A cooperative study was initiated between the University of Arkansas and California State University, Fresno, to determine the effect of rootstock on productivity, fruit, and wine composition. Viticultural data were collected for four years in Arkansas and three years in California, and wine was made one year. Chardonel scion wood was bench-grafted on Cynthiana, Freedom, Kober 5BB, and Richter 110 rootstock. Grafted vines and ownrooted vines were planted in Fayetteville, AR, and Fresno, CA. Vineyard establishment, trellis systems, and cultural practices were standardized between locations. The two locations have different soils and climates, and results differed between locations. Grapes grown in Fresno (3 year means) had higher total soluble solids (23.5 Brix) and titratable acidity (8.0 g/L) and lower pH (3.44) than grapes grown in Fayetteville (4 year means), which had 20.5 Brix, 6.4 g/L titratable acidity, and 3.60 pH. The greatest benefits of using rootstocks were seen in Fayetteville, where yield increases of 40 and 19% were obtained with 5BB and 110R, respectively, as compared to own-rooted vines. Cynthiana produced the lowest yields, and Freedom produced the largest vine size at both locations. Grapes from vines grafted to 110R had a lower pH than own-rooted vines at Fayetteville. Otherwise, there were few composition differences between own-rooted, Freedom, 5BB, and 110R rootstocks. Wines produced from fruit of vines grafted to Freedom had the highest pH at both locations. There were few other differences in wine pH or acidity among grapes that were not attributable to fruit maturity. There was not a major advantage to using rootstock in Fresno. The use of 110R seems to hold an advantage in Fayetteville over own-rooted vines due to higher yield and lower pH.

Chardonel is an upright-growing, white wine grape resulting from the cross of interspecific hybrid Seyval blanc (Seibel 5656 x Rayon d'Or) and Chardonnay (Vitis vinifera L.) made in 1953 at the New York State Agricultural Experiment Station, Geneva, NY. Synonyms for Chardonel are GW-9 and NY 45010. Although Chardonel tended to ripen too late for commercial planting in New York, evaluation at Michigan State University and the University of Arkansas showed this cultivar highly suited for wine production [9]. The vines are more winter hardy than Chardonnay and White Riesling [9]. Own-rooted vines grown in phylloxera-infested soils are productive and moderately vigorous [9]. The grapes mature in late July in Fresno, California, and late August in Arkansas. It has been suggested that Chardonel be evaluated in California as attempts are being made to reduce the use of chemicals in vineyards [13]. Due to the tolerance of Chardonel to powdery mildew Uncinula necator (Schw.) Burr. and Botrytis cinerea Pers., this cultivar may be attractive for use in reduced pesticide or organic farming systems in California. As this is a recently patented cultivar, there is no history of performance of grafted Chardonel vines.

The use of rootstocks is increasing in eastern United States viticultural districts and in the San Joaquin Valley of California. The primary use of rootstocks is for pest resistance [3,4,5,7]. However, rootstocks also influence vegetative growth, yield, fruit composition, and wine quality. Rootstocks used in this study were Cynthiana (V. aestivalis Michx.), Freedom, a seedling of Dog Ridge (V. rupestris Scheele. x V. candicans Engelm.) and Couderc 1613 (Sotonis x Othello), 5BB Kober (V. berlandieri Planch. x V. riparia Michx.), and 110 Richter (V. berlandieri Planch. x V. rupestris Scheele.). These rootstocks are representative of V. aestivalis and the three main classes of rootstocks used in warm-climate viticultural regions. Cynthiana is a native wine grape of Arkansas [6] that was successfully tested as a rootstock for V. labruscana grape cultivars in the 1930s [10,15]. Freedom is known for nematode resistance and high vigor but has also been shown to increase juice pH and potassium [11]. 5BB is known for vigor and phylloxera and nematode resistance; 11 OR is known for drought resistance and low potassium uptake, which results in low juice pH [3].

The objectives for this experiment were to determine the viticultural utility of V. aestivalis and commercially important rootstocks for Chardonel under Arkansas and California conditions and to determine the effect on productivity, fruit, and wine composition.
Materials and Methods
Chardonel scion wood was grafted in spring 1991 to Cynthiana, Freedom, 5BB Kober, and 110 Richter (110R). Grafted vines (Sunridge Nurseries Inc., Bakersfield, CA) and own-rooted vines were planted in Fayetteville, AR, and Fresno, CA. Vineyard establishment and cultural practices were standardized as much as possible between locations. Soil classification for Fresno was San Joaquin loam (fine, mixed, thermic Abruptic Durixeralfs) at pH 6.7. For Fayetteville, soil classification was Captina silt loam (fine-silty, mixed, mesic Typic Fragiudults) at pH 5.8. Both soils had been in grapes for many years; soil amendments had been used to adjust pH in the past but were not applied during this study. The training system was a low bilateral cordon (96.5 cm) with two sets of movable catch wires. Vines were drip irrigated. Vine spacing and row orientation differed between locations: 1.82 m x 2.74 m, north-south for Fayetteville and 2.13 m x 3.35 m, east-west for Fresno. Four replications of three-vine plots were established at Fresno and three replications of single-vine plots were established at Fayetteville. Vines were planted as green growing, bench-grafted vines at Fresno in July 1991 and as two-year-old dormant vines at Fayetteville in April 1993. Leaves were removed at berry set in a zone 0.25 m above the cordon on the north side in California and on both sides in Arkansas. Leaves were not removed from the south side at the California location because sunscald often occurs at this site when the fruit is directly exposed to afternoon sun. Vines were topped at 2 m once during the growing season and balance pruned to a 20 + 10 level (20 buds retained for the first 454 g of prunings and an additional 10 buds left for each additional 454 g of dormant prunings removed). Data were collected during 1994, 1996, and 1997 seasons in Fresno and during the 1997, 1998, 1999, and 2000 seasons in Fayetteville.

Fruit composition (total soluble solids, pH, titratable acidity, berry weight) was determined at harvest from 100 berry samples collected from the cluster apex of the basal cluster. Cluster weights were determined from cluster count per vine divided by yield per vine.
Wines were produced at the University of Arkansas from grapes grown in California in 1997 and Arkansas in 1998. Wine was made using 55 kg of grapes per rootstock with a 52% by weight juice yield. The grapes were compiled from field replicates to provide a single representative lot. Bottling was considered as point of replication for wines. Grapes from California were harvested and shipped overnight. After harvesting, grapes were cooled to 4°C, crushed with 35 mg/L SO₂ destemmed, and pressed in a bladder press. Juice was cold settled overnight at 2°C, racked, and warmed to room temperature. The yeast nutrient Fermaid and EC1118 yeast (Lallemand, Inc. Montreal, Quebec) were added at a rate of 0.26 g/L. Wines were fermented at 21°C, cold stabilized, and filtered with a one-micron filter before bottling with 60 mg/L SO₂.

Standard methods for juice and wine analysis were used [16]. Potassium was determined using a Spectro Model D ICP (Spectro Analytical Instruments, Inc., Fitchburg, MA).

Data were analyzed for each site using statistical analysis software [12] with the ANOVA or GLM procedures for factorial analyses of variance. Duncan's multiple range test at p ≤ 0.05 was used to separate means of main effects.

### Results and Discussion

Due to differences in macroclimate and variations in cultural practices, results from each vineyard location are presented separately. Chardonel performed satisfactorily at both locations. At the Fresno site, the superior disease tolerance of Chardonel, as compared to Chardonnay, was observed. In adjacent plots and in comparable canopies, Chardonnay required two to three additional applications of fungicides to control powdery mildew.

The main effects for rootstock and year from the Fresno location are shown in Table 1. Variations between years were observed as expected. Vines increased in yield as they became mature, but most of the measured yield components remained reasonably constant from year to year. In general, Chardonel produced excellent fruit regardless of rootstock or year. Brix, pH, and acidity were acceptable across all rootstocks; however, differences between rootstocks were recorded. Own-, Freedom-, and 1108-rooted vines produced higher Brix than Cynthiana-rooted vines. The pH was highest on Freedom and lowest on 1108. Grapes grown on Cynthiana roots had the lowest berry weight while 5BB had the highest berry weight. Cluster weights were lowest on Cynthiana. Yield was numerically highest on Freedom and lowest on Cynthiana, but use of rootstock did not provide a yield advantage over own-rooted vines at this site. Freedom produced the greatest vine size as indicated by pruning weight. The Ravaz index (kg fruit/kg prunings) [1,2,8] is an indication of vine balance: a value of 5 to 10 indicates the vine is balanced, a value greater than 12 indicates overcropping, while a value less than 3 indicates excessive vine size [14]. Using these criteria, all rootstocks produced vines in an acceptable range of balance.

The impact of rootstock selection on initial juice and wine composition for California grown grapes is shown in Table 2. There were differences in Brix at harvest, reflected in alcohol level. Chardonel grafted on Cynthiana produced grapes with the lowest Brix and Freedom had the highest Brix. In an examination of juice and wine from treatments at the same Brix level (Freedom, own-rooted, and 110R), Freedom was shown to have the highest wine pH and potassium concentration.
The main effects for rootstock and year for Fayetteville are shown in Table 3. Data were collected from this site for the greatest number of years, and variations existed between years. In 1997, cool night temperatures during ripening were reflected in low pH values for that year. Fruit set was exceptionally good in 1999, which resulted in lower Brix, heavier clusters, and higher yields. Composition differences among rootstocks were limited to pH and potassium. The grapes grown on Cynthiana and 110R had lower pH and potassium concentrations at the same Brix and TA as compared to own-rooted, Freedom, and 5BB vines. Cynthiana tended to produce smaller clusters and fewer clusters per vine than other rootstocks. Yields were highest on 5BB and lowest on Cynthiana. Yield increases of 40 and 19% were obtained with 51313 and 1108, respectively, as compared to own-rooted vines. Vine size was largest for Freedom and smallest for Cynthiana and own-rooted vines. The Ravaz index indicates that all rootstocks produced balanced vines on this trellis system and that vines were overcropped in 1999, but returned to balanced condition in 2000.

Rootstock affected juice and wine composition at the Arkansas location (Table 4). Differences in juice Brix were reflected in differences in alcohol level. Cynthiana grapes had the lowest Brix level. Juice from vines grafted on Freedom, own-rooted, and 1108 had values for Brix and TA that were commercially similar. Among these, 110R had the lowest juice and wine pH and the lowest wine potassium. Wines from the Freedom-rooted vines had the highest pH. Wine pH was much higher in Arkansas than in California.

The rootstocks behaved similarly in some respects between locations. Cynthiana had low yields at both locations. These vines were slow to develop at Arkansas and had depressed Brix. Reynolds and Vail [10] reported a similar delay in maturity when Cynthiana was used as a rootstock for V. labruscana grape cultivars. In addition, Cynthiana is difficult to propagate as either a rooting or a grafted plant. Consequently, Cynthiana does not appear to be suitable for use as a rootstock for Chardonel.

When compared to own-rooted vines, 1108 had similar yield and Brix but lower pH readings at both locations. Low pH and low potassium uptake from 1108 had been previously noted [3]. Freedom produced larger vine sizes and similar yields as compared to own-rooted vines at both locations. Wines from the Freedom-rooted vines had the highest pH at both locations. It has been noted previously that Freedom increases the potassium content and pH of wines [11]. In Arkansas, 5BB produced the highest yields but was otherwise similar in quality attributes to own-rooted vines.

Conclusions
The greatest benefits of using rootstocks were seen in Fayetteville, where yield increases of 40 and 19% were obtained with 5BB and IIOR, respectively, as compared to own-rooted vines. Chardonel grafted on Cynthiana produced the lowest yields at both locations while Freedom produced the largest vine size. Grapes from vines grafted to 1108 had a lower pH than own-rooted vines at Fayetteville. Otherwise, there were few composition differences between own-rooted and Freedom, 5BB, and 11OR rootstocks. Wines from Freedom vines had the highest pH at both locations. That, however, might not preclude the use of Freedom as a rootstock. The application of cultural practices or a cooler climate might allow for lower pH. There were few other differences in wine pH or acidity among grapes that were not attributable to grape maturity. There was not a major advantage to using rootstocks in Fresno. The use of IIOR seemed to hold an advantage in Fayetteville over own-rooted vines due to high yield and lower pH.

Literature Cited