymour 2002); however, yield losses are common by the time onions reach an appropriate crop growth stage for herbicide application (Dunan et al. 1996; Williams et al. 2005).

A more complete understanding of the interaction between the effects of volunteer potato density and duration of interference on onion yield is needed. Therefore, the objective of this work was to quantify the influence of volunteer potato density on the duration of weed interference in onion and CTWR.

Materials and Methods

Irrigated field experiments were conducted at Parma, ID, Ontario, OR, and Prosser, WA in 2003. Onions were planted 2 cm deep with the use of a seeder equipped with four planting shoes (one shoe per row) spaced 56 cm apart, with each shoe configured to plant two lines spaced 7.6 cm apart. Within 1 d of onion planting, whole potato tubers, averaging 59 g/tuber, were planted to simulate volunteer potatoes. Potato tubers were hand planted 15 cm deep between the two

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Table 1. Potato and onion varieties, planting dates and configurations, soil properties, and emergence dates for experiments established near Parma, ID, Ontario, OR, and Prosser, WA in 2003.

Location	Potato variety	Potato planting date	Onion variety	Onion planting date	Onion planting density	Soil type[a]	Organic matter	pH	Potato emergence	Onion emergence
					seeds/ha		%			
Idaho	Ranger Russet	April 15	Vaquero	April 16	391,200	Greenleaf silt loam	1.1	7.6	May 12	May 9
Oregon	Russet Burbank	April 11	Vaquero	April 11	380,800	Owyhee silt loam	2.0	8.1	May 12	April 30
Washington	Russet Burbank	April 22	Pinnacle	April 23	462,600	Warden silt loam	1.1	7.2	May 22	May 21

[a] Greenleaf silt loam (fine–silty, mixed, superactive, mesic Xeric Calciargids); Owyhee silt loam (course–silty, mixed, mesic Xerollic Camborthids); Warden silt loam (coarse–silty, mixed, superactive, mesic Xeric Haplocambids).

onion lines of the center two rows. Tubers were spaced equidistantly within each row. Additional details on planting, emergence, and site characteristics are provided in Table 1.

The experimental design was a randomized complete block with four replications per treatment and plots measured 2.2 m (width of four rows, each with two onion lines) by 7.5 m. Two volunteer potato densities (0.5 and 2.0/m^2) were established in eight durations of interference treatments. Increasing durations of weed interference were accomplished by delaying volunteer potato removal time according to onion leaf number in weed-free plots and was designated as follows: removal at onion emergence (weed-free), or at one-, two-, three-, four-, six-, or eight-leaf. In addition, a treatment was included in which volunteer potato was allowed to grow for the entire season (no removal). Interference duration was ended, depending upon the treatment, by clipping potato shoots 2 cm above the soil surface and brushing on a 5% solution of glyphosate or fluroxypyr to shoot stubble. Potatoes that produced new leaves were immediately retreated until growth stopped.

Experiments were kept free of weeds, except for potatoes, by hand weeding and preemergence applications of 6.7 kg ai DCPA/ha and 1.0 kg ai pendimethalin/ha, and two post-emergence applications of 0.2 kg ai sethoxydim/ha at one-leaf and two-leaf stage of onion. Onions were furrow (Idaho and Oregon) or sprinkler irrigated (Washington) and fertilized according to soil tests and university recommendations (Pelter et al. 1992).

Following crop senescence, onions from the center 6 m (Idaho and Washington) or entire length (Oregon) of each plot were counted and hand harvested September 18, September 22, and September 10, 2003 at Idaho, Oregon, and Washington, respectively. On the basis of maximum onion bulb diameter, bulbs were sorted by market grades, including small (<5.7 cm, i.e., nonmarketable), medium (5.7 to <7.6 cm), jumbo (7.6 to <10.2 cm), colossal (10.2 to <10.8 cm), and supercolossal (≥10.8 cm).[1] Bulb masses of each market grade were recorded.

Statistical Analysis. Weed-free onion stand, total yield, and yield of each marketable grade were tested for homogeneity of variances, and assumptions of homoscedasticity and normality were met. Means were compared with the use of protected LSD tests (NCSS 2000[2]; SYSTAT 11[3]).

Relative onion yield at each weed density was calculated within each block as yield at a given duration of weed interference treatment divided by weed-free yield within that block and expressed as a percentage. Growing degree days (GDD) accumulated after 50% onion and potato emergence were obtained with the use of a base temperature of 7.2 C (Dunan et al. 1996). Minimum and maximum daily temperatures were obtained from an automated weather station located within 1 km of experiments.

A logistic equation was used, as described by Knezevic et al. (2002), to describe the effect of increasing duration of weed interference on relative onion yield:

$$Y = \left(\frac{1}{\exp\left[c * (T - d)\right] + f} + \frac{f - 1}{f}\right) * 100 \qquad [1]$$

where Y is yield (percent of season-long weed free), T is time (expressed in GDD from onion emergence), d is the point of inflection (i.e., time to one-half of the season-long yield loss expressed in GDD), and c and f are constants. Equation 1 was fit to relative onion yield for each weed density and model parameter estimates were then used to determine the amount of time, expressed as GDD and related to onion growth stage, needed to result in predetermined levels of yield loss of 2.5, 5.0, and 10%.

Equation 1 was fit to data for each density within locations with the use of an iterative least-squares procedure (Sigma Plot 8.0[4]). Lack of fit was assessed by reporting standard errors of parameter estimates 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 between weed densities and among locations. Comparisons were made by calculating a variance ratio of individual and pooled residual sums of squares and performing an F test. If parameter estimates were constant across densities or locations, data were pooled accordingly. The significance of all statistical tests used an alpha level of 0.05 unless reported otherwise.

Results and Discussion

Weed-free onion stands at the time of harvest did not vary among locations and averaged 319,400 plants/ha. Weed-free onion yields were highest for Oregon, with 121,000 kg/ha, followed by 88,200 and 81,400 kg/ha for Idaho and Washington, respectively. Yields were comparable with or

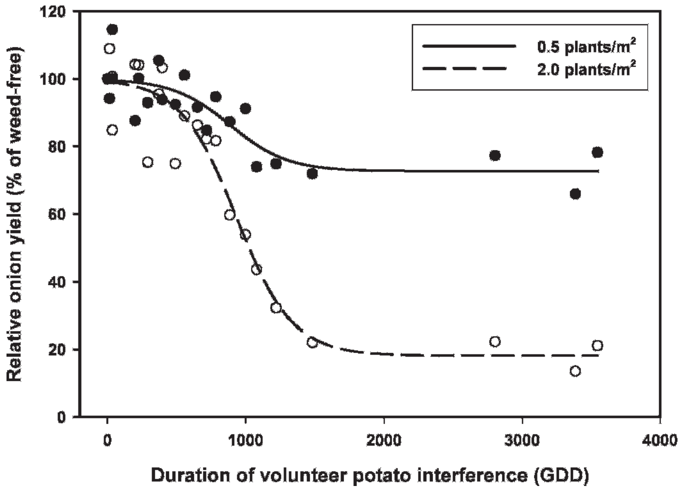

Figure 1. Relative onion yield as a function of duration of volunteer potato interference at 0.5 plants/m^2 (filled circles) and 2.0 plants/m^2 (open circles). Equation 1 parameter estimates (standard errors) are 0.5 plants/m^2, $c = 0.0047$ (0.0017), $d = 610$ (115), $f = 3.66$ (0.41), $R^2 = 0.42$; 2.0 plants/m^2, $c = 0.0053$ (0.0008), $d = 894$ (41), $f = 1.23$ (0.06), $R^2 = 0.84$. Growing degree day (GDD) base temperature was 7.2 C.

exceeded average reported yields for each state (Anonymous 2003). Numerous factors may account for the difference in weed-free yields among locations. Idaho and Oregon used the same onion variety, were planted within the same week, had similar seeding rates and fertility practices, and were separated by only 20 km. Furrow irrigation was used at both locations; however, differences in soil moisture content may have occurred. In a 3-year study at Ontario, Oregon, Shock et al. (1998) reported onion yields increased linearly by 750 kg/ha for each 1 kPa increase in soil water potential. Conceivably, small variations among locations in irrigation management over time could lead to different weed-free onion yields.

The effect of duration of volunteer potato interference on relative onion yield was consistent among locations, but depended upon weed density (Figure 1). The F tests for comparing nonlinear models indicated onion response to duration of potato interference was not consistent between weed densities; therefore, data were analyzed separately for each weed density. The F tests for comparing nonlinear models indicated onion response at individual weed densities was consistent among locations; therefore, data were pooled among locations. Season-long weed interference of 0.5 potato plants/m^2 resulted in 27% onion yield loss (Figure 1). However, season-long weed interference of 2.0 potato plants/m^2 resulted in 82% onion yield loss. Onion response to season-long potato interference agrees with previous research (Williams et al. 2004; Williams et al. 2005).

As volunteer potato density increased, the CTWR in onion was shortened. With 0.5 potato plants/m^2, yield losses of 2.5% were estimated to occur at 534 GDD when onion had 3.9 leaves (Table 2). Five percent yield loss occurred at some 654 GDD when onion had 4.5 leaves, and 10% yield loss was estimated when onion had 5.8 leaves. In contrast, yield losses of 2.5, 5.0, and 10% were estimated to occur at 388, 481, and 598 GDD, respectively, with a weed density of 2.0 plants/m^2.

Table 2. Maximum amount of time (standard error in parentheses) early-season potato interference can be tolerated at two densities of volunteer potato for three predetermined levels of onion yield loss. Onion leaf number related to each time is included.

Potato density	Time for indicated yield loss					
	2.5%		5.0%		10%	
	GDD[a]	Leaf no.	GDD	Leaf no.	GDD	Leaf no.
No./m^2						
0.5	534 (212)	3.9	654 (245)	4.5	830 (58)	5.8
2.0	388 (154)	2.8	481 (71)	3.5	598 (60)	4.5

[a] GDD is growing degree days base 7.2 C from onion emergence to harvest.

Regardless of yield loss threshold, onion growth stage at the CTWR lagged by one leaf or more at 2.0 plants/m^2, compared to 0.5 plants/m^2 (Table 2).

A shortened CTWR as weed density increases is explained largely by the poor competitive ability of onion to weed interference. Onion is slow to emerge, has a low initial growth rate, and its narrow, erect leaves capture little light (Hewson and Roberts 1973; Wicks et al. 1973). At 0.5 potato plants/m^2, weeds were spaced far enough apart that canopies of individual potato plants did not overlap and not all onions were subjected to weed interference. However, at 2.0 potato plants/m^2, the canopy of individual potato plants eventually overlapped, subjecting a larger number of onion plants to weed interference compared to the low weed density.

Postemergence broadleaf herbicides cannot be used in onion before the two-leaf stage because of potential phytotoxicity to the crop. In some cases, weed emergence causes yield losses before the two-leaf stage of onion, particularly when weed emergence precedes crop emergence (Dunan et al. 1996; Williams et al. 2005). Under the conditions of this study, the crop did not suffer yield loss (2.5% level or higher) by the 2-leaf stage in the presence of 0.5 potato plants/m^2. However, as weed density increases, the CTWR shortens, and risk of yield loss prior to the 2-leaf stage increases. Higher volunteer potato densities in commercial fields are likely, as Thorton et al. (2001) observed volunteer potato densities as high as 10 plants/m^2 in Washington.

Yield loss parameters in this study may underestimate the impact of volunteer potato in onion for some field conditions. Potato was planted within 1 d of onion and emerged from 1 to 12 d after onion (Table 1). True volunteer potato tubers at some locations may be at an advanced developmental stage at the time of planting, compared to seeded tubers, and some would emerge with or even before the crop. Weeds emerging prior to the crop shorten the CTWR (Williams et al. 2005), although in practice these are often killed with a nonselective herbicide. Also, weed interference reduces the proportion of larger-sized bulbs (Hewson and Roberts 1971; Wicks et al. 1973; Williams et al. 2004), and growers may receive a premium price for larger market grades. Yield of jumbo, colossal, and supercolossal bulbs decreased with duration of volunteer potato interference ($P \leq 0.1$), and to a greater extent at 2.0 volunteer potato plants/m^2 compared to 0.5 plants/m^2 (Table 3). When growers receive a premium for larger market grades, duration of weed interference would

Table 3. Effect of volunteer potato density and duration of interference on onion yield (mg/ha) by marketable grade in Idaho, Oregon, and Washington. Market grades are based on maximum onion bulb diameter: small (<5.7 cm), medium (5.7 to <7.6 cm), jumbo (7.6 cm to <10.2 cm), colossal (10.2 to <10.8 cm), and supercolossal (≥10.8 cm).

	Volunteer potato density (no./m^2)									
	0.5	2.0	0.5	2.0	0.5	2.0	0.5	2.0	0.5	2.0
	Onion yield by marketable grade									
Duration of interference	Small		Medium		Jumbo		Colossal		Supercolossal	
Onion leaf no.										
Idaho										
Weed-free	8.6	8.9	34.9	30.4	41.4	38.3	8.6	5.5	0.0	0.0
1	9.5	8.3	31.8	34.2	37.4	41.4	8.8	5.9	0.0	0.0
2	7.7	7.8	27.3	27.3	39.6	38.7	7.7	12.2	0.0	0.0
3	8.0	8.6	30.5	27.5	38.5	38.7	10.6	10.9	0.0	0.0
4	9.2	13.1	30.9	30.2	33.1	20.7	6.0	2.7	0.0	0.0
6	10.7	11.1	27.2	16.5	26.1	7.0	5.2	1.7	0.0	0.0
8	12.7	6.3	28.9	6.2	21.9	3.9	3.0	0.8	0.0	0.0
No removal	10.4	3.4	24.5	4.5	22.3	2.8	4.2	0.8	0.0	0.0
LSD (0.05)	4.2		6.2		9.1		NS		NS	
Oregon										
Weed-free	0.6	0.8	2.6	2.7	79.2	85.2	34.1	27.0	6.4	4.4
1	0.9	0.8	3.1	2.0	91.1	81.2	23.9	31.0	3.0	5.8
2	0.9	0.9	2.9	3.2	85.8	75.3	29.5	35.2	3.5	10.2
3	0.7	1.2	2.3	5.2	84.9	75.0	34.7	29.1	6.3	3.8
4	0.9	1.5	3.0	5.2	81.0	63.8	33.0	29.5	5.5	7.0
6	1.2	2.2	3.6	10.3	77.9	57.6	26.9	24.3	5.7	3.8
8	1.5	3.7	4.1	9.5	68.7	41.8	30.9	8.0	6.4	1.5
No removal	2.1	6.1	5.9	7.2	63.2	10.0	20.8	1.3	3.5	0.8
LSD (0.05)	0.7		2.75		12.5		12.7[a]		4.3[a]	
Washington										
Weed-free	2.6	0.8	17.8	14.0	60.9	66.3	0.0	0.4	0.0	0.0
1	1.3	1.0	15.7	13.1	56.9	63.5	0.0	0.0	0.0	0.0
2	0.8	1.5	13.6	16.0	53.6	64.6	0.0	0.0	0.0	0.0
3	1.8	3.3	23.3	21.1	50.3	39.9	0.0	0.0	0.0	0.2
4	1.6	1.6	20.6	22.5	52.5	42.8	0.0	0.2	0.0	0.0
6	2.5	5.3	17.9	20.6	51.0	18.4	0.2	0.0	0.0	0.0
8	3.3	7.0	20.6	13.1	37.5	4.3	0.0	0.0	0.0	0.0
No removal	3.6	6.1	22.7	10.6	35.6	0.9	0.0	0.0	0.0	0.0
LSD (0.05)	1.8		6.9		22.1		NS		NS	

[a] LSD values for colossal and supercolossal yields in Oregon are at $\alpha = 0.10$ confidence level.

most likely have a greater effect on crop value than total crop yield reported here. Nonetheless, relative differences in crop responses of this study indicate weed management becomes inherently more challenging as volunteer potato density increases because the CTWR shortens.

Onion producers are limited on how early they can use herbicides, tillage, or hand labor for volunteer potato suppression. However, using management strategies to reduce the number of volunteer potato tubers, either during potato harvest or in rotational crops preceding onion, will likely provide more time to target volunteer potato postemergence and reduce the risk of yield loss.

Sources of Materials

[1] Idaho-E. Oregon Onions, 118 North Second Street, P.O. Box 909, Parma, ID 83660.

[2] NCSS 2000, NCSS, 329 North 1000 East, Kaysville, Utah 84037.

[3] SYSTAT 11, Systat Software, Inc., 501 Canal Blvd, Suite E, Point Richmond, CA 94804-2028.

[4] 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. 2003. Agricultural Statistics. Washington, DC: U.S. Government Printing Office. Pp. 19–26.

Bleasdale, J.K.A. 1959. The yield of onions and red beet as affected by weeds. J. Hortic. Sci. 34:7–13.

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.

Dunan, C. M., P. Westra, and F. D. Moore III. 1999. A plant process economic model for weed management decisions in irrigated onion. J. Am. Soc. Hortic. Sci. 124:99–105.
Dunan, C. M., P. Westra, F. Moore, and P. Chapman. 1996. Modelling the effect of duration of weed competition, weed density and weed competitiveness on seeded, irrigated onion. Weed Res. 36:259–269.
Ellis, P. J. 1992. Weed hosts of beet western yellow virus and potato leafroll virus. Plant Dis. 76:1137–1139.
Hewson, R. T. and H. A. Roberts. 1971. The effect of weed removal at different times on the yield of bulb onions. J. Hortic. Sci. 46:471–483.
Hewson, R. T. and H. A. Roberts. 1973. Some effects of weed competition on the growth of onions. J. Hortic. Sci. 48:51–57.
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.
Lumkes, L. M. 1974. Research on the control of volunteer potatoes in the Netherlands. Proc. Br. Weed Control Conf. 12:1031–1040.
Lutman, P.J.W. 1977. Investigations into some aspects of the biology of potatoes as weeds. Weed Res. 17:123–132.
Pelter, G. Q., E. J. Sorensen, R. E. Thornton, and R. Stevens. 1992. Dry Bulb Onion Production in the Columbia Basin. Pullman, WA: Washington State University Cooperative Extension, EB1693. 18 p.
Perombelon, M.C.M. 1975. Observations on the survival of potato groundkeepers in Scotland. Potato Res. 18:205–215.
Ratkowsky, D. A. 1983. Pages 135–153 *in* Nonlinear Regression Modeling: A Unified Practical Approach. New York: Marcel Dekker.
Shadbolt, C. A. and L. G. Holm. 1956. Some quantitative aspects of weed competition in vegetable crops. Weeds 4:111–123.
Shock, C. C., E.B.G. Feibert, and L. D. Saunders. 1998. Onion yield and quality affected by soil water potential as irrigation threshold. Hortscience 33:1188–1191.
Thomas, P. E. 1983. Sources and dissemination of potato viruses in the Columbia basin of 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.
Wicks, G. A., D. N. Johnston, D. S. Nuland, and E. J. Kinbacher. 1973. Competition between annual weeds and sweet Spanish onions. Weed Sci. 21:436–439.
Williams, M. M. II, C. V. Ransom, and W. M. Thompson. 2004. Effect of volunteer potato density on dry 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.

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