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Duration of volunteer potato (*Solanum tuberosum*) interference in bulb onion

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Previous research with annual weed species indicates that critical timing of weed removal begins primarily after the two-leaf stage of onion, a time when postemergence (POST) herbicides can first be applied. Volunteer potato is difficult to manage and persists in onion fields of western United States. The purpose of this research was to quantify the duration of volunteer potato interference on yield and market grade of onion as well as potato tuber production. Volunteer potato interference caused a 5% yield loss before onions reached the two-leaf stage, at two of three locations. Relative to weed-free plots, onion bulb diameter was reduced as duration of interference increased, resulting in smaller proportions of marketable bulbs. Volunteer potato produced daughter tubers shortly after emergence, which explains, in part, weed persistence despite removal of shoots with contact herbicides, cultivation, and hand-weeding in onion. Significant losses in onion yield and bulb diameter are likely given current volunteer potato management systems.

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

Key words: Competition, critical time of weed removal, critical weed-free period.

Commercial potato harvest leaves numerous tubers in the field, which are distributed throughout postharvest tillage depths, and volunteer potatoes arise from these nonharvested tubers (Lumkes 1974; Perombelon 1975). In several potato-producing regions of the world, winter temperatures freeze tubers near the soil surface; yet, tubers deeper in the soil profile survive and emerge in rotation crops (Lutman 1977; R. Boydston, unpublished data). Volunteer potatoes are difficult to suppress because of large energy reserves in the tuber and the relatively deep burial depth compared with annual weed species. Short periods of vegetative growth may contribute to volunteer potato persistence because initiation of new tubers begins shortly after emergence. Volunteer potato persistence reduces the benefits of crop rotation because the weed can serve as an alternate host and source of inoculum for serious disease, insect, and nematode pests of potato (Ellis 1992; Thomas 1983).

Bulb onion, hereafter called "onion," is an important crop in western United States, where it is often grown in a 3-yr rotation with potato. Onions are susceptible to weed interference because the crop is slow to emerge, has a low initial growth rate, and its narrow, erect leaves produce little shade (Hewson and Roberts 1973; Wicks et al. 1973). Volunteer potato interference can result in 85% total yield loss (Boydston and Seymour 2002), with complete loss of the most valuable market grades (Williams et al. 2004a).

Onion weed management systems rely heavily on postemergence (POST) tactics because volunteer potatoes are not controlled by preemergence herbicides registered for use in onion. Weed management strategies for control of emerged volunteer potato include cultivation, hand-weeding, and herbicides (Boydston and Seymour 2002; Williams and Boydston 2002); however, cultivation is limited to the crop interrow. In addition, hand-weeding is most effective when potatoes are large enough to retain daughter tubers during weed removal. Bromoxynil and oxyfluorfen, which suppress volunteer potato, are labeled for use in onions that have two or more fully emerged leaves (Boydston and Seymour 2002; Eberlein et al. 1993). As with hand-weeding, volunteer potatoes can interfere with onions for a relatively long period before POST herbicides can be used.

Development of integrated weed management (IWM) systems for onion that target persistent weeds such as volunteer potato will require a greater understanding of when weed interference can be tolerated before crop yield is reduced. Critical timing 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 (Knezevic et al. 2002). Researchers have determined that the critical timing of weed removal begins between two- and four-leaf stage of onion for small-seeded annual weeds such as common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) (Dunan et al. 1996; Hewson and Roberts 1971; Shadbolt and Holm 1956). Weed densities were high (50 to 850 plants m^{-2}) in these studies, relative to observed densities of volunteer potato (0.4 to 10 plants m^{-2}) in the Pacific Northwest (R. Thornton, personal communication). More recently, simulation modeling by Dunan et al. (1995, 1996) suggests weeds may need to be controlled before the two-leaf stage of onion to avoid yield reduction.

The overall goal of this study was to determine the significance of volunteer potato interference in current onion-production systems. Specific objectives were to (1) quantify the influence of duration of volunteer potato interference on onion yield and market grade, (2) determine the critical time for volunteer potato removal, and (3) quantify the temporal dynamics of volunteer potato tuber production when grown in onion.

Materials and Methods

Irrigated field experiments were conducted at Parma, ID, Ontario, OR, and Prosser, WA, in 2002. Onions were planted 2 cm deep using a seeder equipped with four planting shoes spaced 56 cm apart. A planter with a single onion line per planting shoe was used in Washington.[1] Onions at Idaho and Oregon were planted on 28-cm-wide raised beds with double lines, spaced 7.6 cm apart, per planting bed per shoe.[2] Additional details on planting, emergence, and site characteristics are shown in Table 1.

The experimental design was a randomized complete block with four replications per treatment and plots measured 2.2 by 7.5 m. A single volunteer potato density of 2 plants m^{-2} was established and maintained in each plot, and eight durations of interference treatments were established. Increasing durations of weed interference were accomplished by delaying volunteer potato removal time according to onion leaf number and were 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). Once the end of the interference duration was reached and volunteer potato removed, the treatment was kept weed free for the rest of the season. Within 2 d of onion planting, whole potato tubers, averaging 59 g $tuber^{-1}$, were planted to simulate volunteer potatoes. The exception was Idaho, where onion was replanted because of seedling mortality from cool, wet soils (Table 1). Potato tubers were hand-planted 15 cm deep, either between the two onion lines (Idaho and Oregon) or within 2 cm of the single onion line (Washington). Tubers were not planted in outside rows of experimental units. At all sites, tubers were spaced equidistantly within the onion line(s). Interference duration was ended, depending on the treatment, by clipping potato shoots 2-cm above the soil surface and brushing on a 5% solution of glyphosate or fluroxypyr to shoot stumps. Treated potatoes that produced new leaves were immediately retreated until growth stopped.

Experiments were kept free of weeds, except for potatoes, by hand-weeding and POST applications of 6.7 kg DCPA ha^{-1} and 1 kg pendimethalin ha^{-1} and two POST applications of 0.2 kg sethoxydim ha^{-1} at the one- 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). Lambda-cyhalothrin was applied in Oregon and Washington as needed to control thrips.

After crop senescence, onions from the center 6 m (Idaho and Washington) or entire length (Oregon) of each plot were hand-harvested on October 8, September 15, and September 9, 2002, 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).[3] The number of bulbs and mass of each market grade were recorded, with the exception being Oregon, where total bulb number was recorded. When each duration of weed interference treatment was completed at Oregon and Washington, one volunteer potato plant per plot was removed, and oven-dry shoot biomass and daughter

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 2002.[a]

Location	Potato variety	Potato planting date	Onion variety	Onion planting date	Onion planting density	Onion planting configuration	Soil type[b]	Organic matter	pH	Potato emergence	Onion emergence
					seeds ha^{-1}			%			
ID	'Ranger Russet'	March 27	'Vaquero'	April 30[c]	391,200	double lines, 56-cm-rows	Greenleaf silt loam	1.1	7.6	May 4	May 14
OR	'Russet Burbank'	March 27	Vaquero	March 29	380,800	double lines, 56-cm-rows	Greenleaf silt loam	1.7	7.4	April 23	April 14
WA	Russet Burbank	April 24	'Pinnacle'	April 22	261,800	single line, 56-cm-rows	Warden silt loam	1.1	7.2	May 24	May 8

[a] Abbreviations: ID, Idaho; OR, Oregon; WA, Washington.
[b] Greenleaf silt loam (Fine-silty, mixed, superactive, mesic Xeric Calciargids), Warden silt loam (Coarse-silty, mixed, superactive, mesic Xeric Haplocambids).
[c] Onions were originally planted on March 28, 2002, at ID. However, wet and cool soils resulted in high seedling mortality and onions were replanted on April 30, 2002.

tuber number were determined. Idaho was unable to collect volunteer potato shoot biomass or tuber number data.

Statistical Analysis

Relative yield 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 using 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 the 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 yield:

$$Y = ((1/(\exp(c(T - d)) + f)) + ((f - 1)/f))100 \quad [1]$$

where Y is yield (% 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, 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%.

Onion yield was related to shoot biomass, at the time duration of interference treatments were completed, using a rectangular hyperbolic equation (Cousens 1985):

$$Y = Y_{\mathrm{wf}}\left[1 - \frac{I \times N}{100 \times \left(1 + \frac{I \times N}{A}\right)}\right] \quad [2]$$

where Y_{wf} is derived weed-free yield, N is shoot biomass (expressed in g m^{-2}), I is percent yield loss as weed biomass approaches zero, and A is the upper asymptote or maximum yield loss.

Density of daughter tubers produced by volunteer potato in onion was described as a function of GDD using a logistic model:

$$Y = \frac{a}{1 + \exp\left(-\frac{T - T_0}{b}\right)} \quad [3]$$

where Y is tuber production, T is time (expressed in GDD from potato emergence), T_0 is time resulting in 50% tuber production, and b is the slope.

All equations were fit to data for each location using an iterative least squares procedure (SigmaPlot 8.0[4]). Lack of fit was assessed by reporting standard errors of parameter estimates, plotting predicted and observed values, or calculating R^2 values, or all. The extra sum of squares principle for nonlinear regression analysis (Ratkowsky 1983) was used to evaluate the similarity of parameter estimates among locations. 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 locations, data were pooled among locations. The significance of all statistical tests was alpha = 0.05.

Results and Discussion

Weed-free onion yields were 58,800, 113,900, and 80,200 kg ha^{-1} for Idaho, Oregon, and Washington, respectively (data not shown). Lower yields in Washington compared with Oregon largely were attributed to lower seeding rates because of the use of single line per row planting equipment in Washington (Table 1). Lower yields in Idaho compared with Oregon were attributed to a late replanting date, resulting in a shortened growth period. Despite differences among locations, weed-free yields were comparable with or exceeded average reported yields for each state (Anonymous 2003).

Duration of volunteer potato interference had a significant effect on onion yield, with season-long weed interference resulting in greater than 80% relative yield loss (Figure 1). The F test for comparing nonlinear models indicated that onion response to duration of potato interference was not consistent among locations; therefore, data are presented separately for each location. The GDD at which one-half of the season-long yield loss occurred (d parameter = inflection point) ranged from 487 at Idaho to 1,082 at Washington. This level of yield reduction required fewer GDD at Idaho than at Oregon and Washington, largely due to the fact that onion was at a competitive disadvantage at Idaho where the onion crop had to be replanted. Volunteer potato emerged 9 and 16 d after onion emergence in Oregon and Washington, respectively, whereas volunteer potato emerged 10 d before onion emergence in Idaho because of onion replanting. Relative crop–weed emergence at Idaho would be more representative of an early-emerging volunteer potato population left unchecked until after crop emergence.

Relative onion yield was related to volunteer potato shoot biomass at the time of weed removal in Oregon and Washington. The F test for comparing nonlinear models indicated that onion response to potato interference, as measured by volunteer potato shoot biomass at the time of weed removal, was consistent between locations; therefore, data were pooled between these two locations (Figure 2). Relative onion yield decreased hyperbolically as a function of volunteer potato shoot biomass. Others have used destructive (Harrison et al. 2001) or nondestructive (Bussler et al. 1995) measures of weed biomass to develop predictive crop yield loss equations. However, in this study, a smaller percentage of the variation in onion yield was explained by volunteer potato biomass ($R^2 = 0.80$) than by duration of volunteer potato interference ($R^2 = 0.83$ to 0.92).

Yield and bulb number of each market grade was significantly affected by duration of volunteer potato interference. Increasing duration of volunteer potato interference reduced onion bulb size, resulting in lower yields of most valuable market grades such as jumbo, colossal, and supercolossal (Figure 3). Consequently, as duration of volunteer potato interference increased, bulbs in medium and small market grades accounted for a larger proportion of total onion yield. Although overall onion density was less affected by increasing duration of weed interference, reductions in bulb size with time resulted in a higher proportion of total bulbs

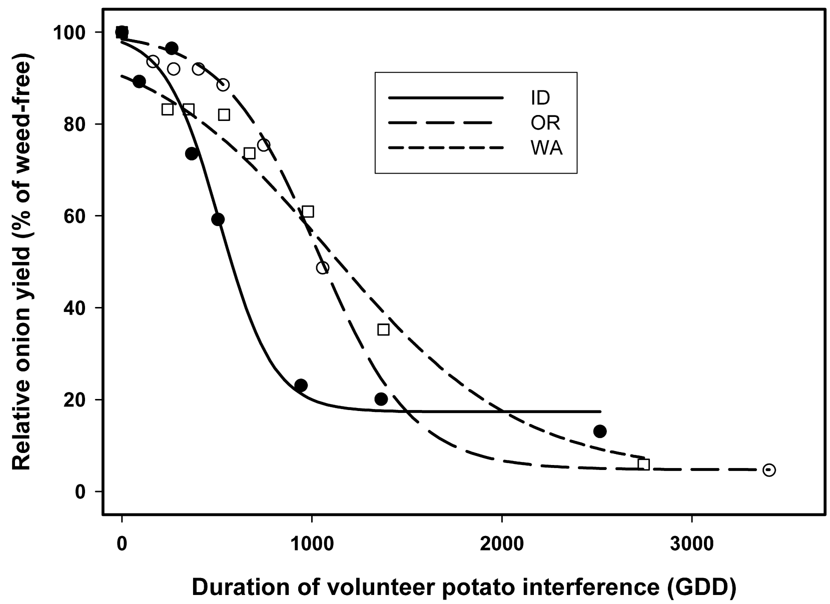

FIGURE 1. Relative onion yield as a function of duration of volunteer potato interference in Idaho (filled circles), Oregon (open circles), and Washington (open squares). Regression equations are: Idaho, relative yield = $((1/(\exp(0.007(x - 487)) + 1.21)) + ((1.21 - 1)/1.21))100$ ($r^2 = 0.83$); Oregon, relative yield = $((1/(\exp(0.004(x - 1{,}018)) + 1.05))+((1.05 - 1)/1.05))100$ ($r^2 = 0.90$); and Washington, relative yield = $((1/(\exp(0.002(x - 1{,}082)) + 1.04)) + ((1.04 - 1)/1.04))100$ ($r^2 = 0.92$). Growing degree day base temperature was 7.2 C.

being accounted for by small bulbs (Figure 4). For instance, although volunteer potato interference through the eight-leaf stage of onion resulted in a similar number of bulbs as the weed-free treatment in Washington, 45% of the bulbs were small (nonmarketable) and the rest of the market grades accounted for only 30% of the weed-free yield. This study is consistent with that of Hewson and Roberts (1971) who reported that duration of annual weed interference decreased onion yield primarily by decreasing bulb diameter.

The approach taken in these field studies provides a statistical method of quantifying the beginning of critical period for weed control in onion, which begins early with volunteer potato interference. As an example, 2.5% yield loss occurred at 120 to 237 GDD, when onion had 0.6 to 1.7 leaves per plant (Table 2). Five percent yield loss was observed when onion had 1.1 to 2.7 leaves, and 10% yield loss occurred with as few as two leaves per plant at Idaho and 3.9 leaves per plant at Oregon. In contrast, several authors have found no yield loss when small-seeded, annual weed species such as prostrate knotweed (*Polygonum aviculare* L.) and redroot pigweed interfere until the two-leaf stage of onion (Hewson and Roberts 1971; Thomas and Wright 1984) or longer (Menges and Tamez 1981; Shadbolt and Holm 1956). Our results indicate volunteer potato interfer-

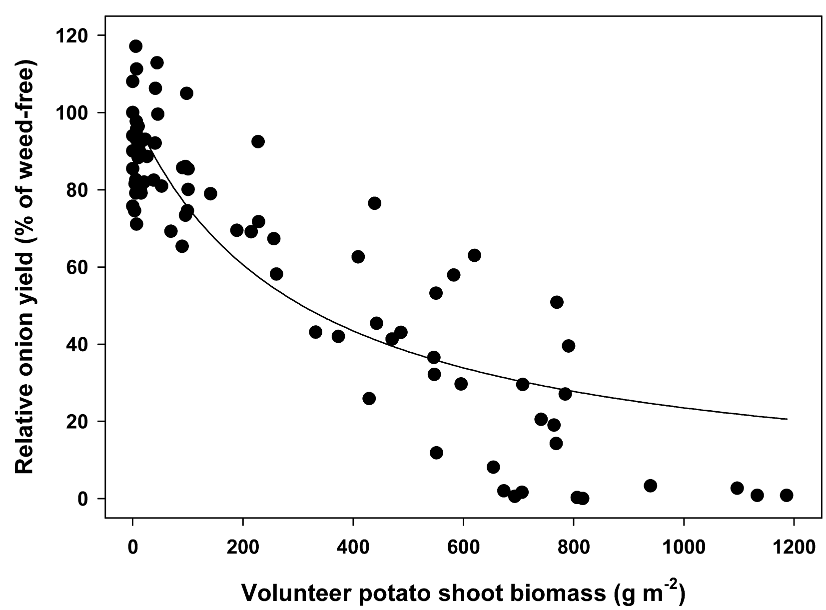

FIGURE 2. Relative onion yield as a function of volunteer potato shoot biomass at the time weed removal treatments were initiated at Oregon and Washington (no potato shoot biomass data were collected at Idaho). Regression equation is relative onion yield = $100[1 - (0.325x)/(100(1 + 0.325x/100))]$ (r^2 = 0.80).

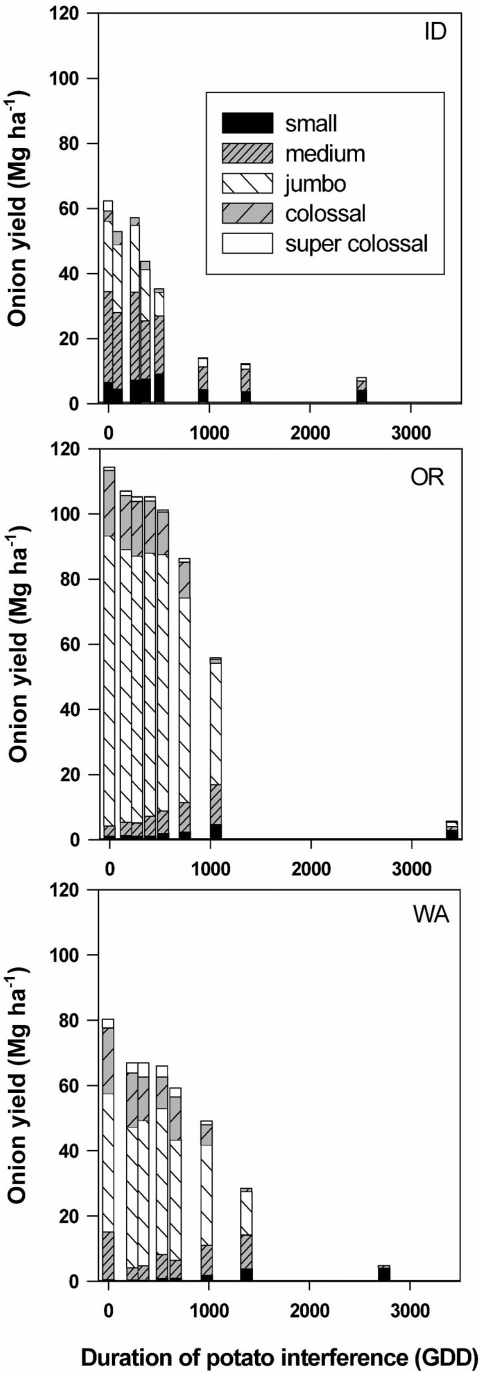

FIGURE 3. Effect of duration of volunteer potato interference on onion yield by market grade in Idaho, Oregon, and Washington. Market grades are based on maximum onion bulb diameter: small (< 5.7 cm), medium (5.7 to < 7.6 cm), jumbo (7.6 to < 10.2 cm), colossal (10.2 to < 10.8 cm), and supercolossal (=> 10.8 cm). Growing degree day base temperature was 7.2 C.

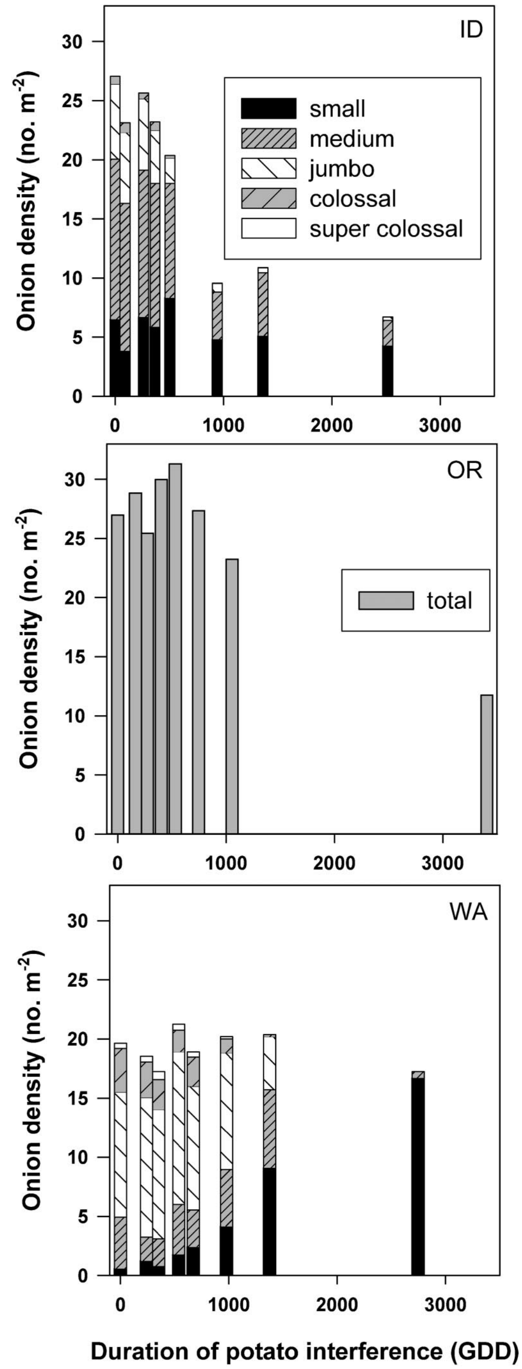

FIGURE 4. Effect of duration of volunteer potato interference on onion density by market grade in Idaho, Oregon, and Washington. Market grades are based on maximum onion bulb diameter: small (< 5.7 cm), medium (5.7 to < 7.6 cm), jumbo (7.6 to < 10.2 cm), colossal (10.2 to < 10.8 cm), and supercolossal (=> 10.8 cm). Note that only total onion density is reported for Oregon. Growing degree day base temperature was 7.2 C.

ence could cause 5% or more yield loss in onion by the two-leaf stage (Table 2). These results are more comparable with those of Wicks et al. (1973), in that yield loss occurred when annual weeds were present during a relatively short period of time from onion emergence to the two-leaf stage onion.

Volunteer potato produced a significant number of daughter tubers while growing in onion. The *F* test for comparing nonlinear models indicated that volunteer potato tuber production was consistent between Oregon and Washington; therefore, data were pooled. Potato at our 2 m^{-2} density allowed to remain in the plots for the entire season produced an average of 42 daughter tubers m^{-2} (Figure 5). Moreover, 50% of the tubers in this treatment were produced within 1,028 GDD after potato emergence. Similar estimates of maximum volunteer potato tuber number have been quantified in both the presence of onion (Boydston and Seymour 2002) and absence of a crop (Williams and

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

	Time for indicated yield loss					
	2.5%		5.0%		10%	
Location	GDD	Leaf number	GDD	Leaf number	GDD	Leaf number
ID	120 (82)	1.3	186 (96)	1.4	270 (96)	2.0
OR	237 (129)	1.7	363 (127)	2.7	521 (111)	3.9
WA	148 (114)	0.6	261 (142)	1.1	438 (133)	3.7

[a] Abbreviations: GDD, growing degree days; ID, Idaho; OR, Oregon; WA, Washington.

Boydston 2002). These data indicate that only short periods of time are necessary for volunteer potato growing in onion to produce large numbers of daughter tubers, which can subsequently grow as volunteer potatoes in crops following onion in the rotation. This volunteer potato problem could persist through time despite current control methods including POST herbicides, mechanical cultivation, or more recently investigated methods such as arthropod herbivory.

Implications for IWM

Onion is subject to significant losses in yield and bulb diameter when volunteer potato control is delayed until two-leaf or greater onion stage. As observed in our study, crop yield loss of 5% or more can occur by the two-leaf stage of onion, the earliest time when herbicides can be applied for volunteer potato suppression. Potato interference not only reduces onion yields but also bulb size, which further reduces market value. Therefore, volunteer potato interference may have an even greater effect on total market value than on total crop yield. Crop prices also should be a factor when considering timing of weed control in addition to the cost and efficacy of onion weed control (Dunan et al. 1995, 1999).

This study raises the importance of an IWM system integrating multiple weed-management tactics, including preventative approaches to reduce volunteer potato population densities before onion planting. Improving tuber recovery during commercial potato harvest is perhaps the most rational solution. Soil fumigation, although primarily used to control nematodes and other soil pathogens, has the potential to greatly reduce the number of viable potato tubers (Boydston and Williams 2003). Using arthropod defoliation inflicted by the Colorado potato beetle [*Leptinotarsa decemlineata* (Say)] has been proposed by Boydston and Seymour (2002) as an additional form of volunteer potato suppression and shows promise when integrated with reduced herbicide doses (Williams et al. 2004b). Moreover, the temporal dynamics of volunteer potato tuber production should be considered in developing IWM systems to minimize the number of viable daughter tubers remaining in the field after onions are grown.

Sources of Materials

[1] Planter, Singulaire 785, Stanhay Webb Ltd., Houghton Road, Grantham, Lincs, NG31 6JE, U.K.

[2] Planters, Mel Beck Precision Planters, 214 Thunderegg Boulevard, Nyssa, OR 97913.

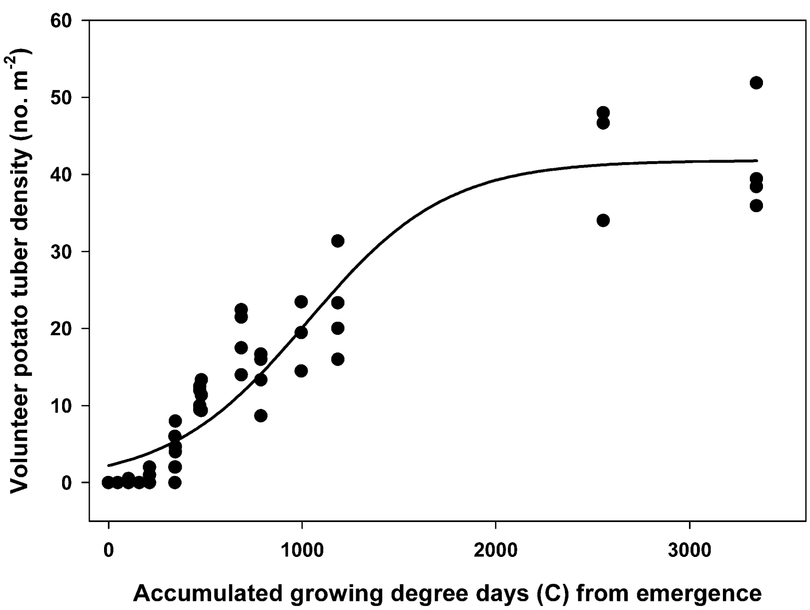

Figure 5. Volunteer potato tuber density in onion as a function of accumulated growing degree days after potato emergence for Oregon and Washington (tuber density data were not collected at Idaho). Regression equation is tuber density = 41.8/(1 + exp(−(x − 1,027.9)/356.7)) (r^2 = 0.90). Growing degree day base temperature was 7.2 C.

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

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

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