Performance of ‘Chambourcin’ Winegrape on Nematode-resistant Rootstocks in Missouri

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SUMMARY. One of the most popular winegrapes (*Vitis* sp.) for red wine production in the midwestern United States is ‘Chambourcin’, a French-American hybrid. It is typically produced on own-rooted vines in the region, but the potential benefits of grafting it to improved rootstocks are becoming better-known. Nematodes present occasional serious winegrape production challenges in the midwestern United States, and are capable of transmitting pathogenic viruses. New rootstocks developed by University of California, Davis (UCD GRN series) are resistant to several species and races of nematodes, but have not been evaluated under midwestern U.S. production conditions. A study with ‘Chambourcin’ grafted to four of these new nematode-resistant rootstocks (‘UCD GRN-2’, ‘UCD GRN-3’, ‘UCD GRN-4’, and ‘UCD GRN-5’) and ‘Couderc 3309’, along with own-rooted vines was established in 2010 in southwest Missouri, and fruited in 2013–15. Three of the nematode-resistant rootstocks (GRN-2, 3, 4) performed as well as the standard ‘Couderc 3309’ and own-rooted vines, with yields among all rootstocks ranging from 10 to 13 kg/vine. The rootstock ‘UCD GRN-5’ generally performed poorly, however, manifested by low pruning weights and a high Ravaz index value (25) in 2013 that necessitated defruiting the vines in 2014. Fruit yields on ‘UCD GRN-5’ rootstocks were satisfactory in 2013 and 2015, but the vines eventually deteriorated, with 99% shootless nodes by 2017. Although more evaluations of these new rootstocks are needed in the midwestern United States, we conclude that ‘UCD GRN-2’, ‘UCD GRN-3’, and ‘UCD GRN-4’ show promise, whereas ‘UCD GRN-5’ does not appear suitable for growing conditions in southern Missouri.

‘Chambourcin’ winegrape (*Vitis* sp.) is a French-American hybrid with a complex pedigree based on Seibel hybrids, released in 1963 (Robinson et al., 2012; UCD, 2020). It is a moderately vigorous and highly productive cultivar for the midwestern United States that produces

a red wine favored by regional consumers. With good management, ‘Chambourcin’ can be economical to produce (Bordelon, 2009; Dami et al., 2005). Most of ‘Chambourcin’ grown in Missouri and the midwestern United States are own-rooted vines. Although the use of rootstocks offers numerous potential benefits in U.S. viticulture (Christensen, 2003), the horticultural and economic advantages of using rootstocks with ‘Chambourcin’ in the midwestern United States have not yet been satisfactorily demonstrated (Thomas et al., 2017).

Nematodes, especially root-knot (*Meloidogyne* sp.), dagger (*Xiphinema* sp.), and root lesion (*Pratylenchus* sp.), create sporadic serious viticultural production challenges in the midwestern United States, although notable economic damage is often confined to specific soils and environments (e.g., Bird et al., 1994; Pokharel et al., 2015; Townshend et al., 1975). Nematodes can weaken plants and reduce yields through physical feeding injury to roots, interfering with transport of water and nutrients, fomenting disease, and diverting plant nutrients into the production of galls (Bridge and Starr, 2007). Certain nematodes, especially dagger nematodes, can vector harmful viruses, such as *Grapevine fanleaf virus* and *Tomato ringspot virus* (McKenry and Bettiga, 2013; Powell et al., 1990; van Zyl et al., 2012; Villate et al., 2008). Traditional methods to address nematode incidence and damage include the use of soil fumigants and nematicides, and long-term fallowing of land planted to vineyards. Resistant rootstocks have now become one of the most important and effective nematode management strategies in viticulture (Esmenjaud et al., 2011; Ferris et al., 2012).

Milkus (2001) documented two nematode-transmitted viruses (*Tomato ringspot virus* and *Arabidopsis mosaic virus*) in five Missouri vineyards, and identified american dagger nematode (*Xiphinema americanum*) in all vineyards sampled. J. Schoelz and D. Volenberg (unpublished data) also identified *Tomato ringspot virus* in Missouri vineyards and confirmed dagger nematodes (species not determined) in one-third of vineyards sampled. A detailed survey of 30 vineyards in Missouri and Arkansas in 2008 (R.T. Robbins, R.K. Striegler,

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
0.4047	acre(s)	ha	2.4711
102.7902	acre-inch(es)	m ³	0.0097
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.4882	lb/ft	kg·m ⁻¹	0.6720
28.3495	oz	g	0.0353
2.2417	ton(s)/acre	Mg·ha ⁻¹	0.4461
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

J.L. Harris, R.A. Allen, T. Kirkpatrick, and E.A. Bergmeier, unpublished data) identified two nematode genera (root-knot, root lesion) and one distinctive species (american dagger nematode) of economic importance. In that study, 93% of vineyards surveyed showed presence of american dagger nematode, with 80% having populations at medium to high levels defined by McKenry and Bettiga (2013) and for which mitigation measures may be warranted. Because american dagger nematode is known to vector *Tomato ringspot virus* in grapes, and root-knot and root lesion nematodes are known to cause economic damage to grapevines (McKenry and Bettiga, 2013), efforts to explore the application of nematode-resistant rootstocks in midwestern U.S. viticulture are justified.

Five nematode-resistant rootstocks ('UCD GRN-1', 'UCD GRN-2', 'UCD GRN-3', 'UCD GRN-4', and 'UCD GRN-5'), derived from various complex genetic combinations of multiple grape species were released by University of California-Davis (UCD) in 2008 and patented in 2009–10 (Ferris et al., 2012; Walker and Ferris, 2009). These rootstocks were selected for broad and stable resistance to nematodes, ease of grafting, appropriate vigor, and other favorable attributes. All have been shown to be resistant to root-knot nematode (*Meloidogyne incognita* Race 3, *M. incognita* pathotype Harmony C, *Meloidogyne arenaria* pathotype Harmony A) and dagger nematode (*Xiphinema index*), and moderately resistant or moderately susceptible to root lesion nematode (*Pratylenchus vulnus*), pin nematode (*Paratylenchus hamatus*), ring nematode (*Mesocriconema xenoplax*), and citrus nematode (*Tylenchus semipenetrans*) (Ferris et al., 2012). Additional information and specific horticultural attributes for the nematode-resistant rootstocks evaluated in this study are detailed in Ferris et al. (2012).

Although these new rootstocks have been evaluated in multiple California environments, their potential utility under midwestern U.S. environmental conditions is uncertain and heretofore had not been ascertained. Before any rootstock can be recommended for broad use in a region and with a particular scion

cultivar, thorough, long-term evaluations are needed. The only other known evaluations of these rootstocks outside of California have been with 'Sangiovese' in the Texas Hill Country (Kamas et al., 2020), and with 'Blanc du Bois' in the Texas Gulf Coast region (Scheiner et al., 2020).

'Couderc 3309' [*Vitis riparia* × *Vitis rupestris* (often and hereafter called 3309C)], is one of the most commonly used rootstocks in U.S. viticulture, and is known for medium vigor, low to medium drought tolerance, and high phylloxera (*Daktulosphaira vitifoliae*) resistance (Christensen, 2003; Pongrácz, 1983). Various studies have indicated that 3309C has low to moderate nematode resistance, depending on soil type (Harris, 1983; McKenry et al., 2001). It was incorporated into the study as a benchmark (control) rootstock that is well adapted to the region for comparison with the new rootstocks. In addition, own-rooted vines were included in the study because most of 'Chambourcin' produced in the midwestern United States are own-rooted vines.

The resistance of the UCD rootstocks to multiple nematode species found in California vineyards has already been established (Ferris et al., 2012). Although we might hypothesize that these rootstocks will also resist certain nematodes in the midwestern United States, their explicit resistance to known pathogenic species in this environment is currently unknown, and such determination was beyond the scope of this study. The objectives of this study were to evaluate the viticultural characteristics and suitability of four of the new UCD nematode-resistant rootstocks in the midwestern United States by systematically quantifying their performance, and to determine their influence on 'Chambourcin' productivity, fruit composition, scion hardiness, and phenology under southern Missouri environmental conditions.

Materials and methods

The study was integrated into a larger research vineyard (2 acres) that included additional studies on grafted 'Chambourcin' vines established in 2008 and 2009 at the University of Missouri's Southwest Research Center near Mt. Vernon (lat. 37.074297°N,

long. 93.879708°W, USDA Plant Hardiness Zone 6a) (Migicovsky et al., 2019; Thomas et al., 2017). The soil was a Hoberg silt loam (fine loamy, siliceous, mesic Mollic Fragiudalfs) that is upland, deep, gently sloping, and moderately well drained to a fragipan at 40 to 90 cm (Hughes, 1982). Soil was pushed into berms (≈25 cm high) to form vineyard rows, and vines planted thereon to improve soil drainage and root penetrable soil depth over the fragipan. Drip irrigation [emitters rated 0.42 gal/h spaced 36 inches (Netafim, Fresno, CA)] was used to supplement rainfall as needed to supply 1 acre-inch of water per week during the growing seasons. Vines in this study were established with paired trunks and trained to high bilateral cordons (single curtain), with average height of 5.8 ft above soil level. More detail on climate, trellis system, and site establishment is provided in Thomas et al. (2017), along with protocols on soil fertilization, pest management, weed control, winter graft union protection, and pruning.

'Chambourcin' scions were bench-grafted to 'UCD GRN-2', 'UCD GRN-3', 'UCD GRN-4', 'UCD GRN-5', and 3309C rootstocks, and own-rooted 'Chambourcin' grapevines were produced and donated by Wonderful Nurseries (Wasco, CA). All were transplanted 16 July 2010 as green-growing potted vines, with graft unions positioned ≈5 inches above soil level to prevent scion rooting. Spacing was 7 ft between vines in-row, and 9.7 ft between rows. Graft unions were afforded winter protection with mounds of mushroom and/or municipal compost (J-M Farms, Miami, OK; City of Monett, Monett, MO, respectively) during the first five winters; the compost was thereafter spread into the vineyard rows each spring. The study was established in a completely randomized block design, with six rootstock treatments (five rootstocks plus own-rooted vines) and four single-row blocks (replications) of each rootstock. Each plot contained two side-by-side vines of the same rootstock, for a total of 48 vines in the study. Additional 'Chambourcin' guard vines were deployed at the row ends and between blocks such that all vines were grown in near-identical environments.

During the establishment seasons of 2010–12, all inflorescences were removed so that no fruit developed to encourage robust vine establishment. All fruit from the experiment was harvested 1 Oct. 2013, 30 Sept. 2014, and 3 Oct. 2015. Harvest data included total fruit yield and cluster number per plot. Samples of 100 random ripe berries per plot were collected, weighed, immediately refrigerated, and then analyzed within 2 d for soluble solids concentration, pH, and titratable acidity in terms of tartaric acid [laboratory methods and instruments used are described in Thomas et al. (2017)]. Mean berry size was calculated, and mean number of berries per cluster calculated by dividing mean cluster weight by mean berry weight. Pruning weight data were collected in Feb./Mar. 2013–16 to quantify vegetative growth during the previous year (2012–15), and Ravaz index (yield/pruning weight) calculated for the 2013–15 growing seasons. Vines were balance-pruned to 20 + 20 formula (20 nodes retained for every 1 lb of pruning weight).

To quantify rootstock influence on scion response to the regional climate, dates of budbreak and shootless nodes data were collected. Spring budbreak date, defined as the date on which 50% or more of buds among both vines in a plot exhibited emergence of green tissue beneath the bud scales (Dokoozlian, 1999), was recorded in seasons 2016–18. Shootless nodes, defined as count nodes retained during dormant pruning that failed to produce viable shoots, were assayed in July 2017 when eight randomly selected nodes per vine were examined for the presence of live shoot growth. This metric, which measures bud survival and the sustainability of a vine's bearing surface, was used to quantify observed differences between rootstock treatments several years after establishment.

All data were subjected to analyses of variance in the form of a randomized complete block design using a general linear statistical model (SAS version 9.4; SAS Institute, Cary, NC) to elucidate differences in fruit production, fruit characteristics, phenology, and vine size among the rootstocks. Means were separated by Fisher's least significant difference test ($P \leq 0.05$). The experimental unit

was the two-vine plot, thus two-vine plot data means were statistically analyzed; however, all appropriate data are reported on a single-vine basis.

Results and discussion

'Chambourcin' initially grew satisfactorily on all rootstocks, as well as on its own roots, as demonstrated by acceptable pruning weights after 2.5 years of growth in 2012 (Table 1). For reference, Jordan et al. (1981) recommend optimum pruning weights of 2 to 3 lb/vine (for 'Concord' with 8-ft cordons) or 0.3 to 0.4 lb/ft of cordon, and Kliever and Casteel (2003) suggest optimal values of 0.2 to 0.4 lb/ft. After the establishment period, the rootstock 'UCD GRN-3' consistently produced pruning weights among the highest recorded, although statistical differences from other rootstocks varied among years. The exception was 'UCD GRN-5', for which pruning weights early in the study (2012, 2013) were lower than most other rootstock treatments. Although 'UCD GRN-5' produced a fruit crop comparable to the other rootstocks in 2013 (detailed yield data not shown), vegetative growth was greatly reduced (likely due to fruiting stress) as indicated by low pruning weights in 2013, resulting in the decision to de-fruit the vines in 2014. After 1 year of rest, 'UCD GRN-5' produced a fruit crop comparable to the other treatments in 2015, but, once again, at the expense of vegetative growth; 2015 pruning weights for 'UCD GRN-5' were significantly lower than all other rootstocks, resulting in very high Ravaz indices.

Fruit yields, as well as cluster, berry, and juice characteristics across the 3 harvest years and five rootstocks/own-rooted are shown in Table 2. Fruit yields generally decreased across the 3 years, from 13.3 kg/vine in 2013 to 9.6 kg/vine in 2015, which roughly extrapolates to 9.4 and 6.8 tons/acre in 2013 and 2015, respectively. For comparison, Bordelon (2009) indicates 5.1 tons/acre is an expected yield for 'Chambourcin' in Indiana, and Dami et al. (2005) produced 'Chambourcin' yields ranging from 4.5 to 7.1 tons/acre in Ohio and 4.8 to 6.7 tons/acre in Illinois in a crop load study. Thus, 'Chambourcin' was highly productive at the study site, which created challenges in achieving and maintaining vine balance. Although seasonal influence had a statistically significant impact on number of clusters per vine, cluster weights, and number of berries per cluster, rootstock did not influence such factors during the 3 harvest years (remembering that 'UCD GRN-5' was de-fruited in 2014). This indicates that the GRN rootstocks 2, 3, and 4 performed as well as both the benchmark 3309C rootstock and own-rooted 'Chambourcin' vines for these economically important parameters. Berries were smaller (2.17 g) in 2013, likely a reflection of the high yields generated during that first year of production. Individual berry weights also varied by rootstock, but such differences were generally modest and of limited commercial significance.

Juice characteristics were variable across the 3 years but all were within commercially acceptable ranges (Boulton

Table 1. Pruning weight and Ravaz index (yield/pruning weight) for 'Chambourcin' winegrape grown on five rootstocks and own-rooted vines at Mt. Vernon, MO in 2012–15.

Rootstock	Pruning wt (kg/vine) ^a				Ravaz index		
	2012	2013	2014	2015	2013	2014	2015
Own	1.66	0.78 abc ^y	0.87	0.98 a	24.0	11.1 b	10.5 b
3309C	1.52	0.88 ab	0.84	1.19 a	16.8	13.1 b	9.7 b
UCD GRN2	1.46	0.72 bc	0.71	0.98 a	19.4	15.4 ab	8.6 b
UCD GRN3	1.57	1.08 a	0.91	1.38 a	9.0	15.4 ab	7.0 b
UCD GRN4	1.55	0.71 bc	0.68	1.00 a	23.4	20.2 a	8.8 b
UCD GRN5	1.26	0.55 c	–	0.50 b	25.0	–	24.6 a
P value	0.5891	0.0470	0.3165	0.0102	0.2355	0.0480	0.0170

^aPruning weight data for the given year were collected in February/March of the following year; data are single-vine means from two-vine plots. To convert this mean per-vine total pruning weight data to cane weight per unit of cordon length [total length 7 ft (2.1 m)], divide number by 2.1336 for kg·m⁻¹, or multiply by 0.3149 for lb/ft.
^yMeans within columns with the same letters are not different according to Fisher's least significant difference test ($P < 0.05$).

Table 2. ‘Chambourcin’ winegrape fruit yields, and cluster, berry, and juice characteristics grown on five rootstocks and own-rooted vines at Mt. Vernon, MO in 2013–15.

Factor	Subfactor	Fruit yield (kg/vine) ^z	Clusters (no./vine)	Cluster wt (g) ^y	Berries (no./ cluster)	Single berry wt (g)	SSC (%) ^x	pH	TA (g·L ⁻¹) ^{y,w}
Year (Y)	2013	13.3 a ^v	72 a	185 b	85 b	2.17 b	21.6 b	3.55 b	6.96 a
	2014 ^u	11.7 a	43 c	278 a	112 a	2.48 a	22.7 a	3.67 a	5.90 c
	2015	9.6 b	56 b	167 b	69 c	2.43 a	21.7 b	3.67 a	6.31 b
	<i>P</i> value	<0.0010	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Rootstock (R)	Own	11.6	56	219	90	2.44 a	21.2 c	3.571 b	6.66 a
	3309C	12.1	63	202	84	2.40 a	21.8 b	3.680 a	6.10 c
	UCD GRN-2	10.8	54	204	86	2.36 ab	22.0 ab	3.641 a	6.57 a
	UCD GRN-3	10.9	55	197	84	2.37 ab	22.4 a	3.625 ab	6.50 a
	UCD GRN-4	12.1	56	221	96	2.28 bc	22.1 ab	3.616 ab	6.46 ab
	UCD GRN-5 ^u	11.6	67	179	81	2.21 c	22.2 ab	3.628 ab	6.22 bc
	<i>P</i> value	0.8533	0.6637	0.2410	0.1158	0.0108	0.0001	0.0015	<0.0001
Y × R	<i>P</i> value	0.1899	0.1278	0.7376	0.6037	0.0490	0.3417	0.7590	0.0170

^zData are single-vine means from two-vine plots; 1 kg = 2.2046 lb.

^y1 g = 0.0353 oz.

^xSoluble solids concentration.

^wTitrateable acidity in terms of tartaric acid; 1 g·L⁻¹ = 0.1%.

^vMeans within sub-columns with the same letters are not different according to Fisher's least significant difference test (*P* < 0.05).

^uValues do not include data from ‘UCD GRN-5’ in 2014, which was de-fruited that year.

et al., 1999). The GRN rootstocks all produced berries with higher soluble solids concentration (collective mean 22.2%) compared with ungrafted vines (21.2%), but only ‘UCD GRN-3’ was higher than 3309C for this parameter. Although some effect of rootstock was observed for pH and titrateable acidity, values for fruit grown on the GRN rootstocks generally were near or between those for 3309C and ungrafted vines. When evaluating growing year × rootstock statistical interactions, the only factors that were affected were single berry weight and titrateable acidity.

Observed weather during this experiment was generally representative of a midwestern U.S. continental climate, with routine seasonal fluctuations in temperatures and precipitation, and occasional temperature extremes (Table 3). Although extreme temperatures are, by definition, rare, their “frequent” occurrence in the midwestern United States presents a perpetual challenge to economical winegrape production in the region. Maximum summer temperature and seasonal heat summation data (growing degree days, base 50 °F) confirm exceptionally hot summers during the establishment years of 2011 and 2012. More normal temperatures occurred during the data years of 2013–15, except for extreme cold during the winter of 2013–14. Despite these

seasonal weather challenges, summer irrigation should have reduced moisture stress during dry periods/seasons, and winter graft union protection should have mitigated freezing stresses somewhat during this experiment.

The challenges observed in this study with ‘Chambourcin’ scions grafted to ‘UCD GRN-5’ are difficult to explain given a limited dataset. One plausible explanation is that ‘UCD GRN-5’ may simply not be adapted to the environmental conditions under which this experiment was conducted, and may have suffered freeze damage or other abiotic stress. A second is that ‘UCD GRN-5’ may be a low capacity or late-establishing rootstock; early cropping stresses may have permanently weakened the vines, thereby directly and/or indirectly increasing susceptibility to additional stresses. When ‘UCD GRN-5’ vines suffered damage during the first years of the study, both the rootstock and ‘Chambourcin’ scion survived, and cordons were reestablished from epicormic buds repeatedly as necessary. By 2017, however, nearly all the ‘UCD GRN-5’ vines had suffered significant long-term cordon or whole vine damage as they continued to weaken. Of eight ‘UCD GRN-5’ nodes evaluated per vine in July 2017, 7.9 nodes were shootless, whereas the other rootstock treatments continued to thrive

(Table 4). Although spring frost/freezing injury was not visibly evident during this experiment, budbreak data show that ‘UCD GRN-5’ apparently hastened spring budbreak by 2 to 3 d in 2016 and 3 to 5 d in 2018, possibly increasing the potential risk of late spring freeze damage (Johnson and Howell 1981; Kovacs et al., 2003). Grapevine rootstocks have been shown to influence scion phenology and budbreak in numerous cultivars (e.g., Ferroni and Scalabrelli, 1995; Menora et al., 2015; Neal et al., 2016; Reddy, 1990).

Kamas et al. (2020) and Scheiner et al. (2020) evaluated these same nematode-resistant rootstocks (‘UCD GRN-2’, ‘UCD GRN-3’, ‘UCD GRN-4’, and ‘UCD GRN-5’), along with additional rootstocks, grafted to ‘Sangiovese’ and ‘Blanc du Bois’, respectively, in Texas. ‘UCD GRN-5’ performed poorly on a pH 8.5 soil with ‘Sangiovese’ (attributed to pH-induced nutritional deficiency), but all four performed satisfactorily on a pH 8.1 soil with ‘Blanc du Bois’ and a pH 6.6 soil with ‘Sangiovese’. In the ‘Sangiovese’ study on pH 6.6 soil, the UCD rootstocks did not statistically influence fruit yields compared with own-rooted vines; however, ‘UCD GRN-5’ produced among the lowest pruning weights and among the lowest number of berries per cluster. Similarly, the UCD rootstocks grafted to ‘Blanc du Bois’ did not statistically

Table 3. Maximum (Max) and minimum (Min) ambient temperatures, total annual precipitation, and growing degree days [base 50 °F (10.0 °C)] recorded at or near the study of ‘Chambourcin’ winegrape grown on five rootstocks and own-rooted vines at Mt. Vernon, MO in 2010–17.

Factor ^z	Period	Avg	2010	2011	2012	2013	2014	2015	2016	2017
Max temp (°F) ^y	July–Aug.	89.1	–	110 ^w	108 ^w	98	101 ^w	95	99	95
Min temp (°F) ^x	Dec.–Feb.	23.4	–13 ^w	5	9	–12 ^w	–2	5	–3	–
Total precipitation (inches) ^y	Annual	46.2	–	46.3	32.9	42	46	53.2	38.2	47
Growing degree days (°F)	1 Apr.–31 Oct.	3891	–	4335	4418	4052	3919	4026	4251	3760

^zWeather data compiled from multiple sources, including manual recording and Commercial Agriculture Automated Weather Station Network, Mt. Vernon and Lamar, MO (University of Missouri, 2020), and National Oceanic and Atmospheric Administration (2020).

^y(°F – 32) ÷ 1.8 = °C, 1 inch = 25.4 mm.

^xMinimum temperature is for the entire winter season beginning in the designated calendar year and continuing into the following year.

^wThis maximum or minimum temperature fell within the ≤ 5% range of days per month to reach or surpass that temperature, thus defined as “extreme” (National Oceanic and Atmospheric Administration, 2020).

Table 4. Budbreak and shootless node data for ‘Chambourcin’ winegrape grown on five rootstocks and own-rooted vines at Mt. Vernon, MO in 2016–18.

Rootstock	Budbreak 2016 (day of the yr) ^z	Budbreak 2017 (day of the yr)	Budbreak 2018 (day of the yr)	Shootless nodes (no./vine) ^y
Own	99.5 a ^x	89.8 a	115.0 ab	0.0 b
3309C	98.5 a	88.2 ab	116.2 ab	0.0 b
UCD GRN-2	99.9 a	86.9 b	114.6 b	0.0 b
UCD GRN-3	99.6 a	86.6 b	117.0 a	0.3 b
UCD GRN-4	99.9 a	87.0 b	115.9 ab	0.0 b
UCD GRN-5	96.5 b	–	111.8 c	7.9 a
P value	0.0017	0.0057	0.0030	<0.0001

^zData are day of the year from 1 Jan.

^yMean number of shootless nodes among eight random nodes surveyed per vine, July 2017, to assess vine viability well into the growing season.

^xMeans within columns with the same letters are not different according to Fisher’s least significant difference test ($P < 0.05$).

influence pruning weight, and only ‘UCD GRN-4’ increased fruit yields compared with own-rooted vines in 1 production year.

Because the rootstocks ‘UCD GRN-2’, ‘UCD GRN-3’, and ‘UCD GRN-4’ generally performed similarly to the standard 3309C and own-rooted vines under identical ambient conditions in our study, we can conclude that they show promise for use in midwestern U.S. winegrape production. ‘UCD GRN-3’ was statistically more vigorous and produced fruit with a higher soluble solids concentration compared with most other rootstocks or own-rooted vines. Concurrently, our study indicates that ‘UCD GRN-5’ may not be suitable for southern Missouri growing conditions, and presumably USDA Hardiness Zone 6a and colder zones. Although these rootstocks are resistant to the enumerated nematodes in California (Ferris et al., 2012), they have not been specifically tested for resistance to nematode species and races that are prevalent in the midwestern United States. In particular, although the rootstocks are resistant to dagger nematode, their resistance to american dagger nematode, which

is of greater concern in the midwestern United States, is presently unknown. This was the first significant trial of these new nematode-resistant rootstocks in the midwestern United States; more testing is needed, including an evaluation of the rootstocks’ resistance to problematic nematodes in the region, before they can be recommended with confidence.

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