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Factors Affecting Sprouting and Glyphosate Translocation in Rootstocks of Redvine (*Brunnichia ovata*) and Trumpetcreeper (*Campsis radicans*)[1]

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Abstract: Greenhouse and growth chamber experiments were conducted to investigate the sprouting potential of rootstock; the effect of temperature, burial depth, and length of rootstock on sprouting; and the effect of shoot removal on resprouting ability of rootstock in redvine and trumpetcreeper. Glyphosate translocation along the rootstock of redvine was also measured. Higher sprouting was observed at 20 to 40 C in trumpetcreeper (60 to 73%) and at 30 to 40 C in redvine (45 to 47%) compared with other temperatures. Redvine sprouting was totally inhibited at 15 C, whereas trumpetcreeper had a sprouting of 12%. Emergence of shoot from a 28-cm planting depth was completely inhibited in redvine, whereas trumpetcreeper had 23% sprout emergence. After shoot removal treatments applied every 3 wk, redvine rootstock segments ≤2 cm long were totally depleted after fifth shoot removal treatment (15 wk after planting [WAP]). In trumpetcreeper, total depletion was not reached by 15 WAP, regardless of rootstock length. ^{14}C-glyphosate was translocated from the treated shoot attached to the apical end of a 35-cm rootstock to the untreated end with slightly less ^{14}C-glyphosate recovered at the untreated end compared with 5 to 10 cm from the treated shoot. These results indicated that vegetative reproduction in redvine is more sensitive to cool temperatures, deep burial depth, and short rootstock segment than trumpetcreeper. Variable control of redvine with glyphosate could be due to inadequate herbicide translocation within the rootstock.

Nomenclature: Glyphosate; redvine, *Brunnichia ovata* (Walt.) Shinners #[3] BRVCI; trumpetcreeper, *Campsis radicans* (L.) Seem. ex Bureau # CMIRA.

Additional index words: Absorption, regrowth, sprout regeneration, uptake.

Abbreviations: DAT, days after treatment; WAP, weeks after planting; WAT, weeks after treatment.

INTRODUCTION

Redvine and trumpetcreeper are native perennial fast-growing woody vines that climb on any support and other vegetation or trail along the ground. They are found in cultivated fields, wastelands, yards, fencerows, riverbanks, right-of-ways, and forests. In cultivated fields, their infestations may range from spotty to severe. Redvine and trumpetcreeper are among the 10 most troublesome weeds in cotton (*Gossypium hirsutum* L.), soybean [*Glycine max* (L.) Merr], and corn (*Zea mays* L.) in the midsouthern United States (Webster 2000, 2001). They are difficult to control because they can propagate from a deep and extensive root system (Elmore 1984). Redvine and trumpetcreeper produce numerous seeds in noncultivated areas such as ditches, roadsides, and fencerows (Chachalis and Reddy 2000; Shaw et al. 1991), and seeds serve as means of propagation and spread into new areas. However, the rapid increase in plant numbers after initial establishment is mainly attributable to the regenerative capability of rootstocks (propagule production) due to numerous adventitious buds (Elmore 1984). The effects of factors such as temperature, burial depth, and size of the root segment on regenerative capacity of redvine and trumpetcreeper are not known.

Herbicides (e.g., acifluorfen, lactofen, paraquat) that are active on these weeds kill only top growth and have little or no effect on the rootstock (Chachalis et al. 2001; Reddy and Chachalis 2004). Desiccation of foliage is temporary, often partial, and new sprouts arise from underground rootstocks (Chachalis et al. 2001; Reddy and Chachalis 2004). Dicamba or glyphosate applied in the spring or fall either to a fallow field or after crop harvest can reduce redvine and trumpetcreeper (DeFelice and Oliver 1980; Edwards and Oliver 2001; Elmore et al. 1989). Glyphosate can be used to control these perennial

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

vines in glyphosate-resistant crops without injuring the crop (Edwards and Oliver 2001; Reddy and Chachalis 2004). In greenhouse studies, glyphosate at 0.84 kg ae/ha controlled redvine and trumpetcreeper 54 to 67% (Chachalis et al. 2001; Reddy 2000). Under field conditions control of these vines is variable, depending on degree of infestation and extent of the underground root system. Edwards and Oliver (2001) reported that glyphosate at 0.84 kg/ha controlled trumpetcreeper 95% 2 wk after treatment (WAT) and 82% 1 yr after treatment in glyphosate-resistant soybean. Reddy and Chachalis (2004) observed less than 35% reduction in redvine and 78% reduction in trumpetcreeper densities with single or sequential applications of glyphosate at 0.84 kg/ha in glyphosate-resistant soybean.

For effective control of redvine and trumpetcreeper, a lethal amount of glyphosate must be absorbed and translocated to meristematic regions (adventitious buds) of rootstocks. Our previous studies have shown that about 50% of total translocated glyphosate was present in rootstocks of redvine (Reddy 2000) and about 70% in rootstocks of trumpetcreeper (Chachalis and Reddy 2004). Despite greater than 50% of total translocated glyphosate accumulation in rootstocks of these vines under field conditions, this amount may not be lethal because of limited translocation of glyphosate (8 to 11% of recovered) even after 8 d exposure (Chachalis and Reddy 2004; Reddy 2000) and presence of large volume of rootstocks. Furthermore, the extent of translocation of glyphosate within the rootstocks is not known. This translocation is of great importance because both vines have long or large rootstocks. The objectives of this research were (1) to determine the sprouting potential of rootstock, (2) to study the effect of temperature, burial depth, and length of rootstock on sprouting, (3) to determine the effect of shoot removal on resprouting ability of rootstock, and (4) to determine the extent of glyphosate translocation along the rootstock of both redvine and trumpetcreeper.

MATERIALS AND METHODS

Redvine and trumpetcreeper rootstocks were collected from a farmer's field near USDA-ARS, Southern Weed Science Research Unit Farm, Stoneville, MS. Soil used in the study was a Bosket sandy loam (fine-loamy, mixed thermic Mollic Hapludalfs). Plastic pots (29 cm diameter, 30 cm depth) or plastic trays (50 cm length, 26 cm width, and 6 cm depth) were used in the studies. Studies were conducted in greenhouse and growth chambers. Plants were watered as needed to maintain adequate soil moisture.

Sprouting Characteristics. Twenty-centimeter-long rootstocks of redvine and trumpetcreeper were planted horizontally 3 cm deep in plastic trays filled with soil. Trays were kept in a greenhouse maintained at 35/25 (±3) C day/night temperatures, respectively, with natural light supplemented by sodium vapor lamps to provide a 14-h photoperiod. After 6 wk, sprouts were counted, clipped at the soil surface, oven dried, and dry weights were recorded. Dry weights of main and secondary sprouts were recorded separately. Ten rootstocks per tray were replicated three times and the experiment was repeated.

Temperature Effect on Sprouting. To study the effect of temperature on sprouting, 8-cm-long rootstocks of redvine and trumpetcreeper were planted horizontally in plastic trays 3 cm deep filled with soil. Trays were kept in growth chambers set at constant temperatures of 15, 20, 30, and 40 C with a 14-h photoperiod (900 $\mu E/m^2/s$). There were ten 8-cm-long rootstocks per treatment. After 6 wk, the rootstocks that produced sprouts were counted, and numbers of rootstock with sprouts were expressed as percent sprouting. Treatments were arranged in two-factor complete block design with four replications, and the experiment was repeated. Data were subjected to combined analysis of variance (ANOVA), and the means were separated using Fisher's LSD test at $P = 0.05$.

Burial Depth Effect on Sprout Emergence. To study the effect of planting depth on sprout emergence, 8-cm-long rootstocks of redvine and trumpetcreeper were planted horizontally 3, 9, 18, and 28 cm deep in pots filled with soil. Pots were kept in a greenhouse at 33/25 C (±3) C day/night temperature with natural light supplemented by sodium vapor lamps to provide a 14-h photoperiod. There were ten 8-cm long rootstocks per treatment. After 8 wk, sprouts were counted and numbers of rootstock with sprouts expressed as percent sprouting. Treatments were arranged in a two-factor complete block design with three replications, and the experiment was repeated. Data were subjected to combined ANOVA, and the means were separated using Fisher's LSD test at $P = 0.05$.

Rootstock Length Effect on Sprouting. To study the effect of rootstock length on sprouting, 1-, 2-, 4-, and 8-cm-long rootstocks of redvine and trumpetcreeper were planted horizontally, 3 cm deep in plastic trays filled with soil. Trays were kept in a greenhouse as described in the previous study. There were ten 8-cm-long rootstocks per treatment. After 8 wk, sprouts were counted and numbers of rootstock with sprouts expressed as percent sprouting. Treatments were arranged in a two-factor complete block design with three replications, and the experiment was repeated. Data were subjected to combined ANOVA and the means were separated using Fisher's LSD test at $P = 0.05$.

Depletion Study. Effect of shoot removal on resprouting potential of rootstocks of redvine and trumpetcreeper was studied using 1-, 2-, 4-, and 8-cm-long rootstocks. Rootstocks were planted horizontally, 3 cm deep in plastic trays filled with soil, and kept in a greenhouse as described in the previous study. Every 3 wk for the first 15 wk after planting (WAP), sprouts were counted, clipped at the soil surface, oven dried, and dry weights were recorded. There were 10 rootstocks per treatment. Treatments were arranged in a two-factor complete block design with four replications, and the experiment was repeated. Data were subjected to combined ANOVA, and the means were separated using Fisher's LSD test at $P = 0.05$.

^{14}C-Glyphosate Translocation along the Rootstock. ^{14}C-glyphosate absorption and translocation along the rootstock was studied only in redvine because of difficulty in getting uniform size rootstock in trumpetcreeper. Thirty-five-centimeter-long rootstocks of redvine were planted horizontally in plastic trays with soil. Trays were kept in a greenhouse until plants reached the four- to six-leaf stage. Plants were selected for study only when sprouting occurred at the apical end of the 35-cm-long rootstock. Plants were transferred from a greenhouse to a growth chamber for acclimatization 2 d before ^{14}C-glyphosate treatment. Growth chamber conditions were 30/25 C day/night temperatures, respectively; 60/90% day/night relative humidity, respectively; and a 14-h photoperiod (900 μE/m^2/s). Plants were presprayed at a rate of 0.84 kg ae/ha glyphosate[4] immediately before ^{14}C-glyphosate treatment. The ^{14}C-glyphosate treatment solution was prepared by diluting ^{14}C-glyphosate (^{14}C-methyl labeled, specific activity 2.04 GBq/mmol, 99% purity in an aqueous stock solution of 7.4 MBq/ml as *N*-[phosphonomethyl]glycine) in a commercial formulation of glyphosate[4] to give a final concentration of 0.84 kg ae glyphosate in 190 L of water (Reddy 2000). Ten microliters of ^{14}C-glyphosate solution containing 5.0 kBq was distributed in 25 droplets on the adaxial surface of the second-youngest fully expanded leaf, which had been covered with aluminum foil while spraying to avoid a double dose of glyphosate. Plants were subirrigated with water as needed. Treated plants were harvested at 4 and 8 d after treatment (DAT). Treated leaves were excised, immersed in 10 ml deionized water, and shaken for 20 s to remove ^{14}C-label remaining on the leaf surface. Plants were sectioned into the treated leaf, shoot above the treated leaf, shoot below the treated leaf, fibrous roots on the rootstock, and rootstock. Each 35-cm rootstock was cut into seven 5-cm-long sections, with each section having a similar diameter. Plant sections were wrapped in Kimwipes[5] tissue paper and dried at 45 C for 48 h. The oven-dried plant samples were combusted in a biological oxidizer,[6] and the evolved $^{14}CO_2$ was trapped in 10 ml CarboSorb E[7] and 12 ml Permaflour E.[7] Two 1-μl aliquots of each leaf wash were mixed with 10 ml scintillation cocktail, EcoLume.[8] Radioactivity from leaf washes and oxidations was quantified using liquid scintillation spectrometry.[9] Total amount of radioactivity present in leaf washes and all plant sections was considered as total ^{14}C recovered. ^{14}C-label recovered averaged 92% of applied ^{14}C-glyphosate. Sum of radioactivity present in all plant sections was considered as absorbed and expressed as percentage of the ^{14}C recovered. Radioactivity present in all parts except the treated leaf was considered as translocated and expressed as percentage of the ^{14}C recovered. Treatments were arranged in a randomized complete block design. Each treatment was replicated four times and the experiment was repeated. Data were subjected to combined ANOVA, and means were separated as described previously.

RESULTS AND DISCUSSION

Sprouting Characteristics. Trumpetcreeper rootstocks produced more sprouts (3.2 sprouts/rootstock) compared with rootstocks of redvine (1.3 sprouts/rootstock) (Table 1). Visual observation of sprouting showed that multiple sprouts were produced mostly at the end of the 20-cm-long rootstock in trumpetcreeper. In contrast, redvine produced predominately single sprouts at any point on the rootstock. In both species, there was a well-devel-

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[4] Roundup Ultra®, isopropylamine salt of glyphosate with surfactant, Monsanto Agricultural Company, 800 North Lindbergh Boulevard, St. Louis, MO 63167.

[5] Kimwipes EX-L. Kimberly-Clark Corporation, 1075 Northfield Court, Roswell, GA 30076.

[6] Packard Oxidizer 306, Packard Instruments Company, Downers Grove, IL 60515.

[7] CarboSorb E and Permafluor E$^+$, Packard Instruments Company, 2200 Warrenville Road, Meridian, CT 06450.

[8] EcoLume, ICN, 3300 Hyland Avenue, Costa Mesa, CA 92626.

[9] Minaxiβ Tri-carb 4000 series Liquid Scintillation Counter, Packard Instrument Company, 2200 Warrenville Road, Downers Grove, IL 60515.

Table 1. Number of sprouts and dry weight of the main and total secondary sprouts produced from 20-cm-long rootstocks of redvine and trumpetcreeper at 6 wk after planting in soil under greenhouse conditions.[a]

		Dry weight	
	Total sprouts	Main sprout	Total secondary sprouts
	No./rootstock	g	
Redvine	1.3	0.60	0.30
Trumpetcreeper	3.2	1.10	0.30
LSD (0.05)	0.2	0.20	NS

[a] Abbreviation: NS, not significant.

oped main sprout on the rootstock with several secondary sprouts with a lesser degree of development. The main sprout of trumpetcreeper had 1.8 times more dry weight than the main sprout of redvine (Table 1). This response was mainly due to the robust growth of the main sprout in trumpetcreeper with similar growth of secondary sprouts in both species. Removal of sprouts resulted in new sprouting at a different point on the rootstock in redvine, whereas, in trumpetcreeper, new sprouting occurred at both the old and new locations on the rootstock. The above data suggest that apical dominance might be present in redvine and absent in trumpetcreeper.

Temperature Effect on Sprouting. Numbers of rootstock with sprouts were higher in trumpetcreeper than that in redvine across all temperature regimes (Figure 1). Higher sprouting was observed at 20 to 40 C in trumpetcreeper (60 to 73%) and at 30 to 40 C in redvine (45 to 47%) compared with other temperatures. At 15 C, redvine sprouting was totally inhibited, whereas trumpetcreeper had a sprouting of 12%. Trumpetcreeper (Chachalis and Reddy 2000) and redvine (Shaw et al. 1991) seed germination data from previous studies, and sprouting data in this study clearly indicate that trumpetcreeper can adapt to wider temperature regimes than redvine. Trumpetcreeper is naturally found in a wider geographical area and a more northern region of the United States than redvine (USDA-NRCS 2002).

Burial Depth Effect on Sprout Emergence. Numbers of rootstock with emerged sprouts were highest in 3-cm planting depth of redvine, and for the 3- to 9-cm planting depth in trumpetcreeper compared with deeper plantings (Figure 2). At 18-cm planting depth, emergence of sprouts was reduced by 81 and 22% in redvine and trumpetcreeper, respectively, compared with 3-cm planting depth. Emergence of propagules from 28-cm planting depth was totally inhibited in redvine, whereas trumpetcreeper had 23% sprout emergence. In other research, the maximum depth of emergence of sprouts was 90 cm for Canada thistle [*Cirsium arvense* (L.) Scop] (Donald 1994). In our study, visual observation revealed that although rootstocks produced sprouts, they failed to emerge because of lack of adequate growth. These observations imply that the rootstocks may not have enough accumulated reserves to sustain shoot growth and to develop a profuse root system needed to allow sprouts to grow up to the surface of the soil. Sprout emergence was not synchronous for all planting depths especially because emergence was delayed with increased planting depths (data not shown). In other spe-

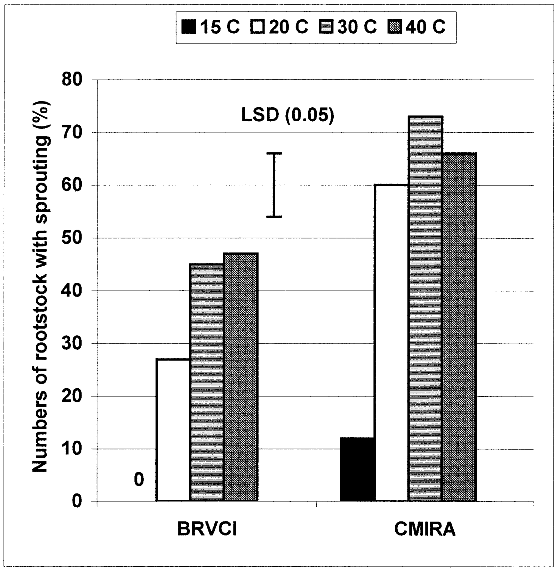

Figure 1. Effect of temperature on percent sprouting based on numbers of ten 8-cm-long rootstocks with sprouts in redvine (BRVCI) and trumpetcreeper (CMIRA).

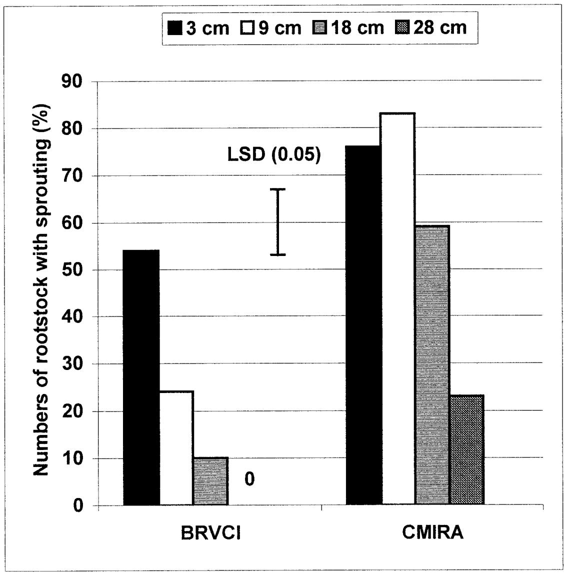

Figure 2. Effect of planting depth on percent sprouting based on numbers of ten 8-cm-long rootstocks with sprouts in redvine (BRVCI) and trumpetcreeper (CMIRA).

cies such as Jerusalem artichoke (*Helianthus tuberosus* L.), shoot emergence was remarkably synchronous for each planting depth up to 30 cm deep (Swanton and Cavers 1988).

Redvine was more prone to inhibition of sprout emergence from rootstocks at greater plantings than trumpetcreeper. One reason might be the higher amounts of accumulated reserves resulting in higher mass per unit length of rootstock in trumpetcreeper than redvine (D. Chachalis and K. N. Reddy, unpublished data). In Jerusalem artichoke, tubers were more successful than rhizomes in producing new shoots, particularly from greater soil depths presumably due to higher amount of stored carbohydrates (Swanton and Cavers 1988). Usually, fall tillage results in redistribution of rootstock segments in the soil profile. Rootstocks left on the surface of soil are more prone to be killed during winter and those buried in the soil are more likely to survive winter. In Johnsongrass [*Sorghum halepense* (L.) Pers], depth of burial greater than 40 cm was clearly related to total rhizome survival during the overwinter exposure (Warwick et al. 1986). Early sprouting, emergence, and growth of new sprouts occurs at the expense of accumulated reserves in the rootstock. Plant density may also be reduced when rootstocks buried below the 28-cm soil depth are compared with those buried up to the 18-cm soil depth.

Incorporation of rootstock segments deeper into soil by appropriate tillage (e.g., mouldboard) would be an effective means of control particularly for redvine. Deep burial has been suggested as an effective means of control in several perennial species such as bermudagrass [*Cynodon dactylon* (L.) Pers] (Satorre et al. 1996), purple nutsedge (*Cyperus rotundus* L.) (Santos et al. 1997), and Canada thistle (Donald 1994).

Rootstock Length Effect on Sprouting. The length of redvine rootstock segment was more critical for sprouting compared with trumpetcreeper (Figure 3). Rootstock segments of <2 cm had no sprouts in redvine, whereas trumpetcreeper had more than 13%. In redvine, rootstocks >4 cm length had a better chance of sprouting than those with <4 cm length. In trumpetcreeper, rootstocks segments of 2 to 8 cm had 60 to 73% sprouting. Tillage is the major mechanism by which rootstock is cut and spread around a field. This research suggests that tillage operations that produce short (less than 4 cm) rootstock segments would be more effective in reducing redvine densities compared with trumpetcreeper.

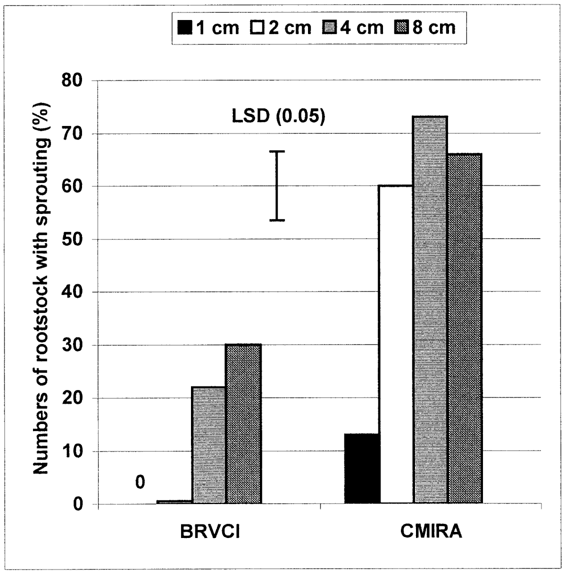

Figure 3. Rootstock length effect on percent sprouting based on numbers of ten 8-cm-long rootstocks with sprouts in redvine (BRVCI) and trumpetcreeper (CMIRA).

Depletion Study. Initial size of the segments of rootstock had a significant effect on shoot number and dry weight of both species (Figures 4 and 5). However, shoot removal had a stronger negative effect on redvine than in trumpetcreeper. In redvine, rootstock segments ≤2 cm long reached a total depletion by fifth shoot removal (15 WAP). On the contrary, redvine rootstock segments ≥4 cm had not reached a total depletion even after fifth shoot removal (15 WAP). Rootstock segments were considered depleted when they no longer produced shoots. In trumpetcreeper, total depletion was not reached by 15 WAP, regardless of rootstock length. There was no increased shoot production after the first shoot removal (3 WAP) in either species, regardless of the rootstock length. In redvine, there was no initiation of new sprouts when the only sprout produced had been removed indicating that apical dominance was not broken. In other species such as purple nutsedge, apical dominance was broken when the first shoot was removed, and a higher number of new shoots were developed after the removal (Santos et al. 1997).

^{14}C-Glyphosate Translocation along the Rootstock. Most of the ^{14}C-glyphosate was not absorbed as evident from the amount of ^{14}C-glyphosate recovered in the leaf washes. ^{14}C-glyphosate absorption, translocation, and distribution within plants were similar 4 and 8 DAT (data not shown), which is in conformity with the results of Reddy (2000). At 4 and 8 DAT, 4.5 and 5.1% of recovered ^{14}C-glyphosate, respectively, was accumulated in rootstock. ^{14}C-glyphosate applied to the shoot attached to one end of a 35-cm-long rootstock did translocate to the nontreated end of rootstock (Figure 6). The 5-cm

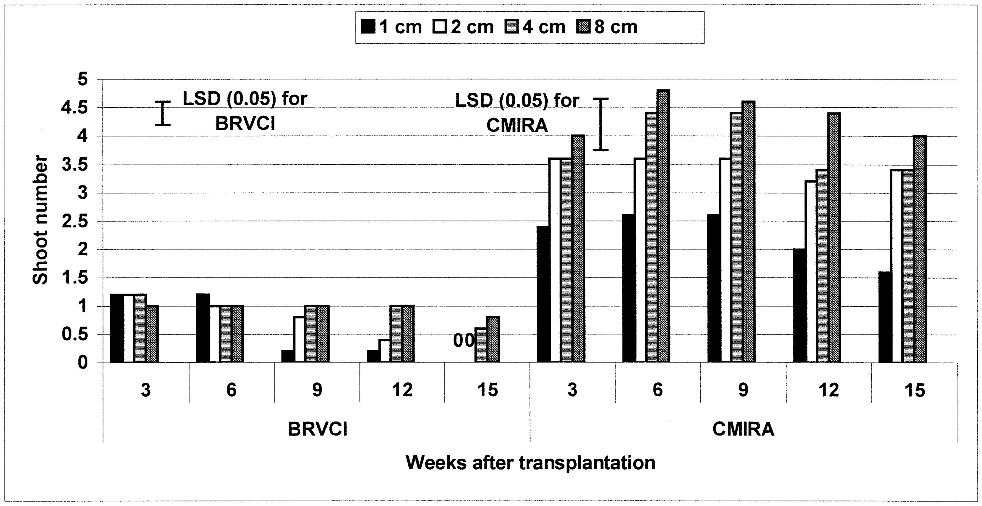

Figure 4. Effect of shoot removal on resprouting potential of rootstocks of various lengths in redvine (BRVCI) and trumpetcreeper (CMIRA) at a 3-wk interval up to 15 wk after planting.

segment represents the treated end of rootstock, and the 35-cm segment represents the nontreated end of the rootstock (Figure 6). Although, translocation of ^{14}C-glyphosate away from the site of application exhibited a declining trend, still a considerable amount has moved as far away as the 35-cm segment regardless of exposure time. Individual plants usually develop an extensive horizontal and vertical root system that extends to several meters (Elmore 1984). Presumably at distances greater than 35 cm of rootstock, a significantly lower amount of glyphosate might be translocated, resulting in the very poor control documented under field conditions (Reddy and Chachalis 2000).

The results of this research indicated that redvine sprouts exhibited a strong apical dominance compared with trumpetcreeper that had no apical dominance. The main sprout of trumpetcreeper had 1.8 times more dry weight than the main sprout of redvine. Sprouting was higher in trumpetcreeper than in redvine rootstocks across all temperature regimes (15 to 40 C). At 15 C, redvine sprouting was totally inhibited, whereas trumpetcreeper had 12% sprouting. Emergence of propagules from 28 cm depth was inhibited in redvine, whereas trumpetcreeper had 23% emergence. Redvine segments of less than 2 cm had almost no sprouts, whereas trumpetcreeper had more than 13% sprouts. Translocation of

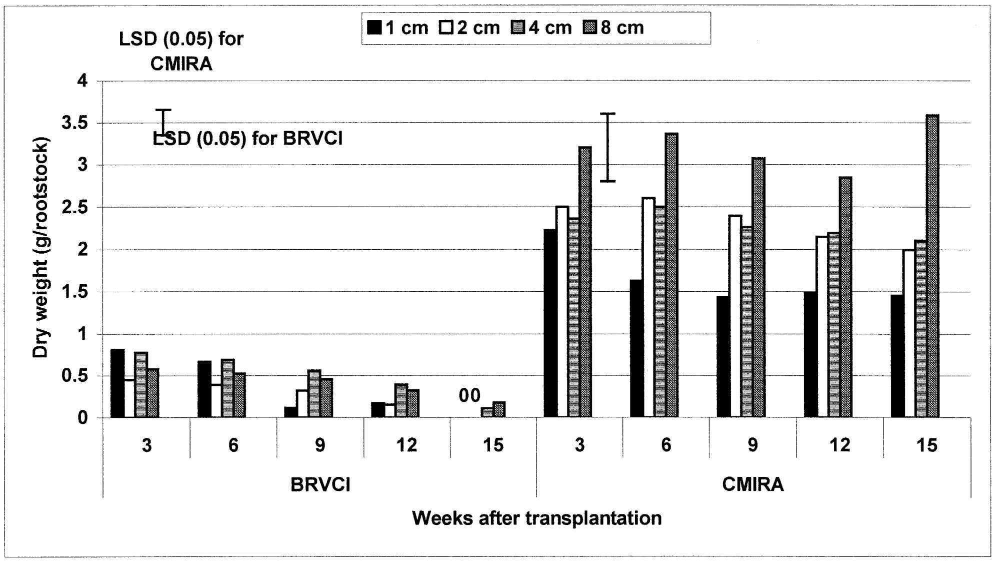

Figure 5. Effect of shoot removal on depletion of dry weight of various lengths of rootstocks of redvine (BRVCI) and trumpetcreeper (CMIRA) at a 3-wk interval up to 15 wk after planting.

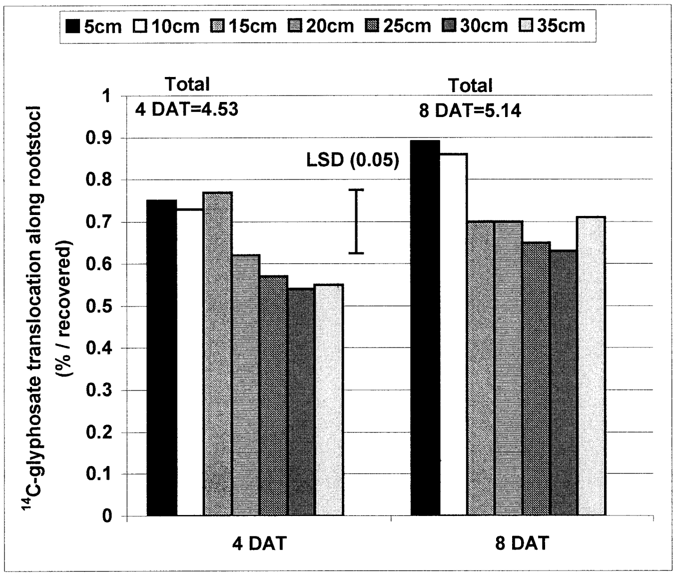

Figure 6. ^{14}C-glyphosate translocation along the rootstock in redvine at 4 and 8 d after treatment (DAT). The 5-cm segment represents the end attached to the treated shoot, and the 35-cm segment represents the untreated end of the rootstock. Plants were grown in a greenhouse and moved to a growth chamber (30/25 C day/night; 60/90% relative humidity; 14-h photoperiod) 2 d before ^{14}C-glyphosate application.

^{14}C-glyphosate was apparent from treated shoot attached to one end of a rootstock to the untreated end of a 35-cm rootstock with slightly lower amounts moving farther and farther away from the treated end. Any tillage practice that cut the rootstocks into short pieces would be more effective to reduce plant density in redvine than in trumpetcreeper.

There are several major aspects of the reproductive biology still missing in these perennial vines that have been reported in other more common perennial species such as Canada thistle or purple nutsedge. Among them are the estimation of the creeping root potential per plant, seasonal differences in regeneration capacity, wintering survival of creeping roots, time required for cold hardiness, and regenerative potential from different populations. Future research should aim toward those aspects to better understand and predict, if possible, the outcome of control measures.

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