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The Effect of Herbicides and Cultural Practices on Weed Communities in Vineyards: An Ohio Survey

Linjian Jiang, Tim Koch, Imed Dami, and Douglas Doohan*

Thirty-one Ohio vineyards were surveyed in 2004 to document weeds that persisted following weed control practices. Weeds were identified and density was determined during visits to each vineyard. Herbicide-use history, grape varieties, and grape age were recorded during interviews with the growers. Data were analyzed by SAS 9.1 with the use of the generalized linear model (GLM), and means were compared according to Student–Newman–Keuls (SNK) at the 0.05 level. Crabgrass, dandelion, pigweed, foxtail, fall panicum, clover, chickweed, common ragweed, smartweed, and oxalis were the most prevalent 10 weeds in Ohio vineyards based on relative abundance values. The frequency and density of crabgrass, dandelion, fall panicum, oxalis, and common purslane were significantly higher in vineyards in which glyphosate was the only herbicide used than in vineyards where other herbicides were applied. The number of species and density were higher in vinifera vineyards that had been hilled for winter protection than in vineyards that had not been hilled.

Nomenclature: Glyphosate; chickweed, *Stellaria media* (L.) Vill. or *Cerastium fontanum* ssp. *vulgare* (Hartman) Greuter & Burdet; clover, *Trifolium repens* L. or *Trifolium pratense* L.; common purslane (*Portulaca oleracea*); common ragweed, *Ambrosia artemisiifolia* L.; crabgrass, *Digitaria sanguinalis* (L.) Scop.; dandelion, *Taraxacum officinale* G.H. Weber ex Wiggers; fall panicum, *Panicum dichotomiflorum* Michx.; foxtail, *Setaria faberi* Herrm. or *Setaria pumila* (Poir.) Roemer & J.A. Schultes or *Setaria viridis* (L.) Beauv.; oxalis, *Oxalis corniculata* L.; pigweed, *Amaranthus hybridus* L. or *Amaranthus retroflexus* L.; smartweed, *Polygonum pensylvanicum* L.; vinifera grape, *Vitis vinifera* L.

Key words: Glyphosate resistant, vineyard, vinifera, weed survey.

Growing wine grapes is a rapidly expanding industry in the United States. The number of licensed wineries in Ohio, Indiana, Michigan, Illinois, and Missouri almost doubled from 1997 to 2004 (Dami et al. 2005). Ohio is one of the top 10 wine-producing states with more than 1.9 million liters produced every year (Ohio Grape Industries Committee, 2007). In surveys conducted during the previous yr, Ohio grape growers have identified weeds as a major factor limiting vineyard productivity and expansion (The Ohio Grape Team, unpublished data). Similar rankings have been made by growers in other states, as reflected by the research priorities published by the Viticulture Consortium East (2007). A recent survey of Ohio viticulturists showed that weeds were even more difficult to control than insects and diseases (Dami et al. 2006). Weeds can compete with grape for nutrients, sunlight, and water, resulting in losses in yield. Weeds also serve as habitat for other pests, thereby contributing to damage by insects and diseases (Dami et al. 2005).

The nonselective herbicide glyphosate was licensed for use in orchard crops during the product's early commercial development, and its use has been widely adopted by growers. In Ohio, glyphosate applications are a preferred weed management method of many grape growers because of the herbicide effectiveness and lack of soil activity. However, the emergence of glyphosate-resistant biotypes is a concern that has not escaped the viticulture industry. Such concerns have escalated since Roundup Ready® soybean, corn, and cotton crops have attained dominance in the U.S. market (Duke 2005). New glyphosate-resistant biotypes continue to be reported. The current list of glyphosate-resistant species is common waterhemp (*Amaranthus rudis* Sauer), common ragweed, giant ragweed (*Ambrosia trifida* L.), hairy fleabane [*Conyza bonariensis* (L.) Cronq.], horseweed [*Conyza canadensis* (L.) Cronq.], goosegrass [*Eleusine indica* (L.) Gaertn.], wild poinsettia (*Euphorbia heterophylla* L.), Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot], rigid ryegrass (*Lolium rigidum* Gaudin), buckhorn plantain (*Plantago lanceolata* L.), Johnsongrass [*Sorghum halepense* (L.) Pers.] (Heap 2006) and Palmer amaranth (*Amaranthus palmeri* S. Wats.) (Culpepper et al. 2006). Of these, hairy fleabane, horseweed, goosegrass, Italian ryegrass, rigid ryegrass, and buckhorn plantain have been found in glyphosate-treated orchards or vineyards (Heap 2006). Thus, fear among Ohio grape growers that glyphosate resistance might develop or spread into local vineyards is strong. Determining the prevalence of potentially resistant biotypes was an impetus to conduct the survey reported in this work.

As previously described, weed management is one of the most serious problems encountered by Ohio grape growers. Currently, three types of grape are grown in the Midwest region: American, French hybrid, and European (*Vitis vinifera* L.), also referred to as vinifera grapes. Vinifera grapes are required for production of high-value wines, and most new vineyards in the state are planted to vinifera varieties. The vinifera grape is more difficult to grow because of its cold- and grape phylloxera sensitivity. American and French hybrid grape varieties are more tolerant of both colder temperatures and phylloxera than are vinifera. To protect vinifera grapes from the aphid-like phylloxera it must be grafted on American grape rootstocks, which are resistant to this pest. However, the graft union must be protected from low winter temperatures so that it can be used to generate a new vine if the grape trunk is damaged. Currently, winter protection is achieved by

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* Current Graduate Student, Research Assistant, Assistant Professor, and Associate Professor, respectively, Department of Horticulture and Crop Science, The Ohio State University/Ohio Agricultural Research and Development Center, Wooster, OH 44691. Corresponding author's E-mail: doohan.1@osu.edu

covering the graft union with several inches of soil in autumn. The mounded soil must be removed each spring to prevent scions from forming roots (Dami et al. 2005), or the plant will lose phylloxera resistance. The annual process of building an insulating hill of soil in autumn and removing the hill in spring may complicate weed management for growers and affect weed community structure; however, the impact has not been measured. Excessive soil tillage is known to change soil structure (Shepherd et al. 2001), and may dilute soil-active herbicides, bring weed seeds close to the soil surface and stimulate weed seed germination.

In 2004, we surveyed 31 Ohio vineyards with three objectives in mind: (1) determine which weeds persisted after control practices were completed, (2) compare weed communities between hilled and nonhilled vineyards, and (3) detect weed species potentially resistant to glyphosate.

Materials and Methods

Questionnaires on vineyard weed problems and weed management methods were mailed to 90 Ohio grape growers in 2004, and 36 responses were received. We visited these 36 vineyards and selected 31 for data collection (Figure 1). Survey vineyards were located throughout the state, but somewhat clustered in three geographic regions: Lake Erie area, which is part of the Lake Erie appellation; southwest Ohio, which is part of the Ohio River Valley appellation; and central Ohio, which is between the two appellations.

Vineyards were surveyed from July to September; about 2 to 3 wk after the last herbicide application. Each grower provided us with a block of grapevines ranging from 0.33 to several acres that contained vines planted at the same time, had received homogeneous management for several years, and was representative of the general weed problems in their vineyard.

Weeds under the grape trellis were identified and counted in 20 quadrats (25 × 25 cm) dropped at random along two diagonal line transects in each field. Weeds showing severe injury likely to cause death in response to herbicide treatment were not counted. It was not always possible to differentiate recently emerged seedlings of certain species clearly. In such cases a general common name was used. For example, data tabulated as foxtail may include giant foxtail, yellow foxtail, and green foxtail. Information on herbicide applications, vineyard age, grape variety, and cultural practices was gathered by interviewing growers.

Weed frequency, field uniformity, mean field density, mean occurrence field density, relative frequency, relative field uniformity, relative mean field density, and relative abundance were calculated according to the method of Thomas (1985). Frequency of a species was the number of the fields where this species occurred expressed as a percentage of the total number of surveyed fields (31 vineyards). Field uniformity (FU) of a species was the number of quadrats where this species occurred expressed as a percentage of all the surveyed quadrats (31 × 20). Mean field density (MFD) refers to the number of individuals of a species per square meter and was calculated by totaling seedling number of a species in each field and dividing by the total number of fields (31 vineyards). Mean occurrence field density (MOFD) refers to the density when only occurrence fields are included in the area determination. Throughout this article relative abundance (RA) is frequently reported. Relative abundance summarizes frequency, field uniformity and mean field density into one value to facilitate comparisons across species. Relative abundance for a species is the sum of relative frequency, relative field uniformity, and relative mean field density for that species. The relative values for frequency, field uniformity, and mean field density for a species express those statistics for the species as a percentage of each variable summed across all species. For example, relative frequency of a species was the frequency of this species over the sum of the frequency of all species in this survey. Weed management strategies were summarized according to the prevailing herbicides (or lack of) used in each vineyard: no herbicide, glyphosate only, glyphosate + preemergence herbicide, and paraquat + preemergence herbicide. Preemergence herbicide was either simazine (6-chloro-*N*,*N*′-diethyl-1,3,5-triazine-2,4-diamine), diuron (*N*′-(3,4-dichlorophenyl)-*N*,*N*-dimethylurea) or dichlobenil (2,6-dichlorobenzonitrile). Data were analyzed by SAS 9.1 with the use of the GLM model. Means were compared by Student-Newman-Keuls (SNK) at the 0.05 level. The main factors were weed management strategies, tillage intensity (hilled or nonhilled), and geographic regions of Ohio.

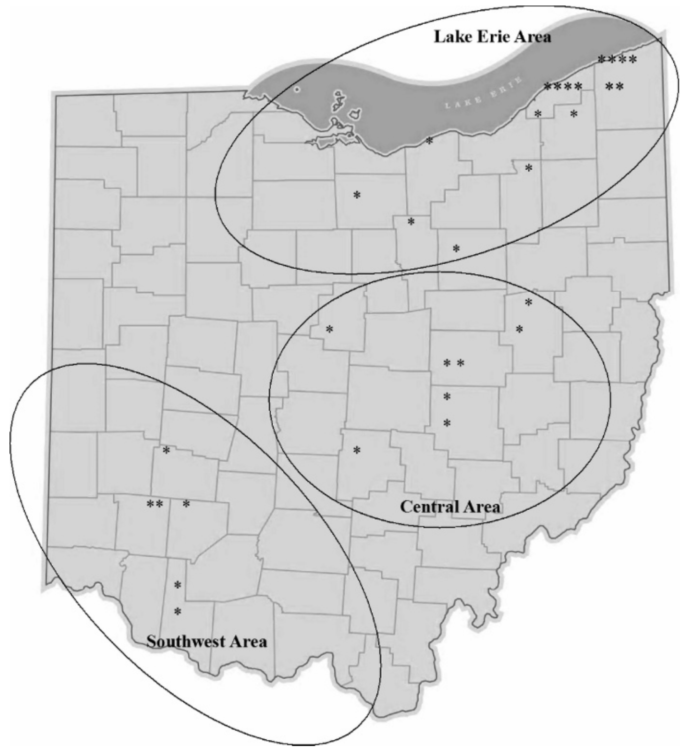

Figure 1. Geographical distribution of surveyed vineyards across Ohio. Asterisk marks the location of survey vineyards.

Results and Discussion

Weeds Surviving Control Practice in Ohio Vineyards. Fifty-three weed species were identified in the 31 vineyards included in this survey (Table 1). The top 10 weeds in relative abundance were crabgrass, dandelion, pigweed, foxtail, fall panicum, clover, chickweed, common ragweed, smartweed, and oxalis. Respective relative abundance (RA) values for these weeds were 44.2, 25.4, 17.7, 17.1, 14.3, 11.6, 11.3, 10.6, 10.3, and 9.3 (Table 1). Although the ranking of weed species differed in the lists based on field uniformity (FU), mean field density (MFD), or mean occurrence field density (MOFD), crabgrass consistently was at the top. This result indicates that crabgrass is clearly the most important grass weed in Ohio vineyards in early summer.

Certain species were unevenly distributed across the state (data not reported). Annual bluegrass, common chickweed, dandelion, common groundsel, and quackgrass [*Elymus repens* (L.) Gould] were more prevalent in the Lake Erie appellation than in central Ohio or in the Ohio River Appellation. Common purslane and clover were more prevalent in central Ohio, whereas crabgrass and prickly sida were more common near the Ohio River in the southwest corner of the state.

Examining the entire data set indicates that broadleaf weeds are more prevalent than grasses in Ohio vineyards; for example, there are 13 broadleaf species with a summed RA value of 116, 6 grass species with a summed RA value of 101, and 1 nutsedge species among the top 20 weeds (Table 1). Dandelion and pigweed species were the two most abundant broadleaf weeds. Dandelion occurred in 87.1% of the total surveyed vineyards and 28.2% of the total surveyed quadrats, and had similar MFD and MOFD values of 16.7 and 19.1 plants/m^2, respectively (Table 1). The characteristic of dandelion to flower in spring and in autumn (Stewart-Wade et al. 2002) may contribute to the species' ability to colonize bare strips under the grape trellis in the fall when preemergence herbicide residues in the soil are low or nonexistent. Also, at that time of year growers may be less vigilant. Dandelions' regular occurrence in turf, coupled with tight restrictions on the use of 2,4-D in vineyards (Dami et al. 2005; Stewart-Wade et al. 2002), probably further contributes to ready growth in the grass-covered alleys between rows and dispersion to bare ground maintained under the grape plants. In contrast to dandelion, pigweed had a much higher MOFD (42.2 plants/m^2) than MFD (19.1 plants/m^2), suggesting that pigweed flourished in the particular vineyards where it occurred (Table 1). Significantly higher pigweed density in the herbicide-free (no-herbicide) vineyards (Table 2) no doubt contributed to the difference between MFD and MOFD, as well as the relatively low frequency and FU. These results indicate that herbicide-based weed management programs for vineyards are controlling pigweed effectively (Table 2), even though resistance to different herbicides including ALS inhibitors, photosystem II inhibitors, and glyphosate has been reported (Heap 2006).

Annual weeds dominated in Ohio vineyards, with the significant exemption of dandelion. Other than crabgrass the density of annual weeds in occurrence fields (MOFD) was much higher than mean field density (MFD), suggesting that site-specific and/or management-specific factors were contributing to survival of most annual weed species. Annual bluegrass, prickly sida (*Sida spinosa* L.), common purslane, groundsel (*Senecio vulgaris* L.), and eastern black nightshade (*Solanum ptychanthum* Dunal) had MOFD values that were more than 10 plants/m^2 and at least three times higher than MFD. For example, annual bluegrass had a MOFD of 30 plants/m^2, and a MFD of 8.7 plants/m^2 (Table 1). The low frequency (29%) and FU (5.3%) contribute to the difference between MOFD and MFD. Unlike pigweed, no significant difference was shown for annual bluegrass control using different herbicide management programs (Table 2), suggesting that herbicide application did not contribute to the difference between MOFD and MFD. In contrast, herbicide application could contribute to the difference between MOFD and MFD for fall panicum, which had a significantly higher density when glyphosate was applied alone (Table 2). Some perennial weeds, such as quackgrass, nimblewill (*Muhlenbergia schreberi* J.F. Gmel.) and wirestem muhly [*Muhlenbergia frondosa* (Poir.) Fern.] also had a much higher MOFD than MFD (Table 1). Quackgrass had a significantly higher density in herbicide-free vineyards than in other vineyards (Table 2); which contributed to the difference between MOFD and MFDD. Wirestem muhly was observed to occur in only one vineyard, where paraquat combined with a preemergence herbicide was applied twice per year. As pointed out by Czapar and Fawcett (1997), wirestem muhly has become problematic in some regions of the north central states (Ohio included). Therefore, wirestem muhly should be watched closely in vineyards with similar herbicide management programs.

Effect of Weed Management Programs on the 20 Most Abundant Weed Species. Analysis of the effect of management on the weed community was restricted to the 20 most abundant species for which the effect was relatively clear (Table 2). Because an important objective of this survey was to detect prevalence of potentially glyphosate resistant biotypes, the glyphosate-alone program was the primary focus.

Crabgrass, dandelion, clover, fall panicum, oxalis, and common purslane had a significantly higher density when glyphosate was used alone than with other herbicide-based management programs. Resistance might explain the higher density of these weeds when glyphosate was used alone; however, confirming resistance was beyond the scope of this survey, and it has not been reported for these species elsewhere (Heap 2006). It is likely that other factors contribute to survival of these weeds in vineyards where glyphosate is used exclusively. For instance, seedling establishment and reproduction during intervals between glyphosate applications may enable summer annuals to perpetuate. Similarly, dandelions may establish in autumn after the final glyphosate treatment is applied and flower in spring before weed control activities commence. However, the observed relationship between these weeds and glyphosate-only weed control suggests that glyphosate resistance may be developing in these weed species and justifies close monitoring in the future. One in three weed scientists surveyed by Culpepper (2006) thought grasses would increase in response to a glyphosate-alone program in glyphosate-resistant field crops. This speculation is supported by the results of this survey, which showed that crabgrass flourished in vineyards managed with glyphosate alone (Table 2).

Table 1. Relative abundance (RA), frequency (F), field uniformity (FU), mean field density (MFD), and mean occurrence field density (MOFD) of weeds in Ohio vineyards. The number in parentheses is the ranking number of this weed species based on RA value.

RA rank	Common name	Scientific name	RA	F	FU	MFD	MOFD
			——— % ———			—— plants/m^2 ——	
(1)	Crabgrass	*Digitaria sanguinalis* (L.) Scop.	44.2	83.9	34.0	51.4	61.3
(2)	Dandelion	*Taraxacum officinale* G.H. Weber ex Wiggers	25.4	87.1	28.2	16.7	19.1
(3)	Pigweed	*Amaranthus hybridus* L. or *Amaranthus retroflexus* L.	17.7	45.2	13.2	19.1	42.2
(4)	Foxtail	*Setaria faberi* Herrm. or *Setaria pumila* (Poir.) Roemer & J. A. Schultes or *Setaria viridis* (L.) Beauv.	17.1	64.5	16.3	12.5	19.4
(5)	Fall panicum	*Panicum dichotomiflorum* Michx.	14.3	58.1	10.8	12.0	20.7
(6)	Clover	*Trifolium repens* L. or *Trifolium pratense* L.	11.6	51.6	12.6	6.0	11.7
(7)	Chickweed	*Stellaria media* (L.) Vill. or *Cerastium fontanum* ssp. *vulgare* (Hartman) Greuter & Burdet	11.3	41.9	9.8	9.0	21.5
(8)	Common ragweed	*Ambrosia artemisiifolia* L.	10.6	51.6	12.7	3.8	7.4
(9)	Smartweed	*Polygonum pensylvanicum* L.	10.3	58.1	11.2	3.6	6.1
(10)	Oxalis	*Oxalis corniculata* L.	9.2	48.4	10.5	3.3	6.9
(11)	Barnyard grass	*Echinochloa crus-galli* (L.) Beauv	9.0	45.2	7.4	5.7	12.6
(12)	Plantain	*Plantago lanceolata* L. or *Plantago major* L.	8.5	38.7	9.4	4.3	11.1
(13)	Annual bluegrass	*Poa annua* L.	8.5	29.0	5.3	8.7	30.0
(14)	Common lambsquarters	*Chenopodium album* L.	7.8	45.2	6.9	3.6	7.9
(15)	Quackgrass	*Elymus repens* (L.) Gould	7.7	25.8	7.7	5.8	22.6
(16)	Prickly sida	*Sida spinosa* L.	7.4	22.6	4.5	8.2	36.1
(17)	Dock	*Rumex crispus* L. or *Rumex obtusifolius* L.	6.0	38.7	4.0	3.2	8.3
(18)	Common purslane	*Portulaca oleracea* L.	5.8	22.6	7.1	3.0	13.1
(19)	Yellow nutsedge	*Cyperus esculentus* L.	5.6	35.5	4.4	2.6	7.3
(20)	Virginia copperleaf	*Acalypha virginica* L.	4.7	29.0	4.4	1.7	5.8
(21)	Canada thistle	*Cirsium arvense* (L.) Scop.	4.5	25.8	4.4	1.8	6.8
(22)	Ground ivy	*Glechoma hederacea* L.	4.3	25.8	4.0	1.7	6.4
(23)	Groundsel	*Senecio vulgaris* L.	4.0	16.1	4.5	2.3	14.1
(24)	Indian tobacco	*Lobelia inflata* L.	3.9	19.4	3.6	2.2	11.3
(25)	Horsenettle	*Solanum carolinense* L.	3.6	29.0	2.7	0.7	2.5
(26)	Nimblewill	*Muhlenbergia schreberi* J.F.Gmel.	3.5	16.1	1.9	3.1	19.4
(27)	Red sorrel	*Rumex acetosella* L.	3.1	19.4	1.9	1.8	9.1
(28)	Carpetweed	*Mollugo verticillata* L.	2.4	16.1	2.3	0.7	4.5
(29)	Eastern black nightshade	*Solanum ptychanthum* Dunal	2.2	12.9	1.5	1.4	10.8
(30)	Knotweed	*Polygonum arenastrum* Boreau	2.2	19.4	1.6	0.3	1.3
(31)	Sowthistle	*Sonchus oleraceus* L.	2.0	12.9	1.9	0.6	4.6
(32)	Pokeweed	*Phytolacca americana* L.	1.5	12.9	1.0	0.3	2.0
(33)	Wild carrot	*Daucus carota* L.	1.4	12.9	1.0	0.2	1.4
(34)	Marestail	*Hippuris vulgaris* L.	1.3	12.9	0.7	0.2	1.6
(35)	Bigroot morningglory	*Ipomoea pandurata* (L.) G.F.W. Meyer	1.3	6.5	1.8	0.3	5.2
(36)	White campion	*Silene latifolia* Poir.	1.3	9.7	1.1	0.3	3.2
(37)	Galinsoga	*Galinsoga quadriradiata* Cav.	1.2	9.7	0.7	0.4	4.5
(38)	Bramble	*Rubus* spp.	1.1	9.7	0.8	0.2	2.1
(39)	Honeyvine milkweed	*Funastrum cynanchoides* (Dcne.) Schlechter	1.1	9.7	0.8	0.2	2.1
(40)	Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	1.1	6.5	1.0	0.5	7.2
(41)	Hemp dogbane	*Apocynum cannabinum* L.	1.0	9.7	0.7	0.1	1.1
(42)	Spurge	*Chamaesyce maculata* (L.) Small	1.0	9.7	0.7	0.1	1.1
(43)	Wild mustard	*Sinapis arvensis* L.	1.0	9.7	0.5	0.2	1.9
(44)	Devil's beggarticks	*Bidens frondosa* L.	1.0	9.7	0.5	0.1	1.3
(45)	Velvetleaf	*Abutilon theophrasti* Medik.	0.8	6.5	0.3	0.4	6.4
(46)	Speedwell	*Veronica persica* Poir.	0.8	6.5	0.7	0.2	2.4
(47)	Bindweed	*Calystegia sepium* (L.) R. Br. Or *Convolvulus arvensis* L.	0.8	6.5	0.7	0.1	1.6
(48)	Buttercup	*Ranunculus parviflorus* L.	0.8	3.2	1.0	0.3	9.6
(49)	White heath aster	*Symphyotrichum pilosum* (Willd.) Nesom	0.7	6.5	0.5	0.1	1.6
(50)	Wirestem muhly	*Muhlenbergia frondosa* (Poir.) Fern.	0.7	3.2	0.3	0.7	22.4
(51)	Groundcherry	*Physalis heterophylla* Nees or *Physalis longifolia* (Nutt.) var. *subglabrata* (Mackenzie & Bush) Cronq.	0.7	6.5	0.3	0.1	1.2
(52)	Cinquefoil	*Potentilla recta* L.	0.7	6.5	0.3	0.1	0.8
(53)	Wild buckwheat	*Polygonum convolvulus* L.	0.3	3.2	0.2	0.0	0.8

Management of crabgrass, dandelion, clover, fall panicum, oxalis, and common purslane was greatly improved when glyphosate was used in conjunction with a preemegence herbicide (glyphosate + residual) (Table 2). This observation indicates that preemergence herbicides efficiently prevented new seedlings from developing between herbicide applications. This also supports our suggestion that the higher density observed under the glyphosate-alone program was due to the germination of weed seeds after glyphosate application (Tharp and Kells 2002). However, this may not be true in every case, because multiple glyphosate applications were used by some farmers under the glyphosate-alone program. Glyphosate was used two or more times per season in 7 of the 11 vineyards in which the herbicide was used alone. In

Table 2. The effect of herbicide management program on density of 20 dominant weed species based on the Relative Abundance statistic.

Weed species	Density[a]			
	Nonchemical	Glyphosate	Paraquat + residual[b]	Glyphosate + residual[b]
	plants/m^2			
Annual bluegrass (*Poa annua* L.)	0.2 a	0.1 a	0.4 a	1.0 a
Barnyardgrass	0.9 a	0.5 ab	0.0 b	0.1 ab
Crabgrass	3.9 b	25.7 a	1.7 b	8.2 b
Chickweed[c]	0.1 b	1.8 a	0.0 b	0.8 ab
Clover[c]	0.7 ab	1.9 a	0.0 c	0.1 bc
Common purslane	0.0 b	0.7 a	0.0 b	0.1 b
Common ragweed	1.2 a	0.5 a	0.0 b	0.3 a
Dock (*Rumex crispus* L. or *Rumex obtusifolius* L.)[c]	0.1 a	0.3 a	0.0 a	0.0 a
Dandelion	3.0 b	14.7 a	0.0 c	0.3 c
Fall panicum	0.0 b	2.7 a	0.1 b	0.0 b
Foxtail[c]	1.4 b	0.6 b	16.9 a	1.8 b
Lambsquarters (*Chenopodium album* L.)	0.2 a	0.2 a	0.0 a	0.2 a
Oxalis	0.5 ab	0.9 a	0.0 c	0.1 bc
Pigweed[c]	5.2 a	0.4 bc	0.0 c	2.6 ab
Plantain[c]	0.9 b	0.3 bc	7.7 a	0.0 c
Prickly sida	0.0 a	0.0 a	0.0 a	1.0 a
Quackgrass	8.5 a	0.0 b	0.3 b	0.0 b
Smartweed	1.4 a	0.1 b	0.0 b	0.6 a
Virginia copperleaf (*Acalypha virginica* L.)	0.0 ab	0.3 a	0.0 b	0.0 ab
Yellow nutsedge (*Cyperus esculentus* L.)	0.0 b	0.0 b	1.2 a	0.1 b

[a] Means within species followed by different letters are significantly different according to the Student–Newman–Keuls test ($P < 0.05$) Square-root transformation was applied to density (plants/m^2) before statistical analysis. Square-root data were back transformed for presentation.

[b] Residual herbicide = simazine or diuron or dichlobenil.

[c] Pigweed = redroot and smooth; foxtail = giant, yellow, and green; clover = red and white; chickweed = common and mouseear; plantain = broadleaf and buckhorn; dock = broadleaf and curly.

contrast, when glyphosate was used in combination with a preemergence herbicide (glyphosate + residual), glyphosate was applied only once per season in 8 out of 11 vineyards. Multiple applications of glyphosate per season is a known factor that increases the probability of resistance development (Heap 1997) and is likely to have decreased the ability for susceptible populations to establish and reproduce between glyphosate applications.

Other factors in addition to possible glyphosate resistance may contribute to the higher density of crabgrass, dandelion, clover, fall panicum, oxalis, and common purslane. Ohio grape growers regularly mow the grass-covered alleyways between rows of grapes. Mowing may benefit species such as dandelion and clover, which flourish in the absence of a heavy turf canopy. Growers often neglect to control broadleaf weeds growing in the grass alleyways between the rows, thereby providing a ready nearby source of seeds for reinfestation. Perennial root stocks of uncontrolled perennials such as morningglory [*Ipomoea pandurata* (L.) G.F.W. Meyer] and Canada thistle [*Cirsium arvense* (L.) Scop.] are likely to invade the trellis area where weed control has been maintained. This may also be a factor contributing to the invasion of the undertrellis area by crabgrass due to its creeping stems. This speculation is supported by the Kim et al. (2002) survey, which showed crabgrass was a common weed that flourishes in turf in the northern region.

Weed Density in Hilled and Nonhilled Vineyards. The data analysis revealed that 18 species had significantly different populations in hilled versus nonhilled vineyards (Table 3). Crabgrass, foxtail, and common purslane were more prevalent in nonhilled vineyards; 15 other species were more prevalent in hilled vineyards (Table 3). Invariably, hilling vineyards resulted in more severe weed problems.

Changes in weed communities and population density in response to different tillage practices have been observed by other researchers (Ball and Miller 1993; Tuesca et al. 2001). Tuesca et al. (2001) reported that broadleaf species had higher populations under conventional tillage than nontillage. A similar result was also observed in this survey considering that the hilling practice constitutes a more intense tillage regime. Of the 15 species that had higher population densities in hilled vinifera vineyards; 13 species were broadleaf weeds (Table 2). Tuesca et al. (2001) also found wind-dispersed species increased in no-till wheat/soybean rotation fields; however, in our survey wind-dispersed species such as dandelion had a higher population in hilled vineyards. Hilled soil may capture more windborne seeds during early spring when dandelion is dispersing. Increased tillage aerates soil and may provide a more suitable habitat for seedling establishment. During establishment of the hill deeply buried weed seeds are likely to be brought close to the soil surface where germination is most likely to occur. Simultaneously, concentration of residual herbicides in the soil is likely to be diluted. It is also possible that residual herbicides may leach more readily from the tilled soil in the hill (Gish et al. 1995).

Currently there are no widely accepted alternatives to hilling for winter protection of vinifera grapes. However, the practice may not be sustainable in some vineyards because it contributes

Table 3. The effect of hilling practice on weed species density.

Weed species	Density[a]	
	Vinifera (hilled)	Nonvinifera (nonhilled)[b]
	plants/m^2	
Barnyardgrass	0.96 a	0.15 b
Clover[c]	1.06 a	0.39 b
Common ragweed	0.81 a	0.33 b
Crabgrass	3.47 b	15.90 a
Dandelion	5.98 a	2.83 b
Foxtail[c]	0.78 b	2.17 a
Groundsel	0.54 a	0.01 b
Hemp dogbane (*Apocynum cannabinum* L.)	0.01 a	0.00 b
Horsenettle (*Solanum carolinense* L.)	0.06 a	0.01 b
Knotweed (*Polygonum arenastrum* Boreau)	0.02 a	0.00 b
Lambsquarters	0.61 a	0.07 b
Oxalis	1.26 a	0.12 b
Plantain[c]	0.73 a	0.21 b
Common purslane	0.01 b	0.31 a
Quackgrass	2.05 a	0.09 b
Smartweed	0.74 a	0.25 b
Sowthistle (*Sonchus oleraceus* L.)	0.06 a	0.00 b
White campion	0.03 a	0.00 b

[a] Means within species followed by different letters are significantly different according to the Student–Newman–Keuls test ($P < 0.05$) Square-root transformation was applied to density (plants/m^2) before statistical analysis. Square-root data were back transformed for presentation.

[b] Nonvinifera = American or French hybrid grape varieties.

[c] Foxtail = giant, yellow, and green; clover = red and white; plantain = broadleaf and buckhorn.

to loss of soil structure and creates conditions conducive to soil erosion (Bhatt and Khera 2006; Kurtural 2005). The heavier weed problems observed among hilled vineyards in this study suggest further incentive to look for alternative methods to protect vinifera vineyards from winter injury.

This survey demonstrated that weed communities present in Ohio vineyards were affected by herbicide programs and by the hilling practice used in vinifera vineyards. This survey also indicated that crabgrass, foxtail, fall panicum, annual bluegrass, barnyard grass [*Echinochloa crus-galli* (L.) Beauv.] and quackgrass were dominant grass species, and that dandelion, pigweed, clover, common ragweed and smartweed were the most prevalent broadleaf species in Ohio vineyards. Considering that improving weed control is a priority of viticulturist throughout the United States, these results indicate that a focus is needed on these species. This survey also indicated that glyphosate resistance or tolerance might play a role in the significantly higher populations of crabgrass, dandelion, fall panicum, oxalis, and common purslane in those vineyards where glyphosate was applied alone. However, growers are likely to minimize both the competitive impact of these weeds and the probability of resistance by including a preemergence herbicide with glyphosate applications. Several weed species had higher populations in hilled vineyards (vinifera), indicating that this practice along with the potential to increase likelihood of soil erosion, is incentive to develop alternate methods of winter protection.

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