The Influence of Phosphorus Availability, Scion, and Rootstock on Grapevine Shoot Growth, Leaf Area, and Petiole Phosphorus Concentration

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Cabernet Sauvignon (CS) and Chenin blanc (Cb) scions on Freedom, A×R#1, St. George, and 110R rootstocks were grown under conditions of sufficient (+P) and deficient (-P) soil phosphorous availability. Shoot length, shoot dry weight, leaf area, and petiole P concentration were lower for -P compared to +P vines. Cb vines had larger leaves and more leaf area than CS vines and the leaf area of Cb vines was less inhibited by exposure to -P than was CS vines. Vines on Freedom had longer shoots, greater shoot biomass, and greater leaf area than vines on other rootstocks regardless of P availability. Under +P vines on St. George produced less shoot dry weight than vines on Freedom, but more than vines on 110R. However, the shoot dry weight and leaf area of vines on St. George was greatly inhibited by -P and vines on St. George appeared to not use P efficiently for growth under these conditions. Vines on 110R produced the least amount of shoot growth and leaf area among the rootstocks under +P, but were also the least inhibited by -P conditions. The shoot dry weight and leaf area of vines on A×R#1 was intermediate between vines on Freedom and vines on St. George and 110R, and were inhibited by -P slightly less than St. George. Freedom and 110R are more suitable for low P soils than St. George and A×R#1.

KEY WORDS: *Vitis*, grapevines, phosphorus, scion, rootstock, shoot growth, shoot elongation, leaf area, Cabernet Sauvignon, Chenin blanc

In California, phosphorus (P) deficiency has been observed in vines growing in soils of low pH (11). Soil phosphorus is taken up by plants in the inorganic, orthophosphate form (17,26). Acidic soils are favorable environments for ligand exchange and precipitation reactions that make orthophosphates unavailable to plants (2,19,31).

P deficiency inhibits the initiation and maintenance of cluster primordia and, hence, fruit yield of grapevines (34). In field trials, soil applications of P fertilizer have successfully corrected P deficiencies, but the cultivars Chardonnay and Chenin blanc differed greatly in the lamina P concentrations associated with maximum yield (33). This observation and others of genotypic differences within crop species in the efficiency of P utilization (16) indicate that informed cultivar selection could minimize the need for P fertilizer.

The potential to exploit genetic variability in mineral nutrition may be greater when vines are grafted due to interspecific variation among rootstocks in nutrient uptake and translocation to scions (14). Grape rootstocks have been shown to differ in their influence on scion nutrient status, growth, and yield (7,9,35), but the influence of rootstock on grapevine P nutrition, particularly under P deficiency, is not well understood. Information on the influence of grape scion and interactions between scion and rootstock with regard to vine nutrient status, growth, and yield is also very limited (29), although ungrafted varieties that are normally used as scions are known to differ in petiole P concentrations (4,6). The purpose of this study was to evaluate grapevine shoot growth responses to P deficiency among a genetically diverse group of scion/rootstock combinations, including those commonly grown for wine grape production in areas of California.

Materials and Methods

Cabernet Sauvignon (CS) and Chenin blanc (Cb) scions were included in the experiment. Both are *Vitis vinifera* cultivars with vigorous growth habits (15,22). Each of the two scions were grafted to the rootstocks Freedom, Aramon Rupestris Ganzin no. 1 (A×R#1), Rupestris St. George (St. George), and 110 Richter (110R). Freedom is a complex hybrid whose parentage includes 1613 Couderc, a Solonis (*V. riparia* × *V. rupestris* × *V. candicans*) × Othello (*V. labrusca* × *V. vinifera*) hybrid, and Dogridge, a selection of *V. Champini* (23). A×R#1 is a hybrid of *V. vinifera* cv. Aramon and *V. rupestris* cv. Ganzin (15,23). St. George is a selection of *V. rupestris* (15,23). The rootstock 110R is a *V. berlandieri* cv. Ressequier no. 2 by *V. rupestris* cv. Martin cross (15,23). Plant materials originated from dormant wood derived from University of California, Davis, vineyards and were bench grafted by the Department of Viticulture and Enology field staff.

Grapevines were planted in a 1:1:1 mix of sphagnum peat moss, sand, and silt from the stream bed of Putah Creek near Davis, California. The pH of the air dry mix was 5.7 as measured by the 1:2.5 air dry

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soil:water suspension method (27). The available P level of the soil was 8 mg/kg of air dry soil by the Bray 1 procedure as described by Knudsen (3,24). This is the critical concentration for soil P deficiency for most agronomic crops (21).

The grapevines were grown in a greenhouse in 11-L pots containing the mixture described above for about 13 weeks to deplete the supply of P stored in the graft wood and roots. Plants were then unpotted, the shoots pruned to a single 2-node spur, and the roots pruned to a length of about 5 cm before replanting each in an 11-L pot in the same low-P potting medium used previously. Roots were trimmed to equalize the root system size, absorptive surface area, and P reserves among the vines.

The experiment had three factors. Two factors, scion and rootstock, were genotypic and the combination of the two formed the composite experimental units. The third factor was P treatment. Each scion-rootstock-P level combination was replicated four times as single potted vines. The vines were arranged in pairs with respect to P treatment such that within a replicate block a +P vine of a given scion and rootstock was paired with a -P vine of the same scion and rootstock. Pairing was adopted to facilitate the calculation of inhibition of growth parameters due to exposure to P deficiency (see below). The pairs were arranged in a randomized complete block design.

Essential plant nutrients other than P were added to the -P vines in the form of a modified 1/4-strength Hoagland solution (18) that did not include P. Thus, the low level of P available in the medium established the P level of the -P treatment. The +P vines received a quantity of nutrients comparable to that received by -P vines plus 0.3 m*M* phosphate-P. Nutrient solutions were applied once per week as an irrigation during the experiment.

Budbreak occurred about one week after replanting. Shoots were thinned to one per vine four days later. The shoot was trained vertically to maintain the apical dominance of the shoot tip. Vines were irrigated twice a week until their shoots were about 50 cm long, when the number of irrigations was increased to three per week. The greenhouse temperature near the plants averaged 26°C, with the average nighttime low being 19°C and the average daytime high being 30°C as measured by a hygrothermograph. The mean relative humidity was 58% with an average diurnal range of 43% to 73%.

Shoot length was measured at weekly intervals beginning four days after budbreak. Shoots were harvested after being allowed to grow for 52 days and were separated into laminae, petioles, main stem, and lateral shoots. At the time of harvest, leaf area was measured with a video-based area meter calibrated with opaque triangles of known area and the numbers of leaves per shoot was determined.

Dry weights of the shoot organs were measured after drying in a forced air oven at 70°C for 48 hours.

Table 1. Formulas for calculated parameters.

Parameter	Formula
Inhibition due to P deficiency	$\frac{\text{(value for +P vine)-(value for -P vine)}}{\text{(value for +P vine)}}$ (100)
Mean area per leaf	$\frac{\text{leaf area per plant}}{\text{number of leaves per plant}}$
Specific leaf area[z]	$\frac{\text{leaf area per plant}}{\text{laminae dry weight}}$
Leaf area per unit shoot weight	$\frac{\text{shoot leaf area}}{\text{shoot dry weight}}$
Leaf area per unit shoot length	$\frac{\text{shoot leaf area}}{\text{shoot length}}$

[z]After Evans (12).

Petioles were used as indicators of grapevine P status because past workers used them extensively, found them to be convenient and reliable indicators of vine P status, and developed diagnostic criteria based on them (1,5,8,10). Dried petioles from the lowest 10 nodal positions on the shoot were ground to a powdery texture with a sample mill and stored in plastic vials until they could be analyzed. Petiole P status was analyzed using a 2% acetic acid extraction and ammonium molybdate-ascorbic acid color development procedure (32).

Table 1 lists the parameters that were calculated from those measured. Inhibition due to exposure to P deficiency represents the decrease in a parameter for a -P vine relative to a paired +P vine.

Analysis of variance was performed to identify scion, rootstock, and P level effects and interactions. Means for rootstocks were separated by Tukey's significant difference. This procedure was selected because, unlike Fisher's least significant difference (LSD) and Duncan's multiple range, the comparison wise level of significance is adjusted for the number of comparisons being made so that the desired experiment-wise level of significance is maintained (20,30). Consequently, Tukey's significant difference is a relatively conservative test that facilitated meaningful comparisons of mean values for the different rootstocks included in this study.

Results

The shoot length of +P grapevines increased rapidly through the growth period, reaching a final length of 265 cm (Fig. 1A). The shoot length of -P vines increased much more slowly. The final shoot length of -P vines was 85 cm.

Under +P, the shoots of vines on Freedom, A×R#1, and St. George grew more rapidly and achieved a greater final length than vines on 110R (Fig. 1B). Under -P, the shoots of vines on Freedom grew more steadily and had a greater final length than those on

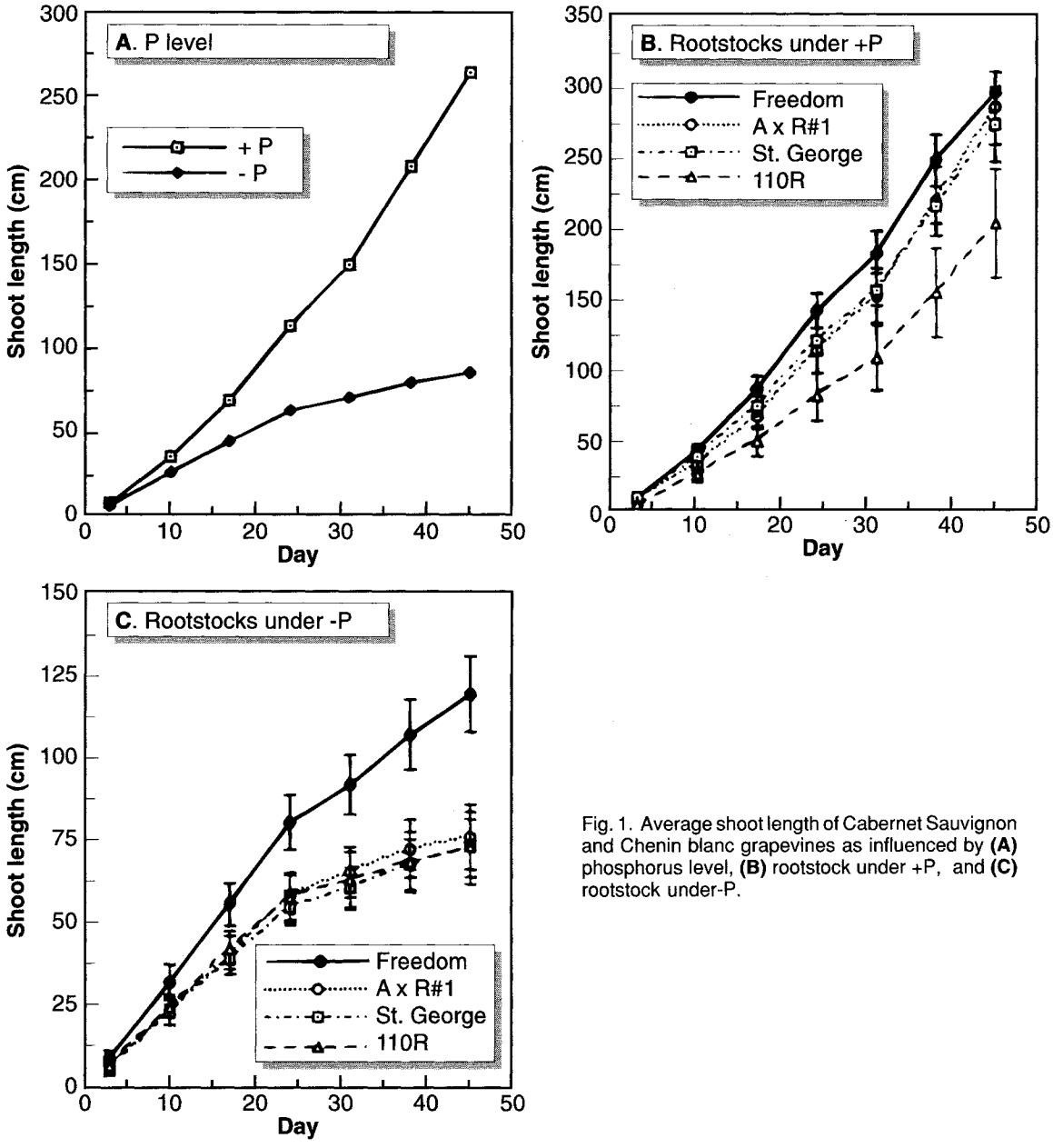

Fig. 1. Average shoot length of Cabernet Sauvignon and Chenin blanc grapevines as influenced by **(A)** phosphorus level, **(B)** rootstock under +P, and **(C)** rootstock under-P.

other rootstocks (Fig. 1C).

Vines grown under +P produced more shoot dry weight than vines grown under -P (Table 2). The biomass of each of the shoot organs of +P vines was greater than the biomass of corresponding organs of -P vines. Cb vines produced greater lamina, petiole, and lateral dry weight than CS vines.

The biomass of laminae, petioles, stems, and lateral shoots of scions on Freedom were greater than those of scions on St. George (Table 2). Similarly, vines on St. George had greater shoot weight than vines on 110R due to greater growth of each of the shoot organs. Although the laminae and laterals of vines on A×R#1 weighed less than those of vines on Freedom, the weight of their stems and petioles were similar. Consequently, the dry weight of shoots of vines on A×R#1 were intermediate between those of vines on Freedom and St. George.

The interaction between P level and scion was significant for lateral dry weight (Table 2). Under +P, Cb vines produced more lateral growth than CS vines (Fig. 2). Under -P, identical lateral growth was produced by both scions.

P level by rootstock interactions were significant for total shoot dry weight and the dry weight of shoot organs (Table 2). Under +P, vines on Freedom produced more shoot biomass than vines on St. George because of greater laminae, stem, and lateral biomass (Table 3). Vines on St. George produced more shoot dry weight than vines on 110R due to greater shoot organ weights. Total shoot weights and weights of shoot organs of vines on A×R#1 were intermediate between those of vines on Freedom and St. George. Vines on A×R#1 produced less lateral growth than vines on Freedom

and only slightly more than vines on St. George. The dry weights of petioles of vines on Freedom, St. George, and A×R#1 were similar, but greater than those of vines on 110R.

Table 2. Dry weight of grapevine shoots and shoot organs as influenced by P level, scion, and rootstock.

	Shoot (g)	Laminae (g)	Petioles (g)	Stem (g)	Laterals (g)
P Level (P)					
+P	46.1	16.3	2.2	21.8	5.7
- P	10.4	5.7	0.6	3.4	0.6
Significance[z]	**	**	**	**	**
Scion (S)					
CS	27.4	10.2	1.2	13.5	2.6
Cb	29.6	12.0	1.6	12.1	3.8
Significance	ns	**	**	ns	*
Rootstock (R)					
Freedom	37.8a[y]	14.1a	1.8a	16.2a	5.6a
A×R#1	32.8ab	12.2b	1.6a	15.8ab	3.2b
St. Geo.	26.1b	10.2c	1.3b	11.9b	2.6bc
110R	17.8c	7.9d	1.0c	7.4c	1.6c
Significance	**	**	**	**	**
Interactions					
P × S	ns	ns	ns	ns	*
P × R	*	*	*	*	**
S × R	ns	ns	ns	ns	ns
R × S × R	ns	ns	ns	ns	ns

[y]ns = not significant, * = significant at the 5% level, ** = significant at the 1% level.

[y]Numbers with different letters differ significantly at the 5% level by Tukey's significant difference.

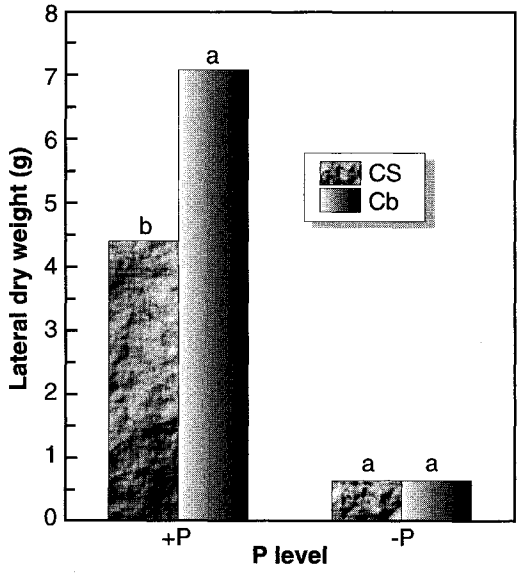

Fig 2. Dry weight of laterals from grapevines under +P and -P as influenced by scion.

Table 3. Dry weight of grapevine shoots and shoot organs for different rootstocks under different P levels.

P level	Root-stock	Shoot (g)	Laminae (g)	Petioles (g)	Stem (g)	Laterals (g)
+P	Freedom	59.9a[z]	20.1a	2.8a	27.2a	9.9a
	A×R#1	53.2ab	18.2ab	2.5a	26.9ab	5.7b
	St. Geo.	44.5b	16.0b	2.2a	21.5b	4.8bc
	110R	27.1c	10.9c	1.5b	12.0c	2.7c
-P	Freedom	15.7a	8.2a	0.9a	5.3a	1.3a
	A×R#1	9.5b	5.3b	0.6b	3.2b	0.3b
	St. Geo.	7.6b	4.5b	0.4c	2.4b	0.4b
	110R	8.6b	4.9b	0.5bc	2.8b	0.4b

[z]Numbers in a column for a given P level with different letters differ significantly at the 5% level by Tukey's significant difference.

Under -P, vines on Freedom produced greater shoot and shoot organ dry weight than vines on other rootstocks (Table 3). The least petiole dry weight was produced by vines on St. George.

The differential response of vines on different rootstocks to P level is depicted by the degree of growth inhibition due to soil P deficiency. The shoot weight of vines on 110R was less inhibited by -P than the shoot weight of vines on St. George (Table 4). The greater shoot growth inhibition of vines on St. George was due mainly to decreased lamina and petiole dry weight. CS and Cb responded similarly to the P treatments, as there was no difference in total shoot or individual shoot organ dry weight inhibition between them.

Table 4. Inhibition of dry weight of grapevine shoots and shoot organs due to exposure to P deficiency as influenced by scion and rootstock.

	Shoot (%)	Laminae (%)	Petioles (%)	Stem (%)	Laterals (%)
Scion (S)					
CS	77.3	65.7	74.9	84.7	78.8
Cb	73.3	61.3	70.5	78.9	89.7
Significance[z]	ns	ns	ns	ns	ns
Rootstock (R)					
Freedom	74.0ab[y]	59.6ab	68.4ab	80.6	86.2
A×R#1	82.2ab	70.4ab	77.2ab	88.1	94.0
St. Geo.	82.6a	72.1a	81.8a	88.5	91.9
110R	62.8b	52.6b	63.8b	70.4	66.8
Significance	**	**	**	ns	ns
Interaction					
S × R	ns	ns	ns	ns	ns

[z]ns = not significant, ** = significant at the 1% level.

[y]Numbers with different letters differ significantly at the 5% level by Tukey's significant difference.

Table 5. Leaf area, leaves per vine, and specific leaf area of grapevines as influenced by P level, scion, and rootstock.

	Area/ leaf (cm^2)	Leaves/ vine	Leaf area/ vine (cm^2)	Specific leaf area (cm^2/g)	Leaf area/ unit shoot weight (cm^2/g)	Leaf area/ unit shoot length (cm^2/cm)
P Level (P)						
+P	135.7	34	4638.6	296	112.2	17.6
- P	69.6	21	1504.7	264	150.7	17.8
Significance[z]	**	**	**	**	**	ns
Scion (S)						
CS	90.7	28	2850.0	275	125.4	16.6
Cb	115.2	27	3335.4	285	136.7	18.8
Significance	**	ns	**	ns	*	*
Rootstock (R)						
Freedom	114.3a[y]	31a	3677.9a	262b	113.4c	17.6
A×R#1	111.3ab	27bc	3322.0ab	276ab	123.2bc	18.1
St. Geo.	97.9bc	28ab	3016.5b	288a	137.4ab	17.4
110R	89.7c	25c	2383.8c	294a	150.0a	17.8
Significance	**	*	**	**	**	ns
Interactions						
P × S	ns	*	ns	*	*	ns
P × R	ns	*	*	*	ns	ns
S × R	ns	ns	ns	ns	ns	ns
R × S × R	ns	*	ns	ns	ns	ns

[z]ns = not significant, ** = significant at the 1% level.

[y]Numbers with different letters differ significantly at the 5% level by Tukey's significant difference.

Vines grown under -P had less area per leaf, fewer leaves per vine, and consequently, less leaf area per vine than +P vines (Table 5). The specific leaf area of -P vines was less than that of +P vines, indicating that -P vines were less able to produce photosynthetic surface per unit biomass than +P vines. However, -P vines were more effective in producing leaf area per unit shoot dry weight than +P vines. There was a negligible difference between -P and +P vines in leaf area per unit shoot length.

Cb grapevines produced greater area per leaf and leaf area per vine than CS vines (Table 5). Cb vines also produced more leaf area per unit shoot weight and per unit shoot length than CS vines.

Vines on Freedom rootstock had greater area per leaf, more leaves per vine, and as result, more leaf area per vine than vines on other rootstocks (Table 5). Vines on St. George had more leaves per vine and greater leaf area per vine than vines on 110R rootstock. Area per leaf and leaf area per vine values for vines on A×R#1 rootstock were intermediate between those for Freedom and St. George rootstocks. Vines on A×R#1 rootstock had leaves per vine values that were intermediate between St. George and 110R.

The specific leaf area values for vines on St. George and 110R rootstock were greater than values for vines on Freedom rootstock (Table 5). Vines on 110R produced more leaf area per unit shoot weight than vines on Freedom and A×R#1.

There were 3 significant P level by scion interactions pertaining to leaf area (Table 5). Under +P, CS vines had more leaves than Cb vines, but under -P vines the two scions had similar numbers of leaves (Table 6). Under +P, vines with either scion did not differ in specific leaf area or leaf area per unit shoot weight. However, under -P, Cb vines produced more leaf area per unit leaf weight and per unit shoot weight than CS vines.

P level by rootstock interactions were also signifi-

Table 6. Leaves per vine, specific leaf area, and leaf area per unit shoot weight for different scions under different P levels.

P level	Scion	Leaves/ vine	Specific leaf area (cm^2/g)	Leaf area/ unit shoot weight (cm^2/g)
+P	CS	36a[z]	296a	110.0a
	Cb	32b	295a	114.4a
-P	CS	21a	252b	141.7b
	Cb	22a	275a	159.1a

[z]Numbers in a column for a given P level with different letters differ significantly at the 5% level by Tukey's significant difference.

Table 7. Leaves per vine, leaf area per vine, and specific leaf area for different rootstocks under different P levels.

P level	Rootstock	Leaves/ vine	Leaf area/ vine (cm^2)	Specific leaf area (cm^2/g)
+P	Freedom	36a[z]	5293.5a	267b
	A×R#1	34ab	5018.4a	291ab
	St. Geo.	36a	4772.5a	300ab
	110R	30b	3470.1b	325a
-P	Freedom	26a	2062.2a	257a
	A×R#1	17b	1210.0b	259a
	St. Geo.	20b	1260.2b	277a
	110R	19b	1297.6b	263a

[z]Numbers in a column for a given P level with different letters differsignificantly at the 5% level by Tukey's significant difference.

Table 8. Inhibition of leaf area, leaves per vine, and specific leaf area of grapvines due to exposure to P deficiency as influenced by P level, scion, and rootstock.

	Area/ leaf (%)	Leaves/ vine (%)	Leaf area/ vine (%)	Specific leaf area (%)	Leaf area/ unit shoot weight (%)	Leaf area/ unit shoot length (%)
Scion (S)						
CS	50.6	41.5	70.9	13.9	-36.5	2.8
Cb	46.6	33.2	64.2	5.5	-45.3	-5.1
Significance[z]	*	*	ns	*	ns	*
Rootstock (R)						
Freedom	45.6ab[y]	28.0b	61.1b	3.2b	-50.2b	2.2
A×R#1	52.9a	43.1a	73.2a	9.1ab	-53.8b	-5.2
St. Geo.	54.2a	44.2a	74.1a	7.2b	-51.6b	1.0
110R	42.0b	34.3ab	61.9b	18.6a	-10.2a	-3.4
Significance	**	**	**	*	**	ns
Interaction						
S × R	ns	ns	ns	ns	ns	ns

[z]ns = not significant, ** = significant at the 1% level.

[y]Numbers with different letters differ significantly at the 5% level by Tukey's significant difference.

Table 9. Extractable P concentration for the basal 10 petioles of grapevines as influenced by P level, scion, and rootstock.

	Petiole extractable P (mg/kg)
P Level (P)	
+P	9240
- P	211
Significance[z]	**
Scion (S)	
CS	5590
Cb	4030
Significance	*
Rootstock (R)	
Freedom	4080b[y]
A×R#1	4560b
St. George	4290b
110R	6240a
Significance	**
Interactions	
P × S	**
P × R	**
S × R	ns
R × S × R	ns

[z]ns = not significant, * = significant at the 5% level, ** = significant at the 1% level.

[y]Numbers with different letters differ significantly at the 5% level by Tukey's significant difference.

cant for 3 leaf area parameters (Table 5). Under +P, vines on 110R rootstock had fewer leaves per vine than vines on Freedom and St. George and less leaf area per vine than vines on other rootstocks (Table 7). Under -P, vines on 110R, St. George, and A×R#1 had fewer leaves per vine and less leaf area than vines on Freedom. Specific leaf area was greater on 110R than on Freedom under +P, but did not differ significantly under -P.

The area per leaf, number of leaves per vine, and specific leaf area of Cb were inhibited less by P deficiency than they were for CS (Table 8). Phosphorus deficiency stimulated the production of leaf area per unit shoot length by Cb slightly, while the reverse was true for CS.

The area per leaf of vines on 110R was less inhibited by P deficiency than it was for vines on A×R#1 and St. George (Table 8). The number of leaves per vine on Freedom was less inhibited by P deficiency than the number of leaves of vines on St. George and A×R#1. The differential responses due to rootstock for area per leaf and number of leaves per vine resulted in less inhibition of leaf area per vine for vines on Freedom and 110R compared to vines on St. George and A×R#1. The specific leaf area of vines on 110R was more inhibited by P deficiency than that of vines on other rootstocks. In addition, the leaf area per unit shoot weight of vines on 110R was less stimulated by P deficiency than it was for vines on other rootstocks.

The concentration of extractable P in basal petioles of -P vines was about 2% that of +P vines (Table 9). CS vines had higher petiole P concentrations than Cb vines under +P. However, there was no difference between the scions under -P (Fig. 3A). Under +P vines on 110R had higher petiole P concentrations than vines on other rootstocks (Table 9), but under -P vines on St. George rootstock had greater petiole P concentrations than vines on A×R#1 rootstock (Fig 3B).

Discussion

Subjecting young potted grapevines to phosphorus deficiency had an inhibitory effect on shoot growth, leaf area, and petiole P concentration. The dry weight of all shoot organs was lowered by -P conditions. P deficient vines had smaller leaves, fewer leaves, and consequently, less photosynthetic capacity than vines with more available P. The reduced growth and leaf area production of -P vines was consistent with their much lower P status as indicated by petiole P concentration.

P deficient vines were more effective than P sufficient vines in producing leaf surface area per unit shoot dry weight, but not per unit shoot length. Apparently

vines sustained the area of individual leaves at the expense of shoot elongation and new node development under P deficiency. The increase in leaf surface area per unit shoot weight under P deficiency was due to a 20% shift in biomass from the stem and laterals to the primary laminae and petioles (data not shown). A similar shift in shoot dry weight partitioning in response to P deficiency has been observed for tomato cultivars (13).

Under +P, Cb vines appeared to use P more effectively for shoot growth than CS vines in that they produced more shoot biomass with comparable petiole P. However, the scions did not appear to differ in this regard under -P. Still, Cb was less sensitive than CS to P deficiency in terms of reduced leaf area and leaves per vine. Cb may thus be better suited to P deficient vineyard sites than CS.

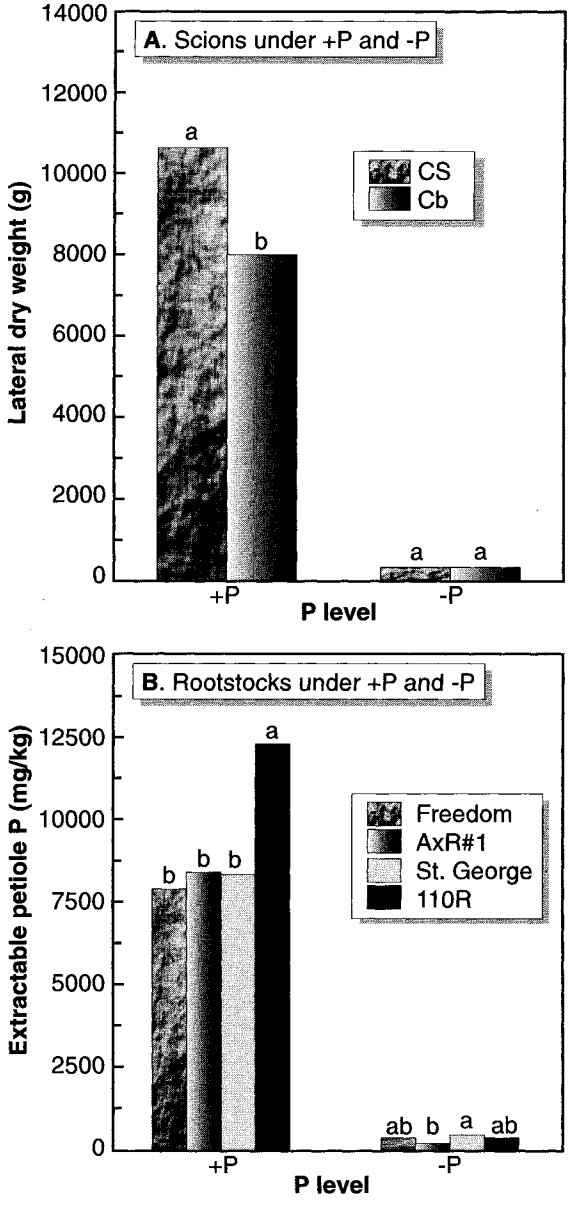

Fig 3. Extractable petiole P of grapevines under +P and -P as influenced by **(A)** scion and **(B)** rootstock.

Rootstocks differed in their influence on scion shoot growth and leaf area. Williams and Smith also observed differences in leaf area for CS vines on different rootstocks under field conditions (35). In our study the influences of rootstock were also dependent on P availability in many instances.

The leaf area per vine of vines on Freedom was less inhibited by P deficiency than it was for vines on AxR#1 and St. George. This influence on potential photosynthetic capacity suggests that Freedom would be better suited to P deficient vineyard sites than the other two rootstocks.

The shoot growth of vines on St. George was inhibited more by exposure to P deficiency than was the shoot growth of vines on other rootstocks due mainly to reduced laminae and petiole growth. The inhibition of shoot growth occurred at relatively high petiole P concentrations, suggesting that vines on St. George were not using P for growth as effectively as vines on other rootstocks. The combination of large shoot growth inhibition and poor P use efficiency make St. George the least suited rootstock for P-deficient vineyard sites among those included in this study.

When sufficient P was available, vines on 110R grew smaller shoots and shoot organs than vines on other rootstocks. However, the growth of vines on 110R appeared not to be limited by P supply because vines on 110R had higher petiole P concentrations than vines on other rootstocks. The limited growth responses of vines on 110R under conditions suitable for ample growth are characteristic of devigorating rootstocks.

When P was deficient, vines on 110R produced as much shoot growth and leaf area as vines on AxR#1 and St. George. Consequently, the shoot growth and leaf area of vines on 110R were less inhibited by P deficiency than were those of vines on the other rootstocks. These responses make 110R well suited to P-deficient vineyard sites.

The reason for the relatively low growth inhibition of vines on 110R may be related to it's *V. berlandieri* parentage. *V. berlandieri* is native to southwest Texas, south New Mexico, and northern Mexico (28). Soils in this area are calcareous and frequently deficient in P due to the precipitation of calcium phosphates (25,28). Having evolved in such an environment, it is possible that *V. berlandieri* possesses a metabolism adapted to limited P availability and that 110R inherited that metabolism.

The rootstocks St. George, AxR#1, and 110R share a common parentage in *V. rupestris*. St. George is a selection of *V. rupestris*, AxR#1 is a *V. rupestris* × *V. vinifera* hybrid, and 110R is a *V. rupestris* × *V. berlandieri* hybrid (15,23). Given the diversity of the genotypes involved, it is perhaps not surprising that the rootstocks differed greatly in shoot growth under low P. However, without a more complete sampling of the hybrid population made from such crosses it is impossible to draw conclusions about the contribution of each

parent species to the growth characteristic of the hybrid progeny.

Conclusions

The shoot growth, leaf area, and petiole P concentration of young, potted grapevines are dramatically reduced when grown in a low P media. The extent of the reduction is influenced both by scion and rootstock. Therefore, some scions and rootstocks appear more suitable for vineyard sites with low P soils. Cb is more suitable for low P soils than CS. Freedom and 110R are better suited to low P soils than St. George and A×R#1. Freedom is preferable to 110R when more vigorous vine growth is desired.

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