Completed

CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)

CDFA Contract # Final Report

Project Title:

CROP MANAGEMENT FOR EFFICIENT POTASSIUM USE AND OPTIMUM WINEGRAPE QUALITY

Project Leader:

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Project Objectives:

The primary objectives were to evaluate approaches to improve vine potassium status on heavy, putatively K-fixing soils. The approaches included:

1. method and placement of fertilizer
2. manipulation of soil water content
3. reducing K fixation by addition of gypsum
4. screening rootstocks for improved K uptake efficiency

In the conduct of the study we also addressed:

the response of root growth to supplemental irrigation and potassium fertilizer applications,
the response of several aspects fruit quality to these treatments and to the use of several rootstocks
the impact of these practices on vine uptake of and soil movement of nitrate
the utility of bloomtime petiole analysis for evaluating vine nutrient status

Experimental sites were selected on the basis of: low concentration of K in petioles (petiole [K]), low soil K analyses, late season K deficiency symptoms, lack of recent application of soil amendments, high soil clay content, presence of premium winegrape varieties that represent large acreage in the state, and relatively uniform soil and vine growth.

SUMMARY:

Experiments were conducted at several sites to investigate different approaches to increasing the efficiency of potassium (K) fertilizer use on clay soils, and to evaluate whether improved plant potassium status leads to improved efficiency of nitrogen fertilizer utilization. The problem of potassium deficiency on heavy soils creates a special need for efforts to improve efficiency because high rates of application are often required to obtain plant responses. Our objectives were to test the potential of altered fertilizer placement, altered irrigation regimes, supplemental gypsum applications, and selection of rootstocks in winegrapes for decreasing the need for high rates of fertilizer applications. High rates of potassium sulfate (8lbs or greater of potassium sulfate per vine) and supplemental irrigation (2 to 4 times the standard rate) to decrease K fixation and increase the availability of K for root uptake. This has successfully increased vine K status and maintained high K status beyond veraison. A slight increase in root growth in the upper 30cm of soil due to both K and water applications may have contributed to increased K uptake. Augering holes next to vines (an expensive operation) has not increased vine K status above placement beneath drip emitters when evaluated at bloom, but the data suggest that augering maintains high K status during fruit ripening. The genetic approach to managing these soils looks promising. For Chardonnay vines on low K soil, vine K status was significantly greater on 5C and St. George rootstocks than on four other root systems. A wider range of genetic material that has little or no *V. vinifera* should be evaluated. Applications of K to these vines increased juice pH on some rootstocks and in some years there has been a significant correlation between vine K status and juice pH. Use of gypsum + potassium sulfate increased soluble K in the soil, vine K status, and yield above that of the potash alone. The use of gypsum can be recommended when applying K on similar soils. At this site (Chardonnay in Healdsburg), treatments that combined nitrogen and potassium applications exhibited the greatest vine K status and yields.

Site 1. Pinot noir site in Carneros. Obectives 1 (fertilizer rates and placement) and 2 (interaction with soil water content) were addressed primarily at this site.

Mineral analysis of initial soil conditions at the Carneros site indicated a clay loam soil with approximately 40% clay and a CEC of over 20 meq/100 g. X-ray diffraction analysis confirmed the presence of K-fixing clays, but we could not qunatify the their relative abundance. Chemical analyses showed moderate-to-low exchangeable K and high Mg in the upper 90 cm.

TABLE 1: SELECTED CHEMICAL, MINERALOGICAL, AND PHYSICAL PROPERTIES OF CARNEROS SOIL

	PARTICLE SIZE ANALYSIS (%)			
	SAND	SILT	CLAY	
DEPTH				TEXTURE CLASS
30 cm	25	35	40	CLAY LOAM
60 cm	27	35	38	CLAY LOAM
90 cm	27	35	38	CLAY LOAM

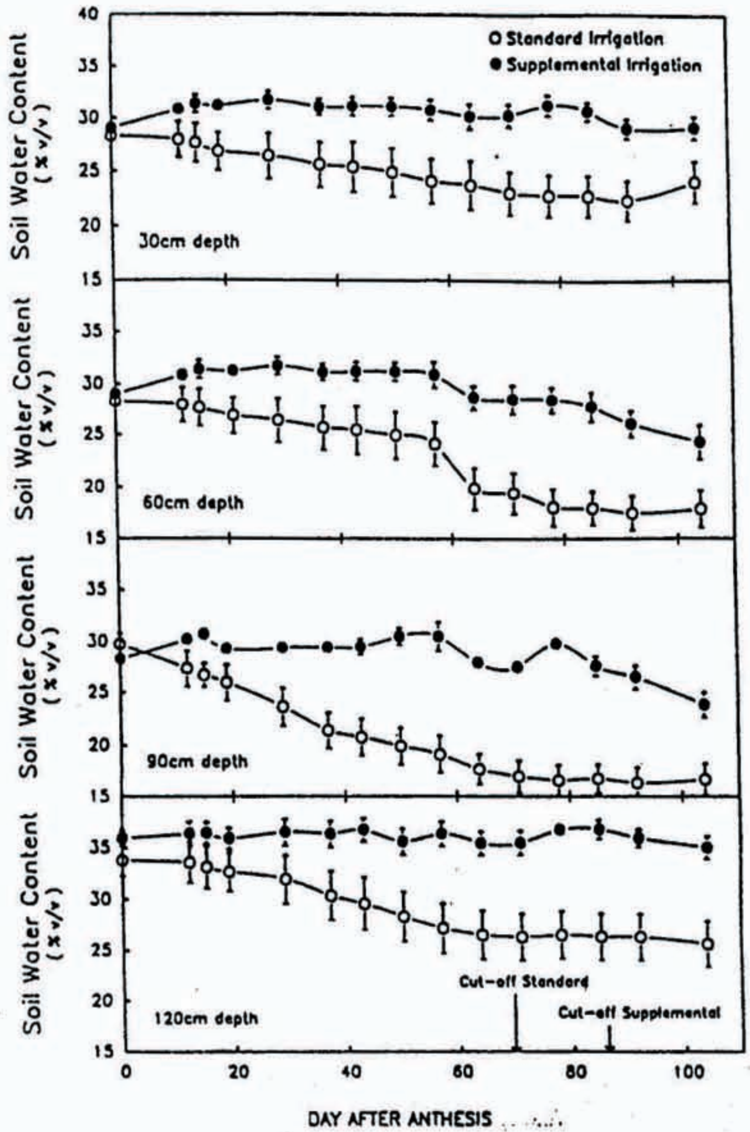
	MINERALOGY OF < 2 um CLAY FRACTION*	CEC meq/100g
DEPTH		
30 cm	SM VR KA	22.2
60 cm	SM VR KA	21.4
90 cm	SM VR KA	16.7

* SM = smectite, VR = vermiculite, KA = kaolinite

SOIL CHEMICAL ANALYSIS AT CARNEROS

DEPTH (cm)	pH	CEC (meq/100g)	K+ (µg/g)	Mg2+ (µg/g)	Ca2+ (µg/g)
0 to 30	7.2	21.4	199	1010	2430
30 to 60	6.5	19.8	148	1018	1730
60 to 90	5.9	14.3	101	625	1100

When water was applied at 3 times the standard irrigation practice, the volumetric soil water content was maintained high throughout the season except for a slight decline near 60 cm depth late in the season. In contrast, soil water status declined at all depths assayed under standard irrigation. The drawdown in soil water was greater at 60-90 cm than near the surface or below 90 cm.



MOISTURE PROFILE NEXT TO VINE ROW
DOMAINE CHANDON CARNEROS VINEYARD

An example of a root map is provided for the treatment receiving supplemental irrigation and potssium sulfate. Roots were placed into one of four diameter categories. The percentage of total root intercepts at each depth are indicated in bar graphs for each of several irrigation/fertilizer treatments. We find only one consistent difference among the treatments. Supplemental water or fertilizer increased root proliferation in the surface 30 cm. Since both water and fertilizer applications increased vine K status, our interpretation is that enhanced root growth in the soil region where most K is available was partially responsible. This response can be anticipated to increase the fraction of applied material that is intercepted by the root system.

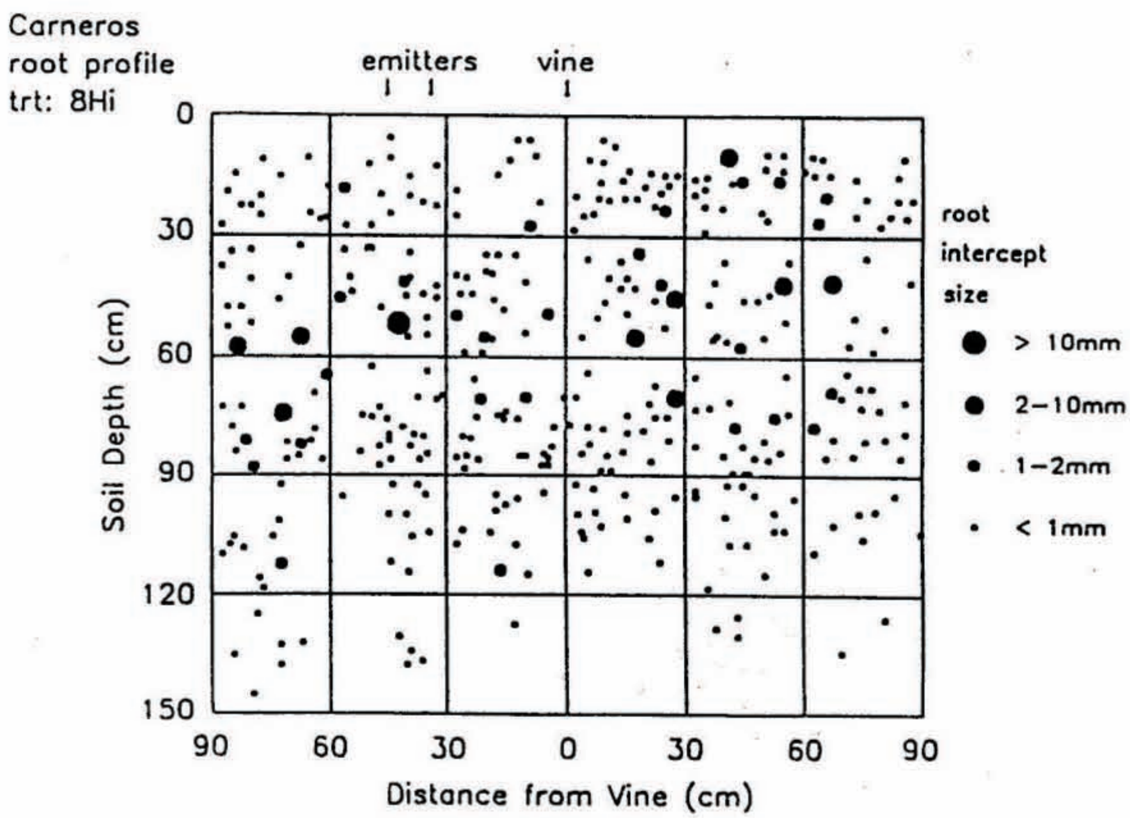


FIGURE R1: Root Distribution for 0-STD Treatment.

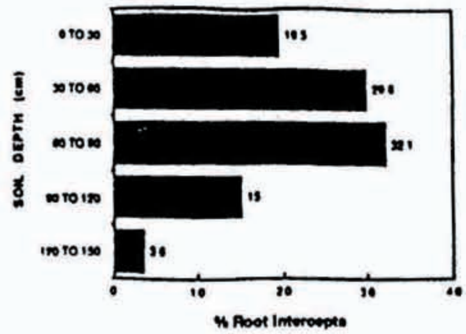


FIGURE R2: Root Distribution for 0-SUPP Treatment.

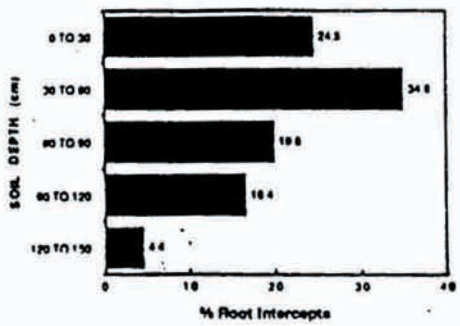


FIGURE R3: Root Distribution For 8-STD Treatment.

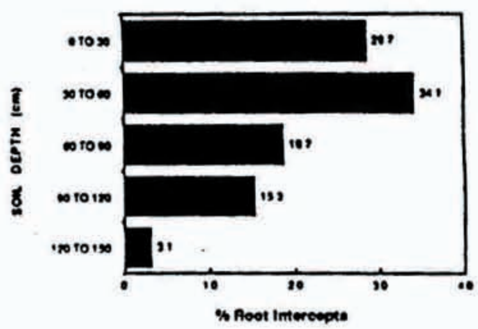
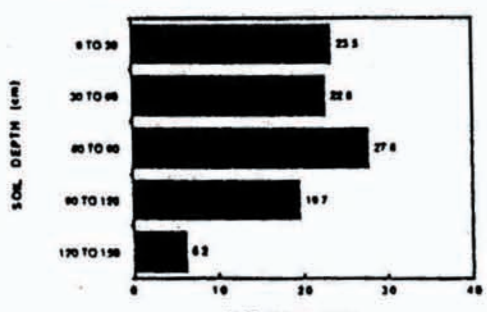
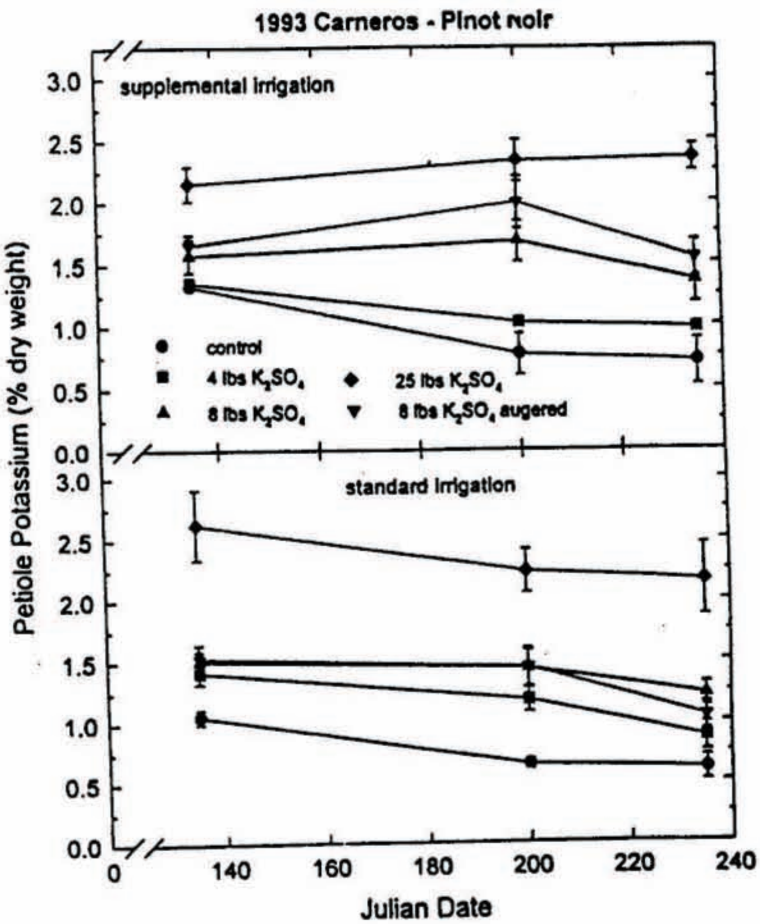


FIGURE R4: Root Distribution for 8-SUPP Treatment.

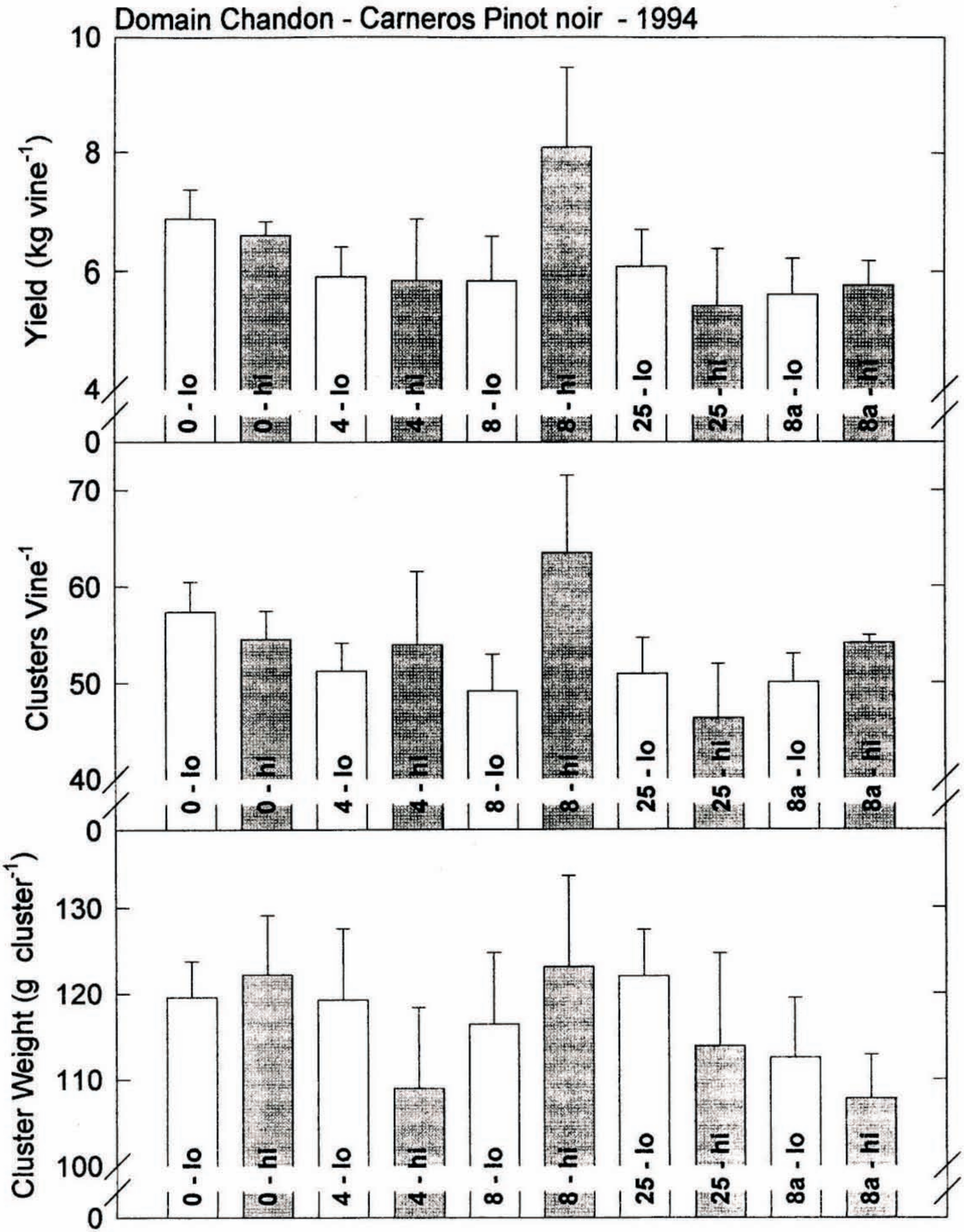


The following figure indicates the petiole K during the past season for several treatments at the Carneros Pinot noir site. The data indicate the following three points that can be made from this and prior seasons. First, on these problem soils, K can be made available and moved into vines if it is supplied at sufficiently high rates to overcome the apparent dry fixation. Second, uptake of K is enhanced by irrigating with more water than is the standard practice. Thus, greater uptake and, hence, fertilizer efficiency was obtained with supplemental irrigation. This was in part due to increased root proliferation in the surface 30 cm of soil. Third, both K applications at high rates (on these heavy, K-fixing soils) and supplemental irrigation increase the maintenance of vine K status beyond the onset of fruit ripening, which the is developmental stage at which deficiency symptoms often occur.



There were no significant differences in shoot growth. For 1993, mean shoot lengths were 176 to 187 cm for the various treatments with standard errors of about 7cm.

The data on the following page indicate the yield components for 1994 at Site 1 (Carneros, Pinot noir). The treatments are labeled by fertilizer treatment)in lbs. per vine), followed by irrigation regime (lo=standard; hi=supplemental). Data for 1993 was presented in earlier reports. The results have consistently showed the highest yield in the 8 lbs. + hi treatment due primarily to larger clusters. However, significant yield increases with irrigation and fertilizer treatments have seldom been observed. Untreated vines have had yields almost as high due to a high number of clusters/vine. It is clear from the petiole analysis that the treatments varied vine K status considerably. Our results with the rootstock trial (discussed in the next section) that showed limited yield response to increased vine K status for Chardonnay on St. George rootstock, but significant increases on some other rootstocks. Based on this observation, St. George may put a low ceiling in yield potential compared to other rootstocks. Thus, the criteria for sufficient K status may need to be adjusted for the specific growth habit imparted by various rootstocks.



Domain Chandon - Carneros Pinot noir - 1994
Yield (kg vine-1)
Clusters Vine-1
Cluster Weight (g cluster-1)
0 - lo
0 - hi
4 - lo
4 - hi
8 - lo
8 - hi
25 - lo
25 - hi
8a - lo
8a - hi
10
8
6
4
0
70
60
50
40
130
120
110
100

Site 2. Summary of Potassium nutrition work in Beringer Chardonnay Rootstock Trial at Yountville

Treatments of 8 lbs. potassium sulfate per vine were applied to some vines prior to 1989 and 1993 seasons. Plots were split and supplmental drip irrigation was supplied to some vines.

KD = K added; drip added	Rootstocks:	1202
KO = K added; no supplemental drip		St. George
OD = no K; drip added		AxR#1
OO = no K; no supplemental drip		5C
		110R
		own roots

The site is K deficient because yield increases were generally observed when K fertilizer was applied. Supplemental irrigation had some effect on improving K status, moreso when fertilizer was applied. A yield response to bloomtime petiole K concentration was not observed. Rootstock 5C obtained K from low K soil better than other rootstocks and produced higher yield on untreated soil. Since vines on 5C did not respond to additional K either in petiole K or in yield, those vines were not K deficient. Vines on St. George also had relatively high K status, did respond to fertilizer by increasing petiole K, but did not, in general, increase yield. The fruit of vines on 5C was consistently lower in K and in pH than the other rootstocks. However, the relationship of juice K to juice pH is not clear and was inconsistent in the several years of this trial. Vine K status is difficult to assess from petiole K at bloom because varieties and rootstocks may create different K status requirements and different patterns of petiole K during the season.

Conclusions:

I. Vine K status can be manipulated by choice of rootstock.

A. Clearly shown that even in the narrow range of stocks at Beringer and with only 3 reps that the root genotype plays a role in bloom petiole K. The data were similar for 4 years running (91-94), showing petiole K status differed among rootstocks on the untreated soil. St. Geo and 5C are on the high side and AxR (and probably 110R) on the low side. Freedom is evidently also a stock that promotes high vine K status, based on data collected outside this trial. See summary table of bloomtime petiole K for several seasons.

B. The data show that bloomtime K status can be increased or decreased compared to own-rooted vines, although <u>decreases</u> are more and more consistent than increases. A recent study by an Italian group has shown similar results.

C. From our data and those of others it would appear to be worthwhile to pursue new genotypes that can be used to change K status of scions on a given soil. This trial was rather limited in scope of stocks, but for improving bloomtime petiole K (which is some indication of vine K status) 5C was consistently high along with St. George.

Rootstock			Bloom Petiole K		% dry wt.
	1990	1991	1992	1993	mean
AxR	1.2	1.4	1.2	0.8	1.15
110R	0.9	1.3	1.5	1	1.18
1202	0.8	1.5	1.5	1.1	1.23
St. Geo	2.3	2.2	1.4	2.2	2.03
5C	2.3	2.2	2.2	2	2.18

Table 1. Approximate values for bloomtime petiole K concentration of Chardonnay vines on various rootstocks at Yountville. The vines were not fertilized with K and were given supplemental irrigation.

II. The response of vine K status to K fertilizer treatments or to supplemental irrigation is to some extent dependent upon rootstock. The effects of applied K and supplemental irrigation on vine K status response varied greatly among rootstocks (Table 2 shows 1993 results; similar results were obtained in previous seasons).

A. When K fertilizer was applied mean K status across rootstocks increased with an average increase of 0.17% to 0.25% K in the several years of the study. AxR and 5C consistently responded least, and St. George and 110R increased bloom petiole K status the most. Vine K status also increased when on 1202 and given fertilizer. The change in vine K status due to fertilizer application varied from about nil on 5C and AxR#1 to an increase of 0.7% on 110R.

B. Although in 93 most rootstocks did not increase bloom petiole K in response to K treatment alone (KO-OO), they did increase (except 5C as usual) when some drip was added (KD-OO). Supplemental water was not necessary in all years. The differences among rootstocks has been fairly consistent: St. George, 1202, & own-roots respond with a 0.2 - 0.4% increase with K or K + drip irrigation; 110R responds but not as consistently; AxR and 5C respond less and 5C often not at all.

Rootstock	Increase in Petiole K (% dry wt.)*	
	K_2SO_4	Irrigation
110R	0.71	-0.29
1202	0.20	0.33
5C	0.03	-0.14
AxR#1	0.00	-0.15
Own	0.07	0.00
St. George	0.50	1.13
mean	0.25	0.15

*data represent difference in bloom petiole [K] between treated and untreated vines

Table 2. Response of petiole K at bloom for Chardonnay vines on various rootstocks that were supplied with supplemental potassium fertilizer or irrigation.

III. The response of vine K status to irrigation is to some extent dependent upon rootstock.

A. There was a general increase in vine K status when supplemental drip was supplied. However, for most rootstocks, there was no effect without K applied. With K applied and supplemental drip, vine K status usually increased except in 5C. The amount of water supplied was much less than the 30 to 40 gal per vine per week that was used in the Carneros Pinot noir trial, and the corresponding increase in vine K status was less in the Yountville Chardonnay.

B. The increase in vine K status due to irrigation in 1993 (shown in Table 2) was approximately one-half of the increase observed the previous season. If vine K status is fairly sensitive to soil water status, then much of the year-to-year variation that is observed may be due to differences in K availability determined by stored water levels and evapotranspiration that vary year-to-year without sufficient adjustment in irrigation regimes.

C. In general (1990, 1992, 1993), the K status of vines on 1202 and St. George was considerably more responsive to irrigation than for vines on the other stocks. This may have to do with root distribution or with differences in the propensity to proliferate roots when water is abundant. Note that the Carneros Pinot noir trial is on St. George and it is there that we observed consistent, large effects of irrigation on vine K status.

I-III. Although there were some differences among rootstocks in how the vine K status responded to fertilizer and irrigation treatments (II and III), the overall ranking of St. George and 5C having high vine K status and AxR and 110R having low vine K status on untreated soil (I) was generally expressed on untreated soil and when K and drip irrigation was added. (see Table 3 for an example ranking from one season.)

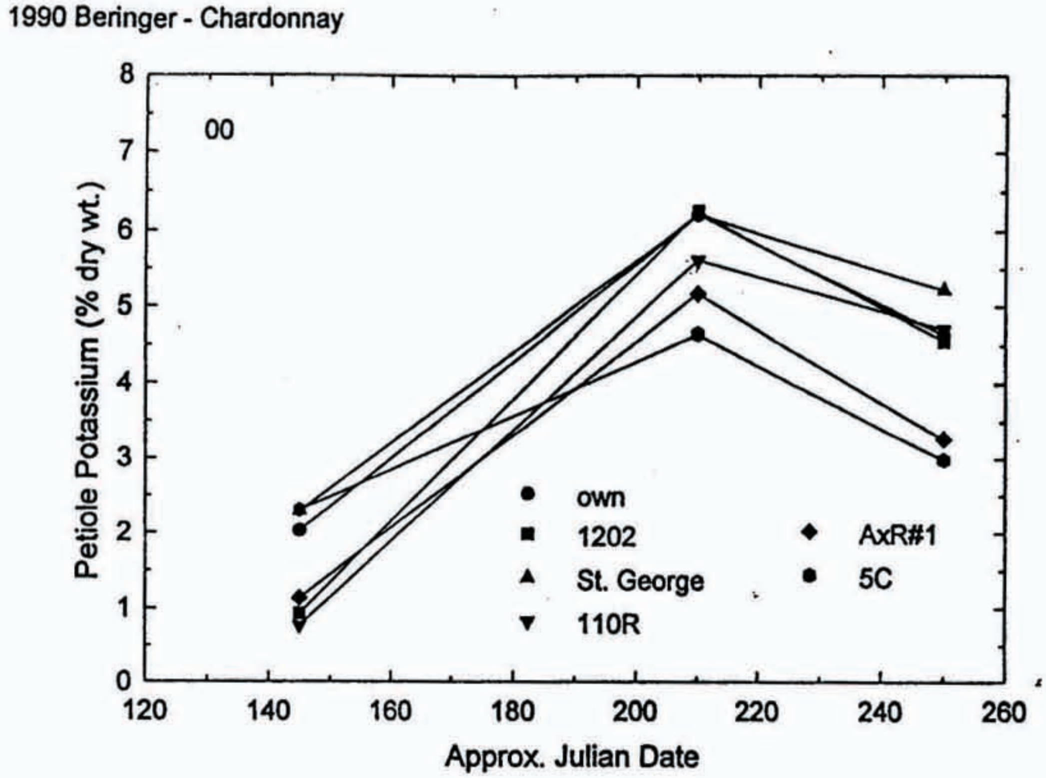
	FERTILIZED PLOTS	
ROOTSTOCK	SUPP IRRIG	STD IRRIG
OWN ROOT	2.48	2.47
COUDERC 1202	1.69	1.78
ST GEORGE	3.02	3.05
RICHTER 110 R	1.56	1.11
A x R #1	1.23	1.16
5C (SO4)	2.69	1.48

Table 3. Bloom petiole K (% dry wt.) for 1993 Chardonnay vines on various rootstocks.

IV. The pattern of petiole K concentration during the season is dependent upon the rootstock.

The pattern of petiole K during the season K was dependent upon rootstock (Fig. 1B). On St. George and 5C initial values at bloom were greater than on other rootstocks. Between bloom and veraison (the 2nd sampling date), petiole K increased slightly on St. George, 5C, and AxR#1, but increased dramatically on 1202, 110R, and own roots.

The results in Figs. 1 A and B (data for 1990 shown in A but not discussed here indicate that different answers would be obtained when determining vine K status on different rootstocks if the question is addressed using samples obtained at bloom, veraison, or harvest. Vines on AxR would probably reveal relatively low vine K status regardless of when sampled; but vines on 1202 would be considered low if sampled at bloom, and high if sampled later.



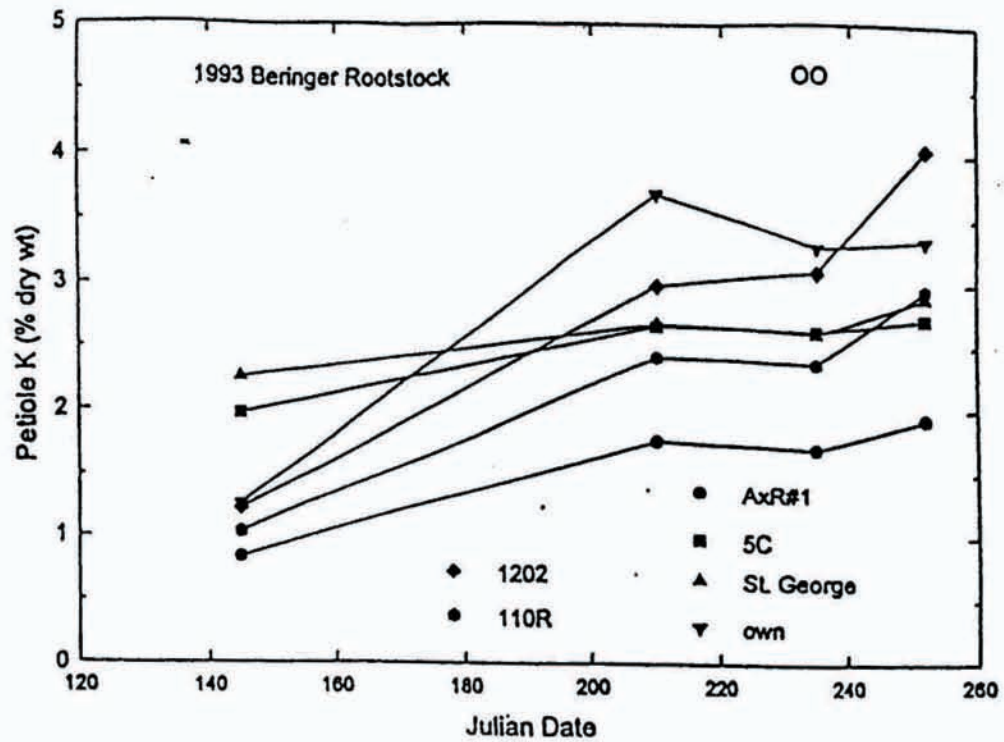


Fig. 1. Petiole K status at different sampling times for Chardonnay vines on various rootstocks in [A] 1990 and [B] 1993.

V. This trial was conducted on a low K site on which vine yield was dependent upon rootstock.

A. Among rootstocks 110R, 5C, AxR#1, St. George, and 1202 and own roots, Chardonnay vines growing on 5C and 110R had similar and comparatively high yields at this site with no soil treatments (examples of 1990 and 1991 shown in Fig. 2 A and B). Vines on St. George had low yields. Yield varied among rootstocks from less than 5 to almost 10 kg per vine. [2 kg/vine = about 1 ton/acre]

B. One year after K fertilizer was applied, yield and clusters/vine increased (up to 60%) for all rootstocks except 5C indicating that both were K limited. Yield increases due to K applications were much less in the following season, but this was unlikely to be due to low K in treated plots. [Note: In the second year after applications, yields were up for all vines regardless of treatments and rootstocks (compare yields in Fig. 2 A and B).] For example, the increase in yield caused by K application was 30% and 6% above the untreated controls for vines on 110R in the first and second season respectively. The large yield for all vines from one year to the next suggests that either some environmental factor that increased K availability in general or relieved an additional yield constraint.

C. Yield responses to K applications have been small or negligible on 5C and St. George and high on AxR, 1202, and own-rooted vines.

D. The high yield, high petiole K, and lack of a yield response to applied K of vines on 5C suggest that 5C is more effective than most other rootstocks at absorbing K and/or translocating it to the shoot. Vines on St. George also exhibit relatively high K status on untreated soil, but the response to applied K differed in two important ways. First, vine K status did improve when K (or supplemental irrigation) was supplied. Second, the increased scion K status resulted in little increase in fruitfulness and yield. Thus, St. George is apparently more effective than most of the other rootstocks in getting K to the scion, but in addition restricts scion fruitfulness in some other way.

E. The yield increases caused by K applications were primarily due to increased number of clusters per vine (Fig. 3A and B).

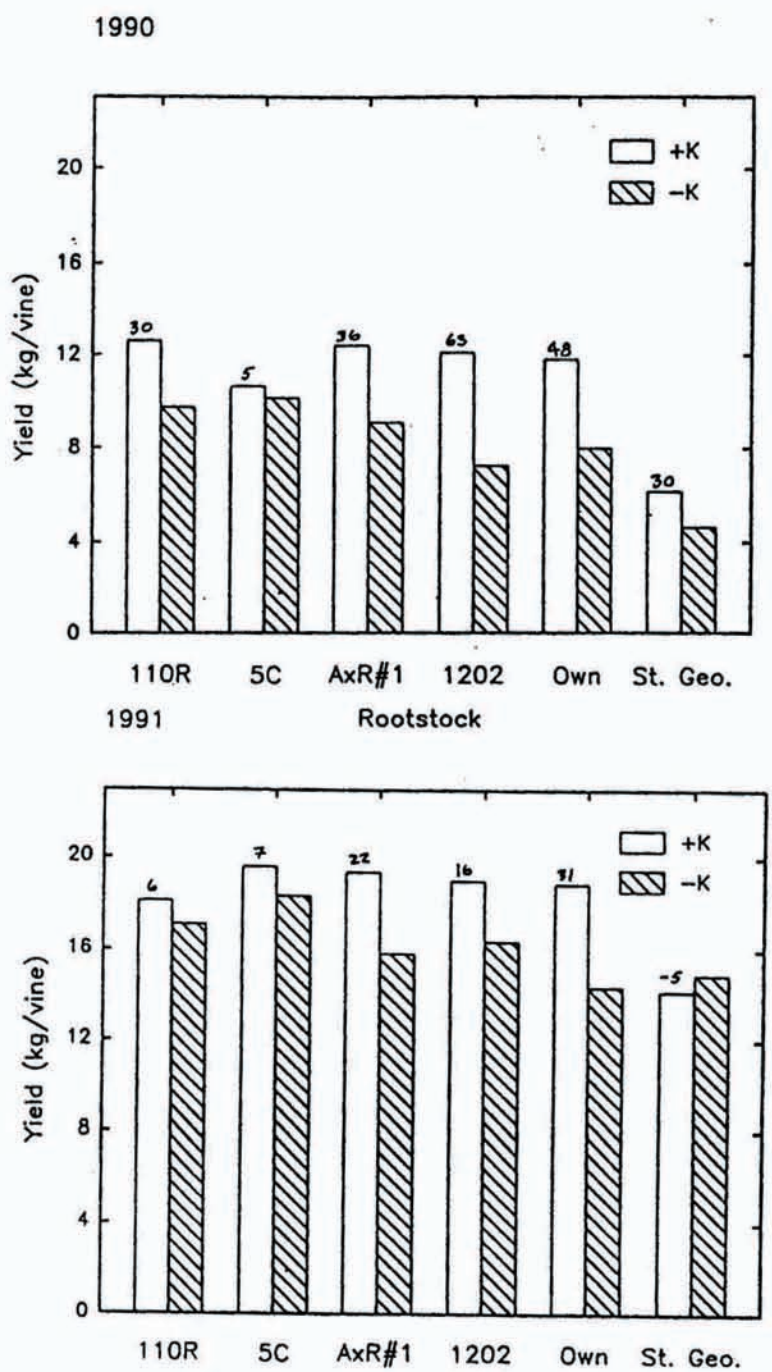


Fig. 2. Yield for 2 seasons of Chardonnay vines on various rootstocks with and without supplemental K.

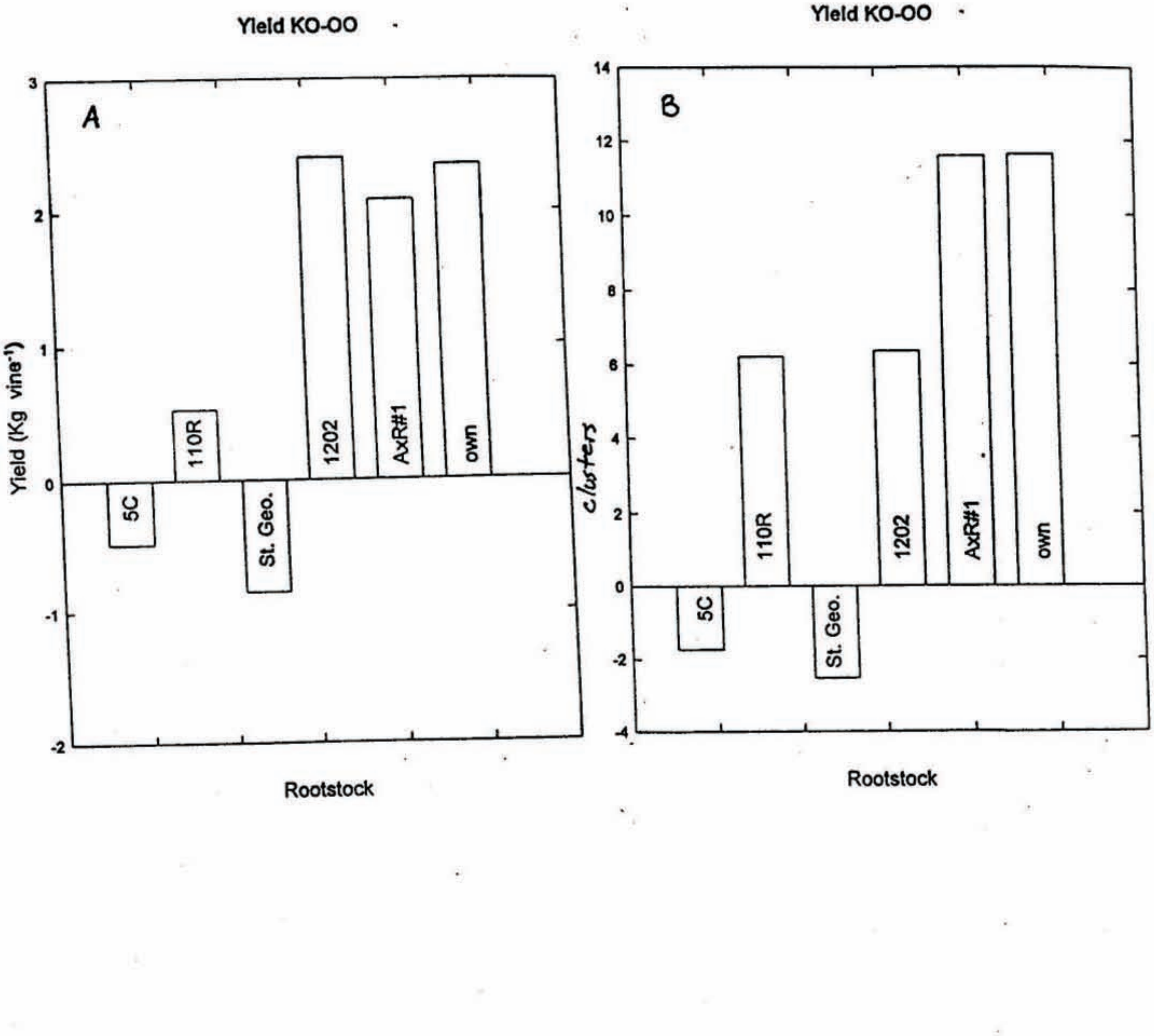


Fig. 3. [A] Yield increase due to K applications for Chardonnay vines on various rootstocks in 1993. [B] Increase in the number of clusters per vine for Chardonnay vines on various rootstocks in 1993.

VI. The only consistent effect of rootstock on Brix has been that own-rooted vines lag behind the other stocks.

A. Although there have been statistically significant differences among rootstocks in Brix at harvest most years, the rankings have been inconsistent. For example, St. George had the lowest sugar in 1990 and the highest in 1991. Except in 1990, the differences among roostocks have been small.

VII. The concentration of K in juice of untreated vines has not shown consistent differences among rootstocks.

A. If there is a consistent difference, it is a trend for juice of St. George to have higher K than the other stocks and for 5C to have lower juice K (Figs. 4 A).

B. The mean juice K among rootstocks varies significantly among years. For example, juice K was about 1550 ppm in 1990 and about 2000 ppm in 1991.

VIII. The pH of the juice depends to some extent on rootstock.

A. For untreated vines, the pH of the juice has been lower on 5C and AxR, and higher on 1202, own roots and, to a lesser extent, St. George (Fig. 4B). In mosts seasons the maximum difference among rootstocks has been about 0.1 pH units. This ranking often also holds when juice pH is assessed across all irrigation and fertilizer treatments. [example from 1991 in appendix]

B. Overall juice pH was just under 3.3 in 1990, over 3.4 in 1991, and about 3.25 in 1993.

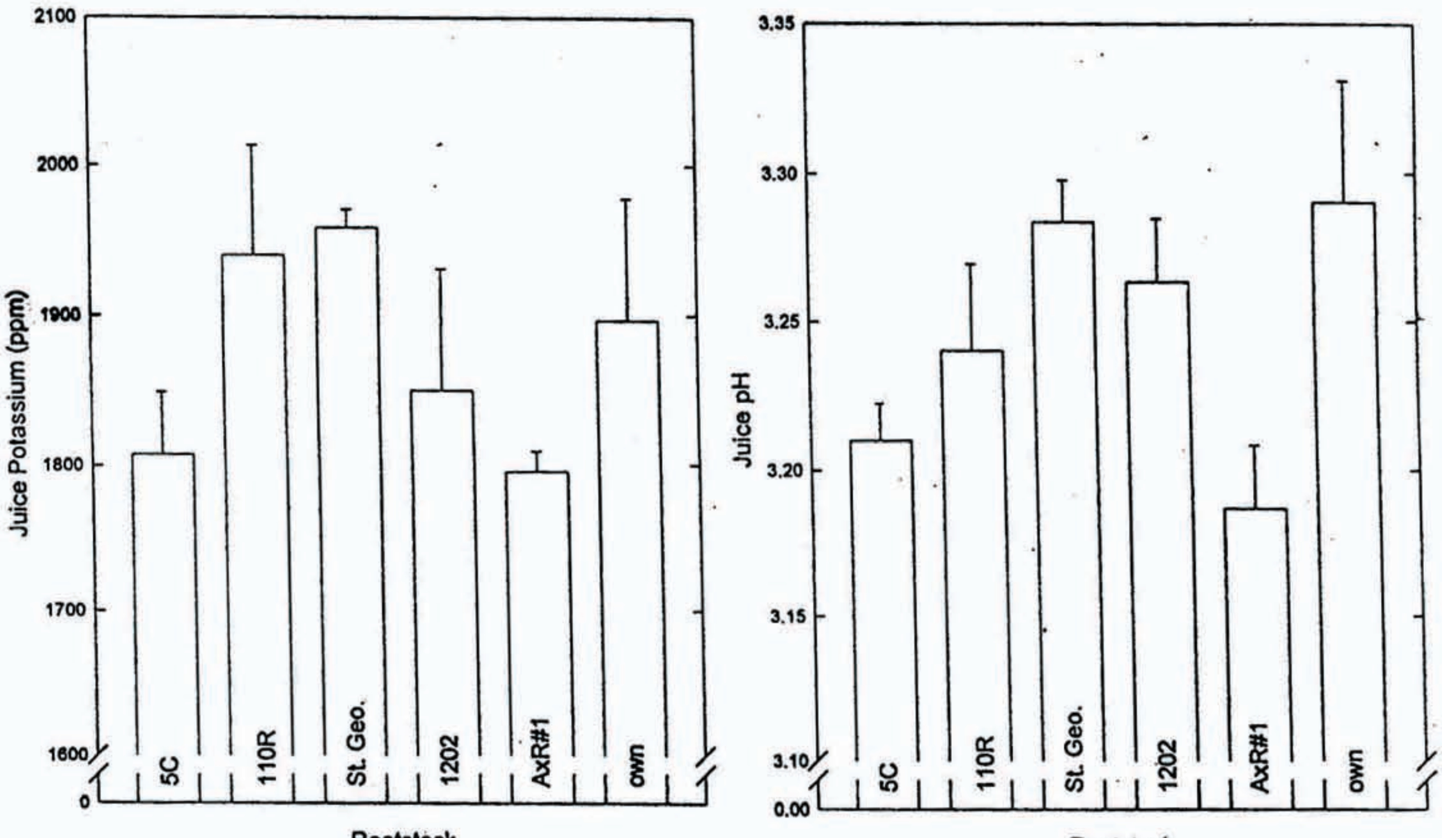


Fig. 4. The concentration of potassium and the pH in juice of Chardonnay vines on various rootstocks in 1993.

IX. The response of juice K and pH to soil treatments is not clear because the treatment effects have been very inconsistent over seasons.

A. In response to K fertilization, juice K has often increased for vines on St. George (90 - 120 ppm) and has changed about 50 ppm or less for vines on 5C. The response of other rootstocks has not been at all consistent, although the trend has been for juice K to decrease in response to fertilizer treatments (1990 and 1991, but a general increase in 1993).

B. There has also been a tendency for juice K to decrease following K applications for when analyzed across all rootstocks, especially for irrigated vines.

C. Statistically, rootstock has had more significant effects on juice pH than K fertilizer treatments.

D. When comparing non-irrigated vines, the effect of K fertilizer has been to decrease juice pH for vines on 1202 by almost 0.08 pH units and for vines on own roots by about one-half that amount. For vines on 110R, pH has increased by about 0.05 pH units.

E. Juice pH is (1993) or is not (1990, 1991) determined by the concentration of K in the juice.

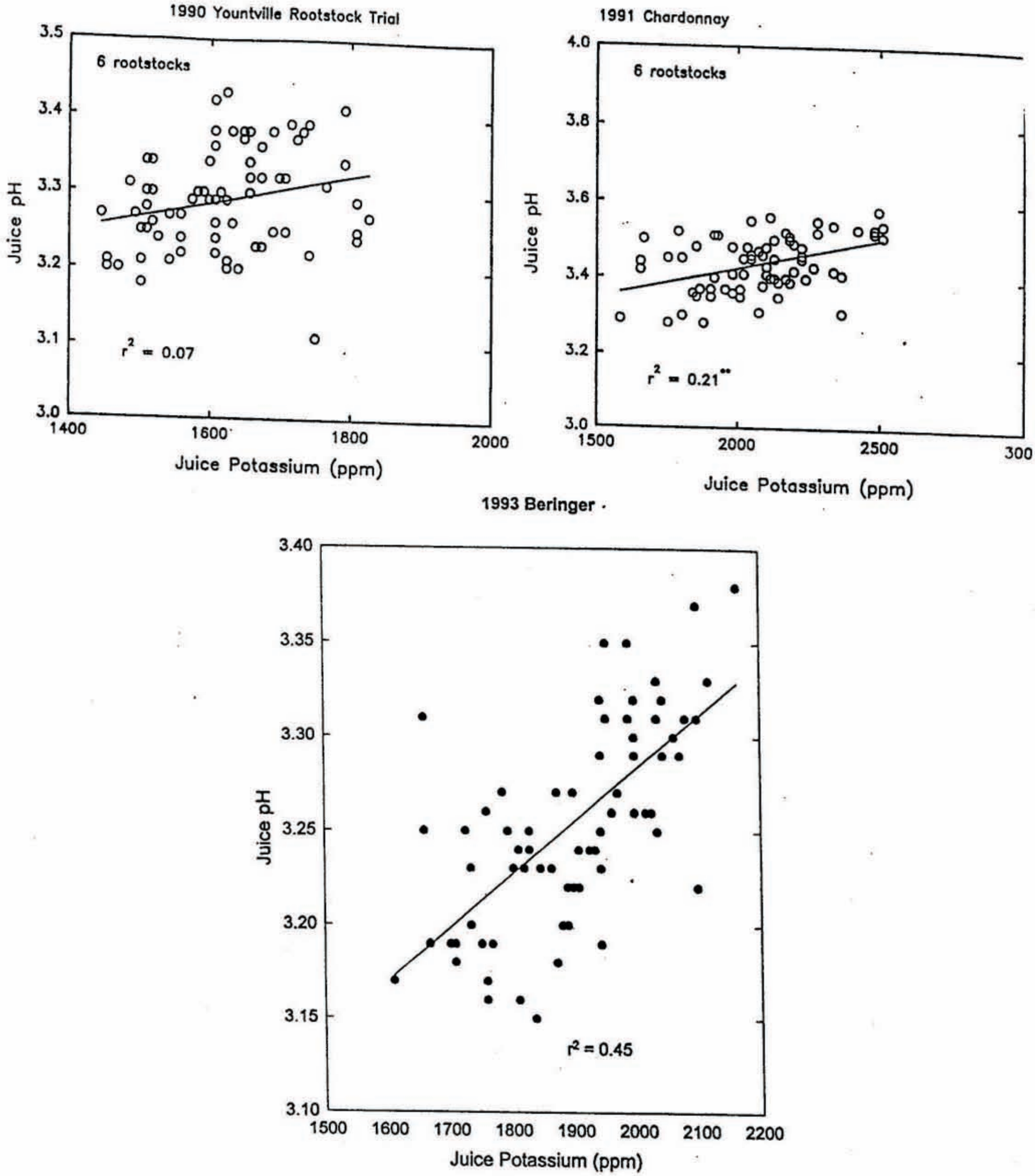


Fig. 5. The relationship of juice pH to the concentration of K in the juice for fruit from Chardonnay vines grown on various rootstocks for three different seasons.

Although increased bloom petiole K has been inconsistently observed when K was applied, there have been clear and consistent increases in yield on some rootstocks. The corresponding increases in growth and yield may lead to less of an increase in petiole K than intuition would suggest, because growth can dilute mineral concentrations. Because of these responses, we have never been able to develop a good yield vs. bloom pet K relationship. Since we can increase yield, we think that this raises the question of whether we are getting a good indication of vine K status with the bloom petiole K. Clearly with different patterns of K during the season depending on rootstock (if this holds up to be true generally) the situation is complicated. It is further complicated by our consistent observation that the pattern of petiole K differs between scions, specifically Chardonnay and Pinot noir.

The results suggest that Pinot noir may require lower concentrations of K in the vines for maximum productivity than Chardonnay. We have observed no yield responses to potassium sulfate treatments in Pinot noir, whereas yield increased between 5% and 60% in the Chardonnay rootstock trial. This difference is not attributable to lower initial K status (bloomtime petiole K) nor to a greater increase in K status in the Chardonnay compared to the Pinot noir. The range of yield responses among the rootstocks (e.g.g, 0 to 60% increases in 1990) indicates that common rootstocks vary significantly in K uptake and in the responses in reproductive growth to K fertilizer applications on a low K soil. Thus, among the alternatives for managing a soil with low available K are the choice of fruiting variety and rootstock. Our results indicate that supplemental irrigation eliminated the decline in vine K status that occurs during the season under the standard irrigation regime. For existing suspect vineyards, sampling and analysis of vineyard K status and soil water status at or after veraison may be important tools for management decisions. For future plantings, more knowledge of the physiological differences among varieties and rootstocks is needed.

Site 3. Chardonnay on AxR#1 rootstock in Healdsburg.

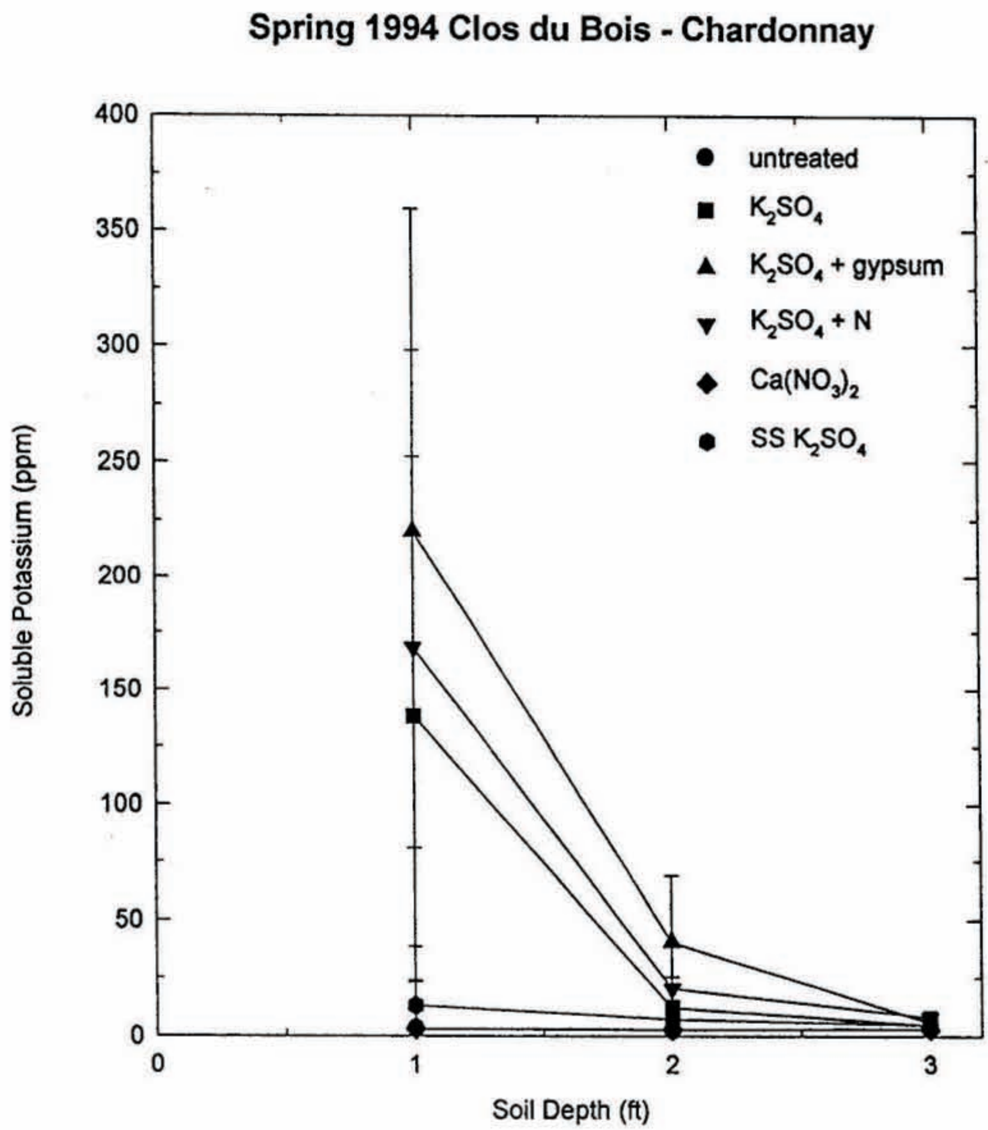
A third field trial was established near Healdsburg, CA, in a mature vineyard of Chardonnay vines where the vines generally express symptoms of K deficiency late in each season. Twelve-vine plots were established incorporating five treatments including an untreated control; potassium sulfate; potassium sulfate + gypsum at similar rates; potassium nitrate; and calcium nitrate at a rate to produce similar nitrate as in the calcium nitrate treatment.

Site Summary:

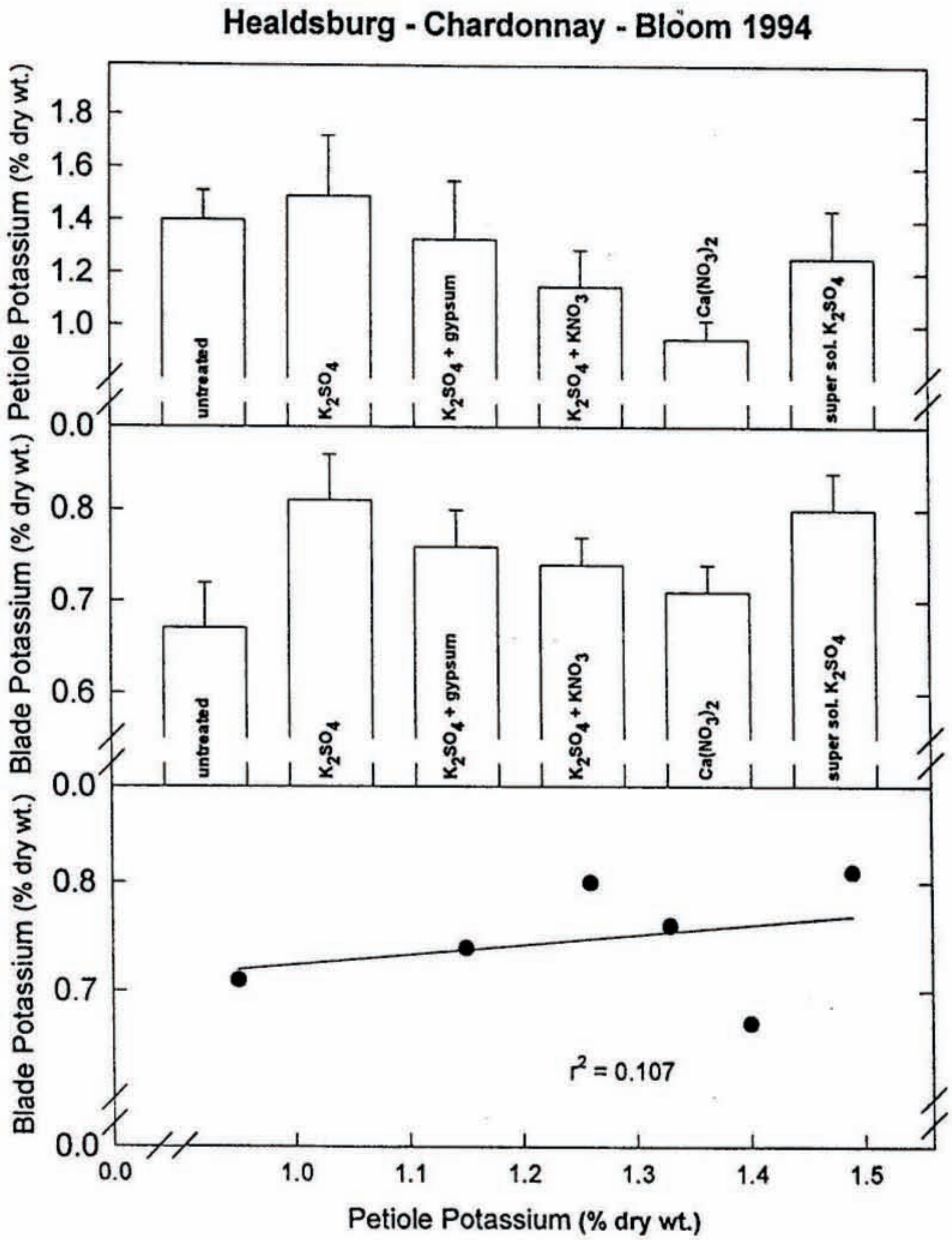
Applying gypsum with potash was effective in increasing the soluble K in the upper soil (1-2 ft). Although the effect of improved soluble K in the soil was not clearly reflected in the bloomtime petiole K, these and other results throughout this project raise questions about the utility of the standard assay of vine K status. The supplemental gypsum did increase yield via increased number of clusters, and it is via increased number of clusters that we have most often observed increased yield when applying K. There was a large synergism of N and K applications, the nature of which should be evaluated. The soil treatments had no consistent effect on juice K but when juice K was high the pH was also usually high.

Analysis of soil and vine N is underway.

Analysis of soluble K in soil samples from three depths showed that the concentration of K was quite low in the untreated soil. All potash treatments increased K in the surface 1-foot and had little or no significant effect in deeper samples. The highest concentration of K at each depth was with the additional gypsum, indicating the efficacy of this approach.



These treatments did not create differences in bloomtime petiole [K] or in yield in 1993. Analysis of bloomtime petioles in 1994 again showed no increases due to treatments (below). However, analysis of blades showed significant increased K in samples from all K treatments. The highest K levels were found in the potash and in the soluble potash treatments. Thus, the use of petioles may be less sensitive than blades for determining K status in some situations. This was shown to be the case for phosphorus in earlier work from this lab, and is one of the areas addressed in the follow-up project that is submitted to this program by Wolpert, Matthews, and Williams.



Yield was increased in the potash treatments in 1994 (below). The addition of gypsum may have increased yield more than potash alone by increasing the number of clusters. Clearly, the combination of nitrogen and potash had a synergistic effect on reproductive growth. Since the combined N and K treatment did not produce evidence of the highest vine K status, this result may have occurred in part as a direct response to N, rather than an indirect increase in K uptake due to improved N status. The interactions of N and K with genotype is another area that is addressed in the follow-up proposal.