

NUTRITIONAL CONDITIONS OF CONCORD
VINEYARDS IN MICHIGAN

By
Robert Paul Larsen

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
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R. L. Kenworthy

ABSTRACT

A survey of Michigan Concord vineyards was made in 1953 and 1954 to determine the nutritional conditions of the vineyards. Approximately 50 vineyards in Berrien and Van Buren counties were used for the survey. Leaf petioles from each site were analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, manganese, iron, boron, and copper. Soil samples were analyzed for cation exchange capacity; exchangeable calcium, magnesium, and potassium. The samples were tested for phosphorus, calcium, magnesium, potassium, and pH. Representative vineyards were harvested to obtain yield records, and soluble solids were determined on the ripe grapes.

Potash fertilizer trials were established in 1954 in six different vineyards of varying potassium levels. Various levels of muriate of potash (KCl) and sulfate of potash (K_2SO_4) were used as treatments. Petiole analyses and yield data were obtained in the same manner as the survey samples.

The survey revealed that potassium shortages were prevalent in a high percentage of Michigan vineyards and that these shortages are appreciably reducing grape yields in many instances. Although deficiency symptoms were not apparent, petiole analysis indicated that manganese may be deficient in several vineyards. Except in isolated instances, other nutrients were apparently in satisfactory supply.

Applications of either potassium sulfate or potassium chloride at rates of 180 pounds per acre of actual potash resulted in good growth and increased yields of fruit during the year of initial application. Potash applied at 90 pounds per acre materially reduced deficiency symptoms but was not sufficient to increase yields.

Cation exchange capacity of the soil and soil potassium were both related to yield, indicating that additions of organic matter as well as potash might be of value in many of the vineyards located on sandy soils. The ratio of potassium to calcium + magnesium appeared to be more important in relation to yield than the percent saturation of the three cations either individually or collectively.

High levels of potassium in the petioles were associated with low levels of other nutrients, except nitrogen, in the petioles. Applications of potash to the soil resulted in decreased accumulation of all elements, except potassium. Because of this effect of potassium, high amounts of potash fertilizers could result in deficiencies of other elements, particularly magnesium.

Yield was more closely related to the number of bunches per vine than to the weight per bunch indicating the importance of preceding season's growth on yield. Soluble solids content of the fruit was low under conditions of either potash deficiency or high yields associated with good vigor. Applications of potash increased the soluble solids content of fruit from the deficient vines.

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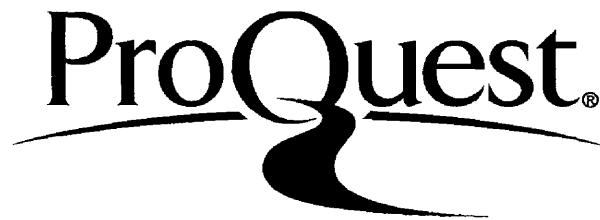
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INTRODUCTION

The grape is one of Michigan's most important fruit crops. Michigan vineyards produce from 35,000 to 40,000 tons of grapes annually valued at about four million dollars. Concord, a variety of a native American grape (*Vitis labrusca*), is the most important variety. Concord grapes are used largely for the production of unfermented grape juice. The recent introduction of a frozen juice concentrate has greatly increased the consumption of grape juice.

Production to meet the new demands for Concord grapes may be accomplished by increased acreage or by increasing production of the current vineyards. The average annual production for Michigan vineyards has been below three tons per acre. This low average yield may be associated primarily with depletion of soil and soil nutrients through erosion and failure to apply the proper amounts of needed fertilizers.

As a result of early experiments conducted in Southwestern Michigan, (Partridge, 29) fertilizer recommendations for Michigan vineyards for many years tended toward use of only nitrogen or manure when the latter was available. During recent years, however, complete fertilizers containing N, P, and K have been commonly used. The majority of growers have been applying various grades and amounts of complete fertilizers.

The purpose of this investigation was to determine the nutritional conditions of Michigan Concord vineyards and to begin field experimentation as to ways of improving these nutritional conditions in order to obtain larger fruit yields.

REVIEW OF LITERATURE

The growth and productiveness of a grape vine is dependent, to a large extent, on the growing conditions the preceding year and the methods of training and pruning the vine. Partridge (31) observed that the size of the crop was dependent upon the number of fruit clusters and their size. He found that the number of bunches probably was more closely associated with the characteristics of the one-year-old cane than with those of the shoot. However, the number and size of blossom clusters were dependent upon nutritional conditions of the current shoot growth. Partridge (30) also found that a vine should be pruned according to its vigor, and that the number of buds to be left on a vine could be determined by the weight of one-year-old wood removed from the vine during pruning. He suggested that the four-cane Kniffen system was the best method of training for most Michigan vineyards.

Partridge (30) further stated that increasing the vigor of most vines as found in Michigan vineyards would increase their capacity to produce fruit. Numerous workers (10, 16, 29, 33, 51) have reported that the replacement of soil organic matter or humus was of greater value for growth and production than any commercial fertilizer practice. Partridge (29), Holland (16), and Van Haarlem and Upshall (51)

found manure or cover crops to be most effective for continued high yields. Fleming, Alderfer, and Frear (10) found that manure, grape stems, or pomace increased vine growth and yield more than inorganic fertilizers. Shaulis (39) reported response to the application of nitrogen with manures, waste hay, straw, grape stems, and grape pomace. Beattie (3) recently obtained increased yields of grapes by over four tons per acre with the addition of straw mulch plus 120 pounds of ammonium nitrate per acre.

Various workers (13, 22, 32, 39) have shown the value of nitrogenous fertilizers. Gladwin (12) reported in 1915 that commercial nitrogen together with good tillage could restore a neglected vineyard. He further stated that two applications of nitrogen (when the first three or four leaves of the shoot were developing and two or three weeks later) were preferable to a single application of the same amount. Lagatu and Maume (23) and others (7, 35) stressed the need for balanced nutrition of nitrogen, phosphorus, and potassium in French vineyards. Various combinations of organic and inorganic sources of nitrogen were used in their experiments.

The recommended nitrogen sources and rates of application have varied with different workers. Partridge (32) and Gladwin (13) recommended nitrate of soda or ammonium sulfate at rates of 150 to 250 pounds per acre. Fleming, Alderfer, and Frear (10) found that annual spring applications of 20 pounds of actual nitrogen per acre were adequate for the

greatest vine growth and yield. Shaulis (39) and Beattie (2) have found that the nitrogen requirements of grape vines will usually be satisfied with 40 to 80 pounds of actual nitrogen per acre. Partridge (32) suggested that ammonium sulfate be used as the nitrogen source under alkaline conditions and that nitrate of soda be used under acid conditions. Chauzit (7), in France, found that a combination of dried blood and sodium nitrate was superior to any other source of nitrogen tried, including ammonium sulfate, cyanamide, and grape residue.

Responses from foliar sprays of nitrogen have been inconclusive (28). Leaves sprayed with four, eight, and twelve pounds of urea per 100 gallons of water resulted in no significant accumulation of nitrogen in the leaves. Furthermore, the grape foliage was sensitive to urea, being severely injured by a single application of four pounds per 100 gallons.

The applications of phosphate fertilizers have not generally resulted in any direct effects on either vine growth or yield (13, 33, 39, 50). Lilleland (26) questioned the value of using phosphate fertilizers on any deciduous fruits since they do not respond to phosphate fertilizers even on deficient soils where other crops show marked increase in growth. Using radioactive phosphoric acid applied to the soil, Ulrich, Jacobson, and Overstreet (50) found that less than one percent of phosphorus added to the soil was taken up by the vines.

On the other hand, Lagatu and Maume (20) obtained increased yields through additions of phosphorus, either as superphosphate or as rock phosphate. They attributed the increased yield to a better balance of the three elements, nitrogen, phosphorus, and potassium. Randolph (34), in Texas, obtained more vigorous growth and higher yields with the variety Carman wherever phosphorus was used than with treatments of nitrogen alone, nitrogen and potassium combined, or no fertilizer.

The value of potassium as a fertilizer for grape vines has been known for many years in Europe as well as the United States. Numerous cases of leaf browning and marginal chlorosis as symptoms of potassium deficiency on grape vines have been reported in France (21, 35, 52) and Germany (55). Lagatu and Maume (25) found that 540 pounds of K_2O per acre was required for three consecutive years in order to restore vigor to potassium deficient grape vines. Wilhelm (55) reported that potassium deficiency in Germany appeared most frequently and severely on young plantings. The application of potash was suggested for new plantings, especially those on meadow or pasture lands and on heavy lime-rich soils. Ravoz and Verge (35) reported that large amounts of potassium resulted in vines with well developed root systems and also improved grape quality.

In New Zealand, chlorosis and necrosis of the leaves of grape vines were found to be due to a deficiency of potassium (1).

An application of potassium sulfate at the rate of 400 pounds per acre eliminated symptoms and brought about healthy growth during the season applied.

In the United States, Steve (45), Boynton (5), Forshey (11), and Shaulis (40) have reported potassium deficiencies in grapes. Steve found distinct reduction in yields when potash was omitted from the fertilizer. Boynton obtained partial recovery from the interveinal chlorosis and marginal scorching of the leaves from applications of muriate of potash, and the recovery was associated with increase in leaf potassium. Forshey reported that deficiencies of potassium reduced grape yields in Ohio, and that 60 percent of Ohio vineyards probably would respond to applications of potassium. Shaulis reported potassium deficiency in the vineyards of New York and suggested the use of potassium sulfate at rates of 300 to 500 pounds per acre as the control for this deficiency

Chauzit (7), Vinet (52), and Shaulis (40) have suggested the use of potassium sulfate in preference to potassium chloride for grape vines. Vinet reported that the sulfate ion when applied with the potassium ion proved better than the chloride ion. It was his opinion that the chloride ion hindered the action of the K_2O while the sulfate ion favored this action.

The appearance of calcium deficiency symptoms in vineyards has not been reported; however, in sand culture experiments

with the Muscadine grape, Hagler and Scott (15) found that the young leaves of calcium deficient vines developed interveinal and marginal chlorosis followed by necrotic "pinhead" spots near the margin of the leaf. There also was considerable dieback of the tips of the vines.

Reports of Partridge (29), Gladwin (13), and Shaulis (39) indicated that applications of lime resulted in no appreciable increases in growth or yield of grapes; however, it has been found to benefit cover crops grown in the vineyard, and applications have been recommended if the pH is below 5.5 (39).

Lott (27) corrected magnesium deficiency of James and Scuppernong grape varieties by injecting magnesium sulfate solutions into the stalks. Applications of magnesium sulfate to the soil gave no visible results during the first year of treatment. Scott and Scott (38) found that soil applications of magnesium sulfate had no effect on foliar symptoms or magnesium concentration of the leaves during the year of initial application but gave partial correction of chlorosis the following year.

Crawford (9) and Wann (54) have reported instances of iron chlorosis in the West due to high lime soils. They obtained temporary control of the deficiency by injections of certain iron salts into the chlorotic plants or by spraying the foliage of the chlorotic plants with iron salt solutions. Soil treatments were ineffective; however, Wann found that

Concord scions grafted onto vinifera roots produced vigorous vines which remained practically free from chlorosis for a period of five years.

Scott (36, 37) found boron deficiency of grapes to be associated with dwarfed shoot growth in the early spring, chlorotic areas near the margin and between the leaf veins, and the failure of vines to set fruit. He reported that the relationship between time of fruit set and the appearance of deficiency symptoms, accompanied by the failure of boron deficient vines to set fruit, strongly suggested a very close relationship between boron nutrition and fruit setting of the grape. Correction of the deficiency was accomplished for many varieties by the application of borax to the soil at the rate of 10 pounds per acre.

Studies of Snyder and Harmon (43) indicated that poor setting of the Alexandria grape may have been associated with zinc deficiency even though leaf symptoms were not apparent. A solution of zinc sulfate brushed on the pruning wounds practically doubled the yield of this variety. Clore (8) found that zinc deficiency on Concord vines may be confused with injury caused by 2,4-D. Zinc deficiency caused both leaves and shoots to become curled and twisted with deformed leaves having veins gathered together resembling a partly opened fan. The dwarfing effect of 2,4-D on grape leaves was greater on the interveinal tissues. It left the veins extended and resulted in a finger-like appearance.

The zinc deficiency was corrected by sprays of zinc sulfate solutions.

The relationships between nutrient elements and their interactive effects have been the subject of numerous reports (6, 25, 41, 46). Lagatu and Maume (18, 19, 23, 24), in early experiments with the grape, considered that a physiological balance between the major elements was necessary for optimum growth and yield. They found that each of the elements may have a profound effect on the behavior of others. Deficiencies of one of the elements -- nitrogen, phosphorus, or potassium -- increased assimilation of the other two. Applications of lime inhibited potassium assimilation, while applications of potassium inhibited calcium and magnesium assimilation. They further found that as the season progressed, calcium and magnesium contents of grape leaves increased while the potassium content decreased.

The reports of Lagatu and Maume are in general agreement with those reported for other crops. Carolus (6), Thomas (46), and Shear, Crane, and Myers (42) have reported that additions of one element may depress the accumulation of another element. This has been particularly true for the three cations, calcium, potassium, and magnesium. Carolus found that bean plants grown on a soil medium without added fertilizer were able to absorb sufficient calcium and magnesium; but when an N-P-K mix was added, the intake of calcium and magnesium was greatly reduced.

In experiments with Zea Mays Thomas and Mack (47) found that the highest yields were associated with the highest intensities of nutrition with respect to nitrogen, phosphorus, and potassium. Limed plots resulted in higher yields due to more favorable equilibrium between calcium, magnesium, and potassium.

Shear, Crane, and Myers (41, 42) working with nutritional requirements of tung reported that maximum growth and yield result only when the proper balance of nutrient elements occurs in combination with their optimum intensity, and that plants may be lacking any distinctive symptoms of malnutrition, yet varying over a wide range in growth or yield or both.

They further state, "All other factors being constant plant growth is a function of two variables of nutrition, intensity and balance, as they are reflected in the composition of leaves when the plants are in the same stages of growth or development. At any given level of nutritional intensity (total equivalent concentration of all functional nutrient elements in the leaf) a multiplicity of ratios may exist between these elements. Maximum growth and yield occur only upon the coincidence of optimum intensity and balance."

EXPERIMENTAL PROCEDURE

Survey

During July and early August of 1953 and 1954, soil and leaf petiole samples were collected in 50 Concord vineyards or vineyard sites in Southwestern Michigan (Berrien, Van Buren, and Kalamazoo counties). The sites selected represented many different cultural practices and soil types and included vineyards of varying vigor and production.

Ten vines for sampling were selected in each of the 50 sites. Approximately 15 petioles were removed from each vine*. The petioles were selected from mature leaves usually located in the mid-portion of fruiting shoots and beyond the fruit clusters.

Soil samples were taken from the surface six to eight inches. Two cores of soil were taken for each vine. The soil cores were then thoroughly mixed and a one-half pint sample saved for analysis. The samples were dried and stored in original one-half pint containers.

Thirty of the original 50 sites were selected as representative vineyards from which to obtain yield records. Vineyards, whose yields were obviously affected by frost, hail,

*Ulrich (48, 49) found that the leaf petioles reflected the nutrient status of a grape vine better than the leaf blades. Also, their use prevented certain difficulties involved in the use of the leaf blade.

over vigor due to unbalanced pruning, and other external factors were not selected. Due to frost injury and hail damage early in 1954, nine of the 30 vineyards harvested in 1953 were deleted from the yield studies. Thus the final studies contained 21 vineyards from which complete data were available for both 1953 and 1954.

These representative vineyards were harvested in mid-September to obtain yield records as measured by total weight of fruit per vine and number of bunches per vine. At harvest, samples of grapes were taken for refractometer determination of soluble solids. In 1953, representative bunches were chosen from each site for these determinations. In 1954, 10 to 15 grapes were selected at random from each vine and soluble solids determined on each grape*.

Petiole analysis. The petiole samples were washed free of spray and other deposits, dried, and ground. The ground samples were analyzed for nine essential elements -- nitrogen, phosphorus, potassium, calcium, magnesium, manganese, iron, boron, and copper. The analyses were made by the Department of Agricultural Chemistry. Samples were analyzed spectrographically for phosphorus, calcium, magnesium, manganese, iron, boron, and copper. Potassium was determined by use of a flame photometer. Nitrogen determinations were made by the standard Kjeldahl method.

*A comparison of methods of determining soluble solids showed that individual grapes were as reliable as expressing juice from whole bunches as was done in 1953.

Soil analysis. The soil samples were tested for phosphorus, potassium, magnesium, and calcium using the Spurway Active test and for phosphorus and potassium using the Spurway Reserve test (44). Soil pH was determined on all samples using a Beckman pH meter. The soil tests were made by the Experiment Station Soil Testing Laboratory.

In addition the samples were analyzed for exchangeable calcium, magnesium, and potassium, and cation exchange capacity.

For the determination of exchangeable calcium, magnesium, and potassium, a soil extract was prepared by leaching a weighed sample of soil with a solution of neutral normal ammonium acetate. The leachate was evaporated to dryness, ignited at 400° C in a furnace for five to six hours, dissolved in 1.0 percent hydrochloric acid, and filtered. Exchangeable calcium, magnesium, and potassium were determined by the use of a flame photometer.

Cation exchange capacity was determined on the original soil sample. The sample was washed with 95 percent ethyl alcohol, saturated with sodium using a solution of 10 percent sodium chloride, and then washed again with 95 percent ethyl alcohol to remove the excess sodium chloride. The soil was then leached with neutral normal ammonium acetate and the leachate used to determine exchangeable sodium as a measure of the cation exchange capacity. A flame photometer was used for the final determination.

Exchangeable calcium, magnesium, potassium, and cation exchange capacity were expressed as m.e. per 100 grams of dry soil. Exchangeable calcium, magnesium, and potassium were also calculated as percent saturation of the cation exchange capacity.

Fertilizer Trials

In the spring of 1954, four potash fertilizer treatments plus an untreated check were established in each of six different Concord vineyards. The treatments were as follows: Muriate of potash (KCl), applied at rates of 150 and 300 pounds per acre; and potassium sulfate (K_2SO_4), applied at rates of 180 and 360 pounds per acre. These treatments represented two rates each of 90 and 180 pounds of actual potash (K_2O) to an acre, applied to single rows of 40 to 95 vines. Each plot also was treated with 50 pounds of actual nitrogen to an acre.

Initially, the six vineyards were at different nutritional levels of potash as well as calcium and magnesium. Three were in various stages of potash deficiency. A fourth was low in potash, but no potash deficiency symptoms were apparent, perhaps because calcium and magnesium were also very low. A fifth vineyard had higher than average amounts of potash in the soil, but potassium deficiency symptoms appeared on the leaves, probably due to very high calcium and magnesium levels in the soil. The sixth vineyard had adequate amounts of all nutrients, and no deficiency symptoms were apparent.

During late July petiole samples were taken from 10 successive vines in two areas from each sample row. The two sampling sites from each row were selected to be as representative of the whole row as possible. The sampling technique was the same as for the survey samples.

During the harvest season all treatments were harvested to obtain yield records and soluble solids data. All the grapes on each row were picked and weighed. The average weight of fruit per vine was determined according to the total weight divided by the number of vines in each row. The soluble solids determinations were made on individual grapes.

RESULTS

General Field Observations

The nutritional conditions of the vineyards were believed to be associated with certain general cultural practices. Soil erosion was serious in vineyards where cultivation down a hill was necessary. Vine vigor was greatly reduced in the eroded areas. Cover crops were used by most of the growers. Rye or wheat was predominantly used as a cover crop, with some growers using oats and vetch. Some growers were discontinuing the use of the grape hoe for weeding.

Balanced pruning was being practiced by most of the growers to some degree, but there still appeared to be much desired in the proper application of this principle. The present application involved the consideration of a rather rough estimate of vigor during pruning.

Grape prunings were being left in the vineyard by a few growers. The prunings were cut into the soil with a disc or various types of cutters or shredders. This practice saved time formerly used to remove the prunings from the vineyard and returned organic matter and nutrients contained in the prunings to the soil. In addition, the prunings left in the vineyard would tend to reduce erosion.

Complete fertilizer (200 to 500 pounds per acre) was being used by most growers. The fertilizer formulas varied but tended toward a 12-12-12 or 10-10-10. Manure was being used in some vineyards according to its availability. Some growers had used urea sprays, usually at the rate of five pounds in 100 gallons. In several instances where the urea sprays had been used, the leaves showed a marginal chlorosis that became necrotic late in the season. The marginal chlorosis was from one-eighth to one-fourth inch in width and was believed to be biuret injury.

A marginal and interveinal chlorosis of the leaves was observed in many vineyards. This symptom was found throughout the area and was particularly severe in vineyards located on light sandy soils. As the season progressed the deficiency symptom became more severe, usually developing into marginal and interveinal necrosis of the leaves (Figure 1). The grapes on such vines were smaller in size and did not ripen as fully as on normal vines. Petiole analysis confirmed this deficiency as being potassium. Because of the widespread occurrence of this deficiency being found in 1953, potash fertilizer trials were established in the spring of 1954.

Survey

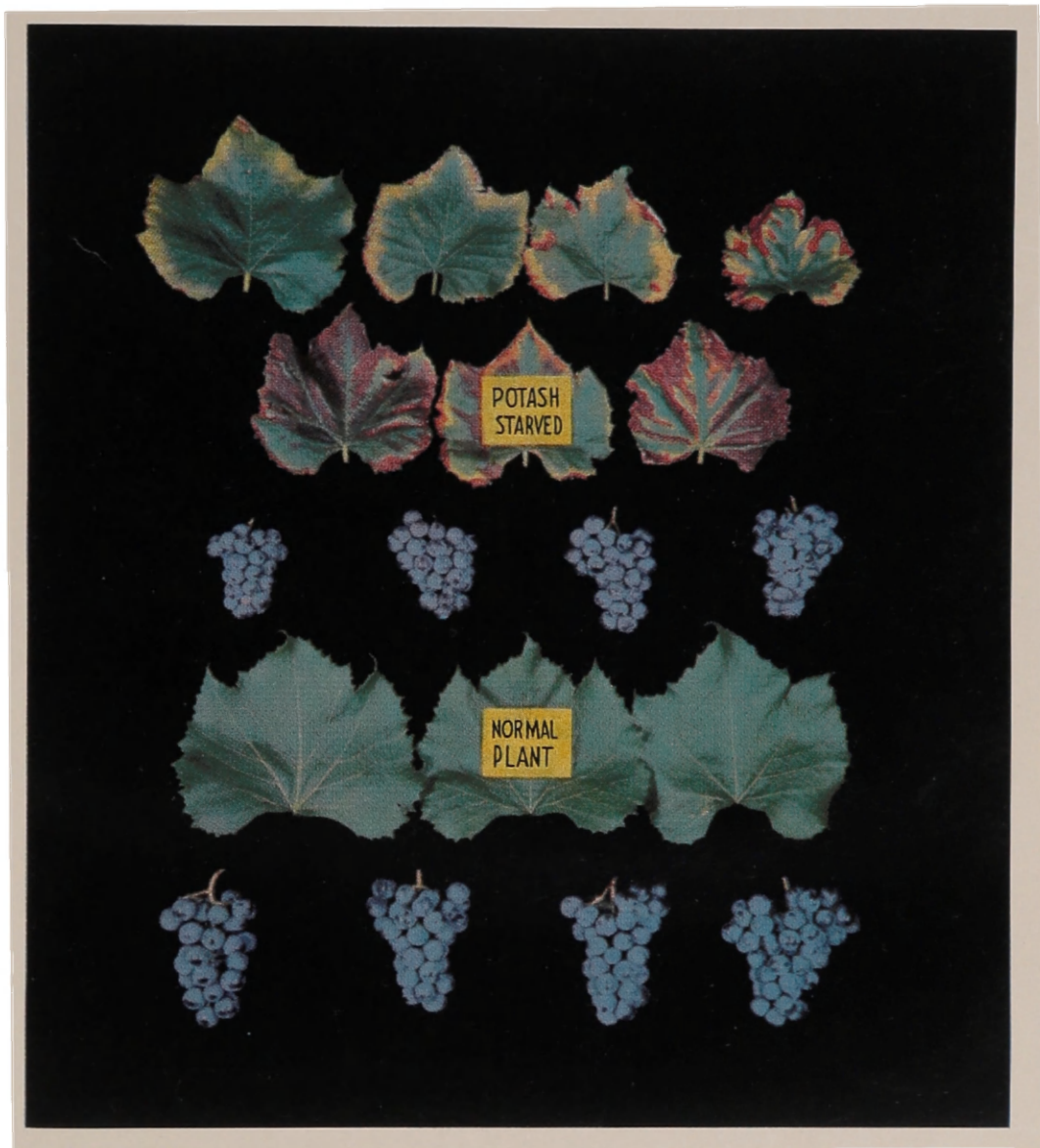
The data for each vineyard for the two years, 1953 and 1954, were averaged in order to reduce the biennial effects of pruning and other factors as pointed out by Partridge (31).

Figure 1. Leaves and fruit clusters taken from potassium deficient and normal vines on September 23, 1954.

Upper leaves show varying degrees of severity of potassium deficiency. Potassium deficient vines were low in vigor, had small chlorotic or necrotic leaves, and the fruit clusters were small and immature.

Healthy vines had large green leaves, and the fruit clusters were large, well formed, and matured earlier.

(Photograph, courtesy - American Potash Institute)



This method was desirable not only from the physiological standpoint but, as shown in Table I, there was a high degree of correlation for the 21 vineyards between the two years in regard to yield, plant analysis data, and soil analysis data. It can be noted from Table I that the average yield was higher during 1954 than 1953. This difference may have been due to more favorable moisture conditions during 1954 than 1953 or to more available potassium, which was also higher in 1954 than 1953. Furthermore, in order to facilitate effective study of results the data were grouped into three yield classes. The first class comprised vineyards which produced an average of over six tons per acre. The second class comprised the moderate producing vineyards, from four to six tons per acre. The third class consisted of vineyards which produced an average of less than four tons per acre. There were seven vineyards in each yield class (Appendix Tables I, II, and III).

Petiole composition in relation to the yield classes is shown in Figures 2 and 3. The nitrogen levels were not appreciably different between the three yield classes. Phosphorus increased from 0.20 to 0.49 percent as yield decreased. Potassium increased from 1.03 to 2.01 percent as yield increased.

Calcium, magnesium, manganese, iron, and boron all increased as yield decreased. Or, they all increased as potassium decreased. This inverse relationship between potassium and the other elements was particularly apparent between

TABLE I. Influence of Season upon Yield, Petiole Analysis, and Soil Analysis, 1953 and 1954

(21 Vineyards)

	1953	1954	Correlation coefficient
Yield - lbs./acre	17	23	0.687**
Petiole analysis			
Nitrogen - %	0.78	0.85	0.580**
Phosphorus - %	0.35	0.34	0.571**
Potassium - %	1.32	1.66	0.777**
Calcium - %	1.88	1.83	0.453*
Magnesium - %	0.75	0.88	0.880**
Manganese - %	0.069	0.091	0.754**
Iron - ppm	42	50	0.457*
Boron - ppm	31	26	0.481*
Copper - ppm	35	46	0.263
Soil analysis			
Cation exch. cap. - m.e./100 gm.	5.76	6.02	0.951**
Exch. Ca - m.e./100 gm.	1.86	1.92	0.946**
Exch. Mg - m.e./100 gm.	0.39	0.42	0.772**
Exch. K - m.e./100 gm.	0.15	0.19	0.806**
Percent base saturation	40.0	42.3	0.869**
Percent Ca saturation	30.5	31.6	0.905**
Percent Mg saturation	6.7	7.5	0.746**
Percent K saturation	2.7	3.2	0.845**

*Statistically significant at the 5 percent level.

**Statistically significant at the 1 percent level.

Figure 2. Petiole composition in relation to yield of survey vineyards, 1953 and 1954. Average content of nitrogen, phosphorus, potassium, calcium, and magnesium.

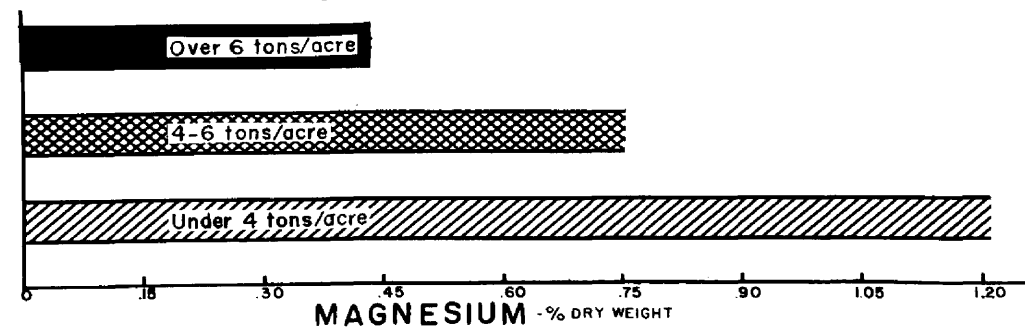
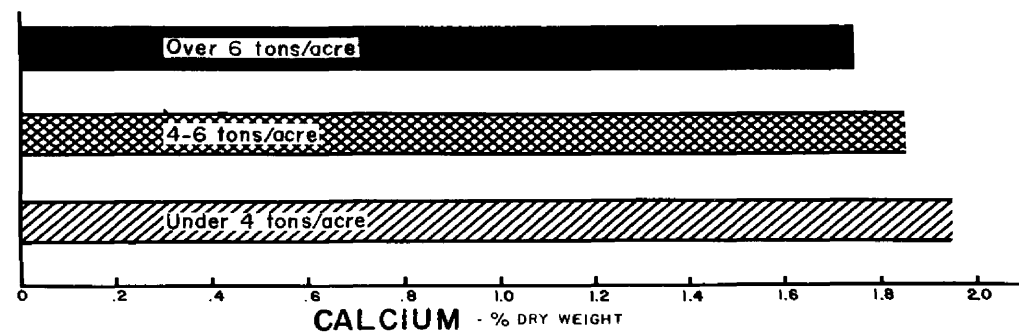
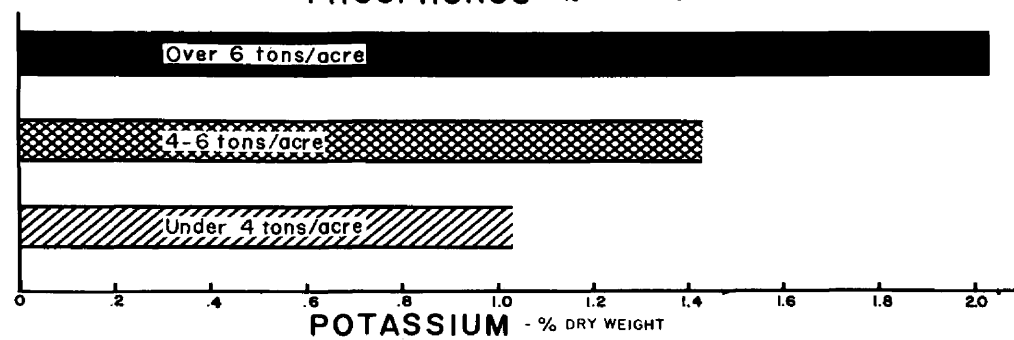
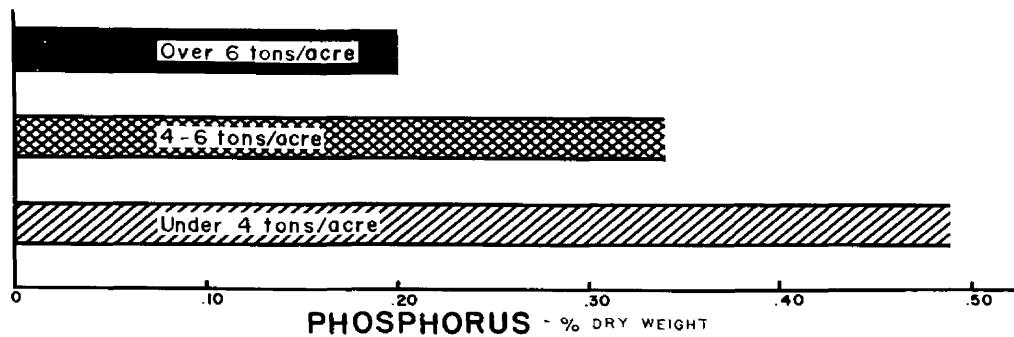
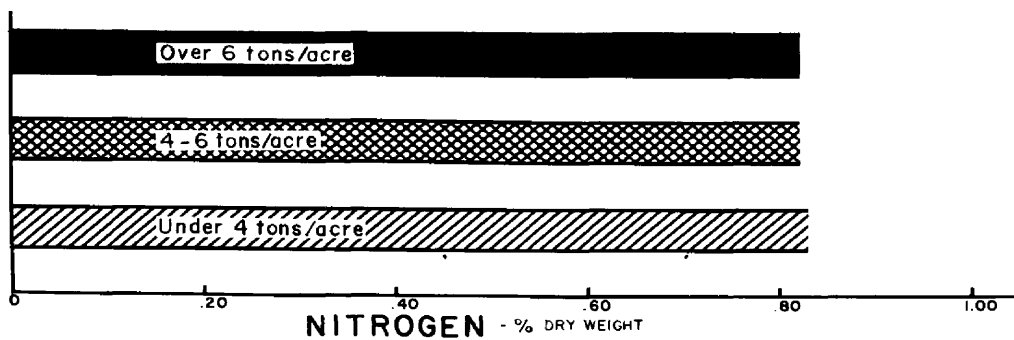
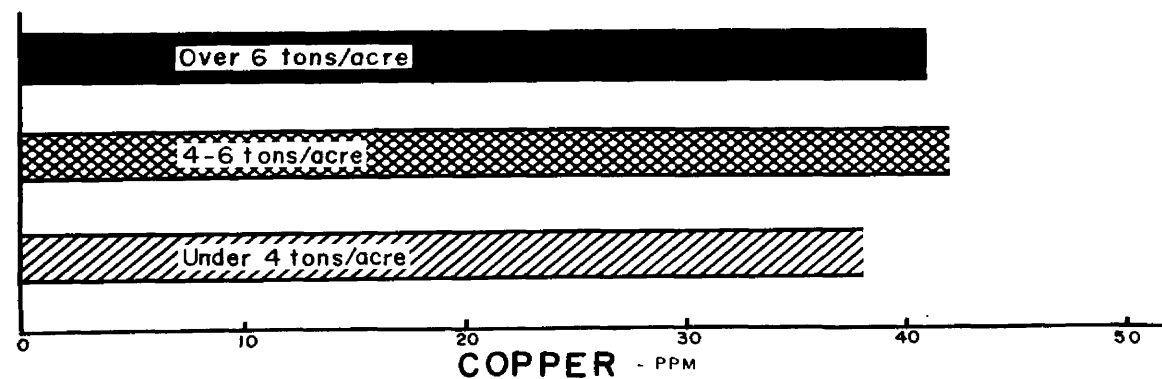
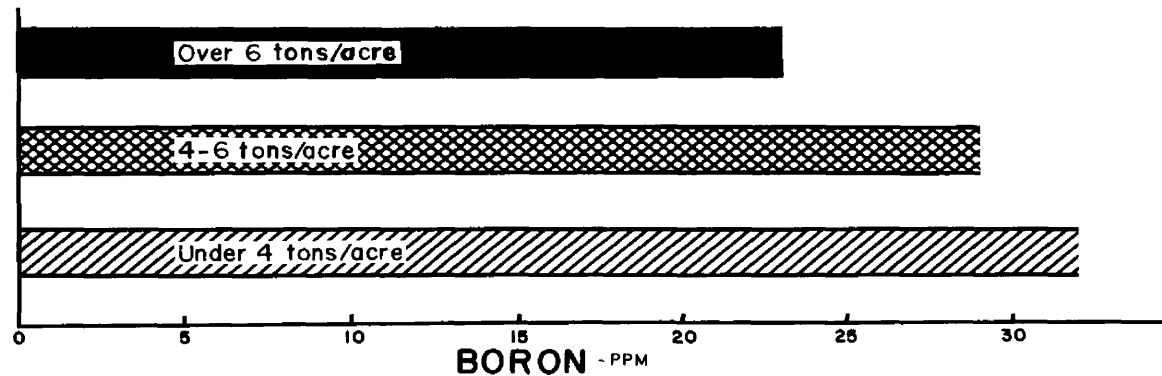
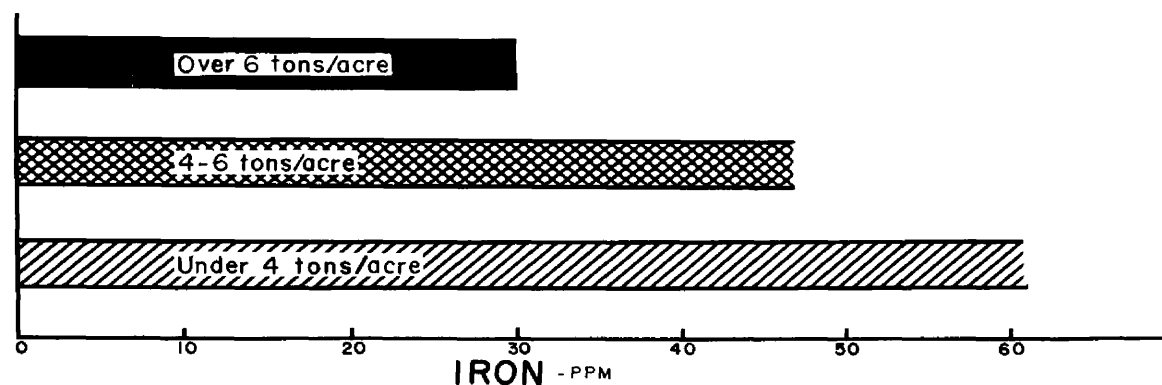
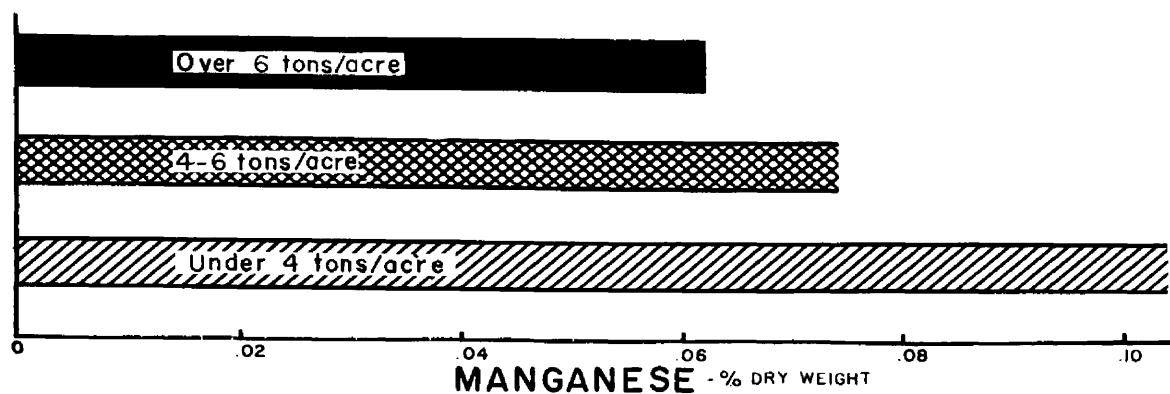


Figure 3. Petiole composition in relation to yield of survey vineyards, 1953 and 1954. Average content of manganese, iron, boron, and copper.



potassium and phosphorus, magnesium, manganese, or iron, and to a lesser degree between potassium and calcium or boron. The statistical significance of these relationships are shown in Table II.

The copper contents showed no consistent behavior either in relation to yield or to other nutrient elements. This inconsistency of copper behavior may have been due in part to the incomplete removal of copper spray residues from the petioles before analysis.

Figure 4 shows the positive relationship that existed between yield and cation exchange capacity of the soil. As the cation exchange capacity increased from an average of 4.14 m.e. per 100 grams of soil to 8.34 m.e. per 100 grams of soil, the yield likewise increased from less than four to over six tons per acre. Exchangeable calcium and magnesium were similar to each other in their relation to yield. There was little difference in either exchangeable calcium or magnesium between the two higher yielding classes, but both elements were appreciably lower for the low yield class.

Exchangeable potassium was closely related to yield (Figure 4). Vineyards producing under four tons per acre contained 0.09 m.e. of potassium per 100 grams of soil. Those producing from four to six tons per acre contained 0.17 m.e. potassium per 100 grams of soil, and the vineyards producing over six tons per acre contained an average of 0.25 m.e. potassium per 100 grams of soil.

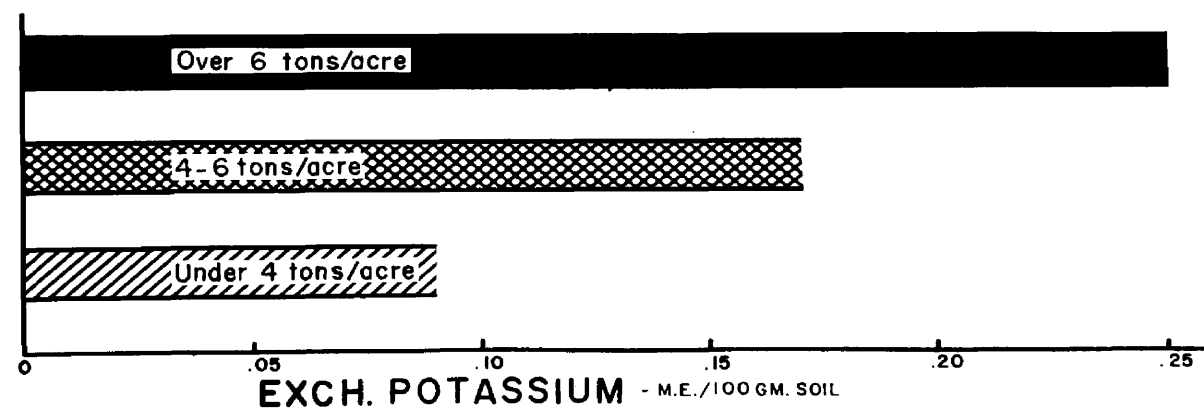
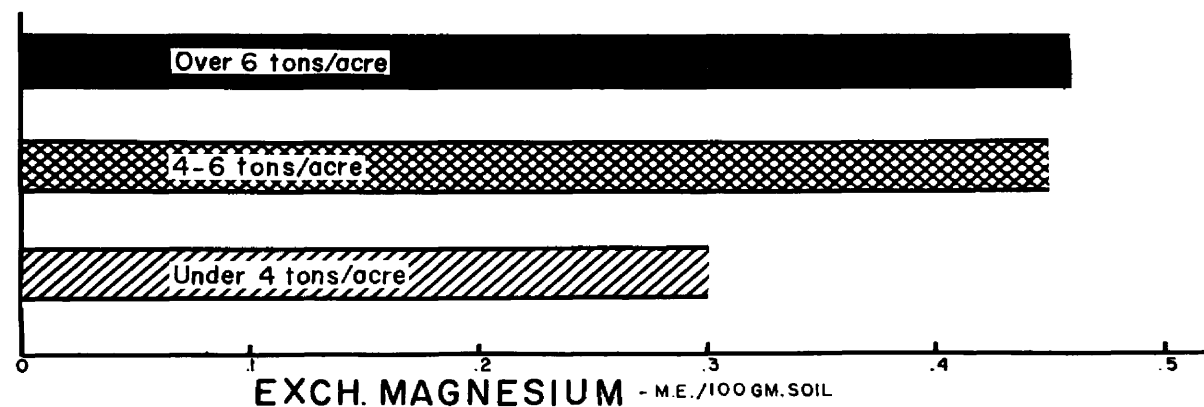
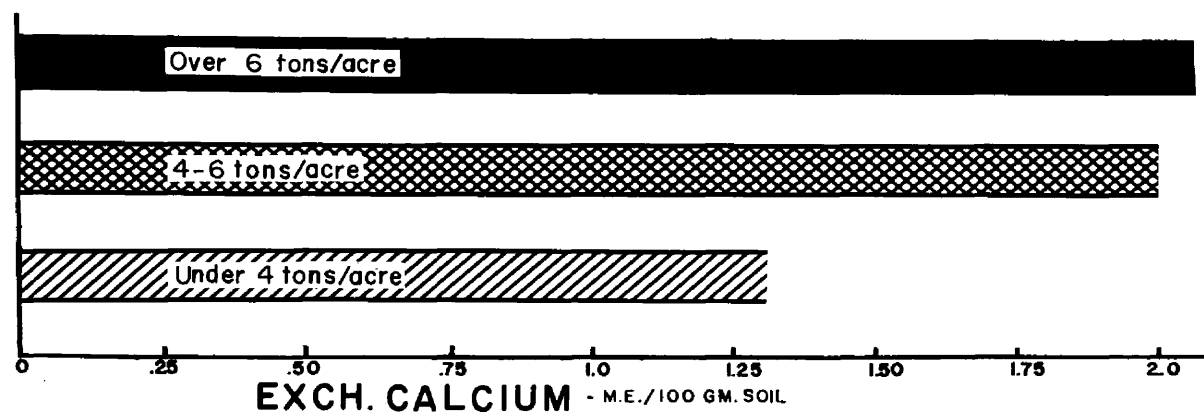
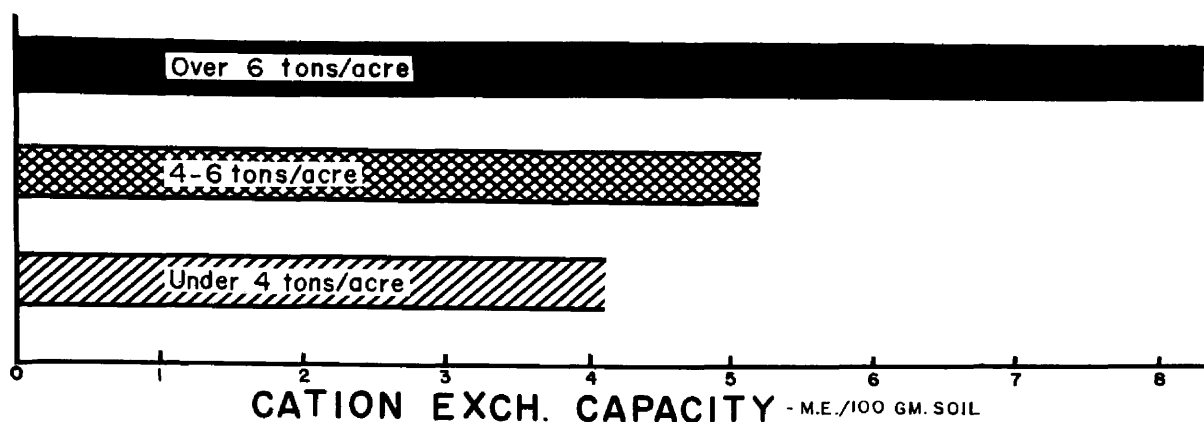
TABLE 11. Coefficients of Correlation for Various Relationships. Concord Survey, 1953 and 1954

Correlation		Correlation	
Factors correlated	coefficient	Factors correlated	coefficient
Petiole K vs pet. P	-.419*	Pet. K vs exch. Ca	.279
Petiole K vs pet. Ca	-.444*	Pet. K vs exch. Mg	-.194
Petiole K vs pet. Mg	-.781**	Pet. K vs exch. K	.685**
Petiole K vs pet. Mn	-.077	Pet. Ca vs exch. Ca	.419*
Petiole K vs pet. Fe	-.708**	Pet. Ca vs exch. Mg	-.294
Petiole K vs pet. B	-.761**	Pet. Ca vs exch. K	-.558**
Petiole Ca vs pet. Mg	.761**	Pet. Mg vs exch. Ca	-.181
Yield vs bunches/vine	.854**	Pet. Mg vs exch. Mg	.277
Yield vs weight/bunch	.554**	Pet. Mg vs exch. K	-.561**
Yield vs sol. solids	-.553**	Exch. K vs act. K	.787**
Exch. Ca vs active Ca	.771**	Exch. K vs res. K	.826**

*Statistically significant at the 5 percent level.

**Statistically significant at the 1 percent level.

Figure 4. Cation exchange capacity and exchange-able calcium, magnesium, and potassium in relation to yield of survey vineyards, 1953 and 1954.

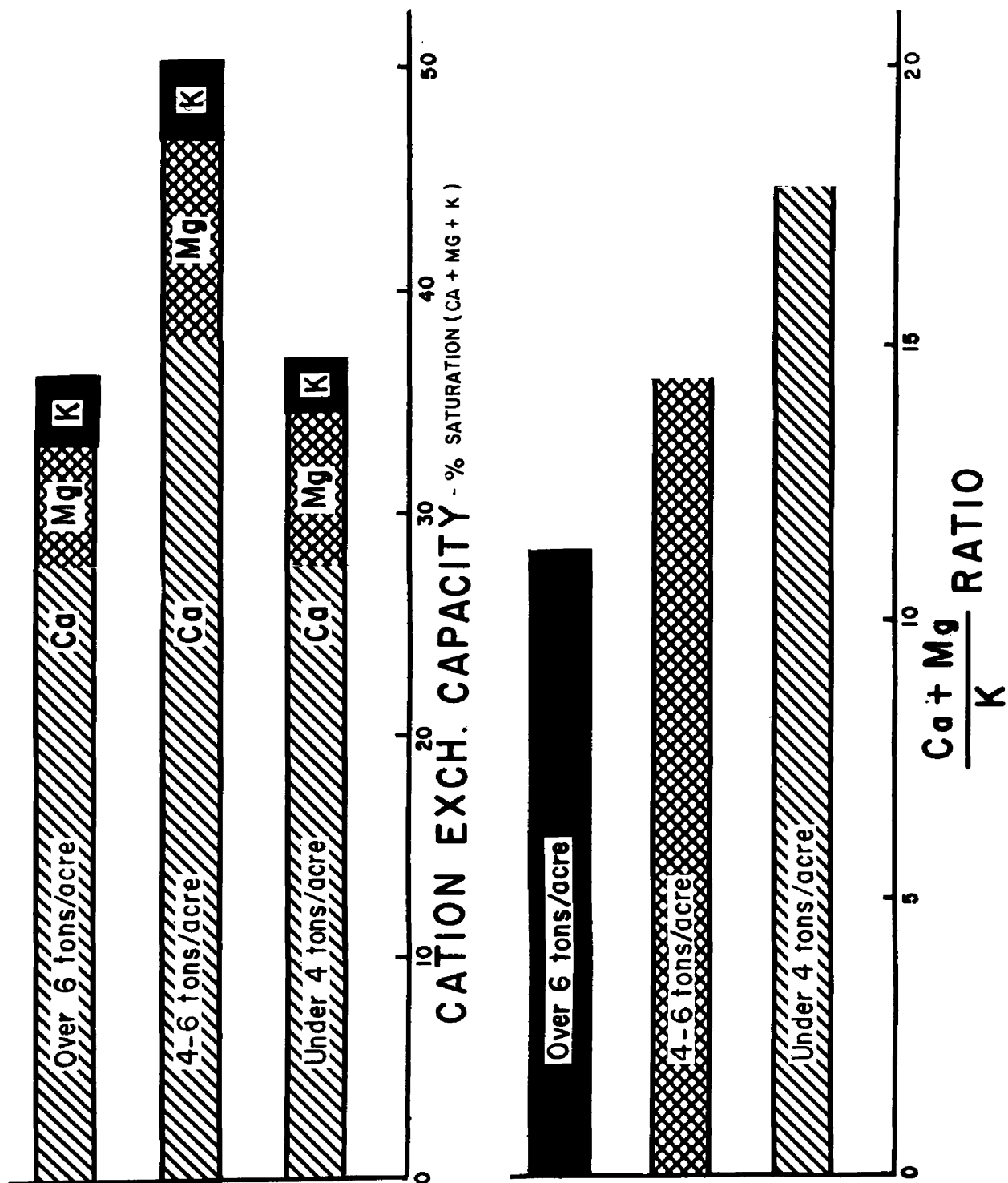


The degree of saturation (with Ca, Mg, and K) of the exchange capacity did not show any relative trend with yield (Figure 5). The highest and lowest yield classes both contained about the same percent saturation of calcium and magnesium. The medium yield class, four to six tons per acre, contained the highest average percent saturation of all three of the cations concerned.

These data indicate that the percent saturation of the three cations, either collectively or individually, had little influence on yield. However, the ratio of potassium to calcium + magnesium decreased as yields increased (Figure 5). In the vineyards which produced over six tons per acre the ratio of potassium to calcium + magnesium was 11.3. As the yield decreased this ratio increased to 14.4 for the vineyards which produced from four to six tons per acre and to 17.9 in the vineyards which produced under four tons per acre. The complete soils data for each of the 21 vineyards are shown in Appendix Tables IV, V, and VI.

In addition to its role in relation to yield and accumulation of certain nutrient elements in the leaf petioles, potassium also appeared to be dominant in influencing nutrient absorption from the soil medium. As shown in Table II, there was a significant positive correlation between potassium content of the soils and the potassium content of the leaf petioles. The highly significant negative correlations between exchangeable potassium and petiole calcium and magnesium

Figure 5. Percent saturation of the cation exchange capacity with calcium, magnesium, and potassium and their relation to yield. Also, the ratio of calcium + magnesium to potassium in relation to yield. Survey vineyards, 1953 and 1954.

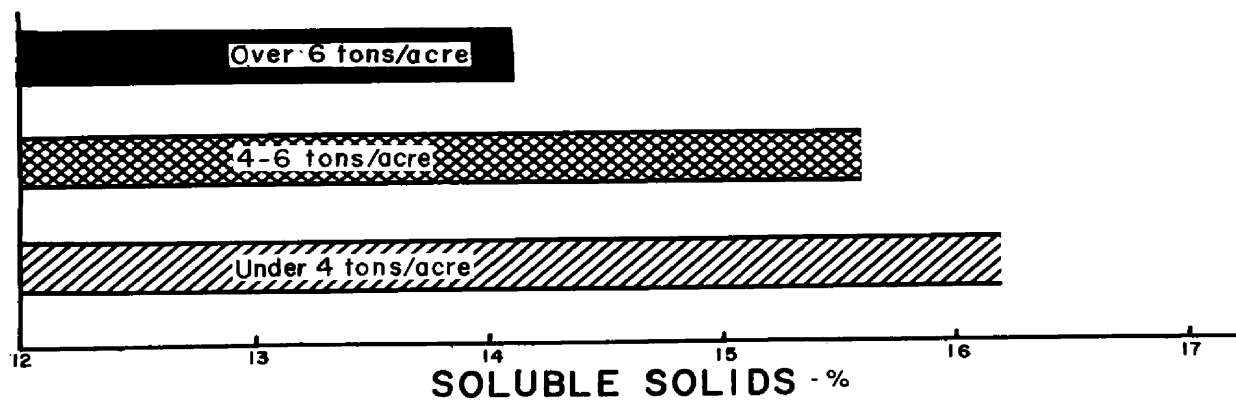
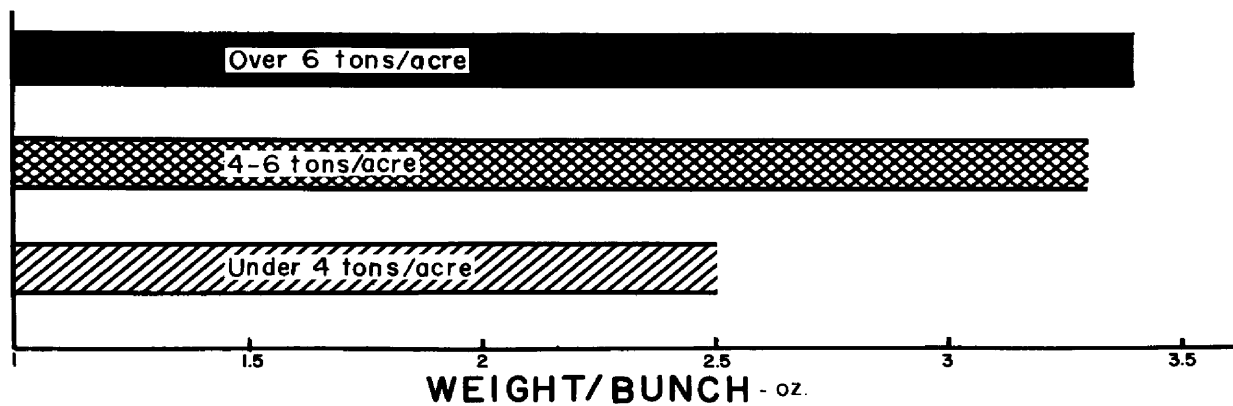
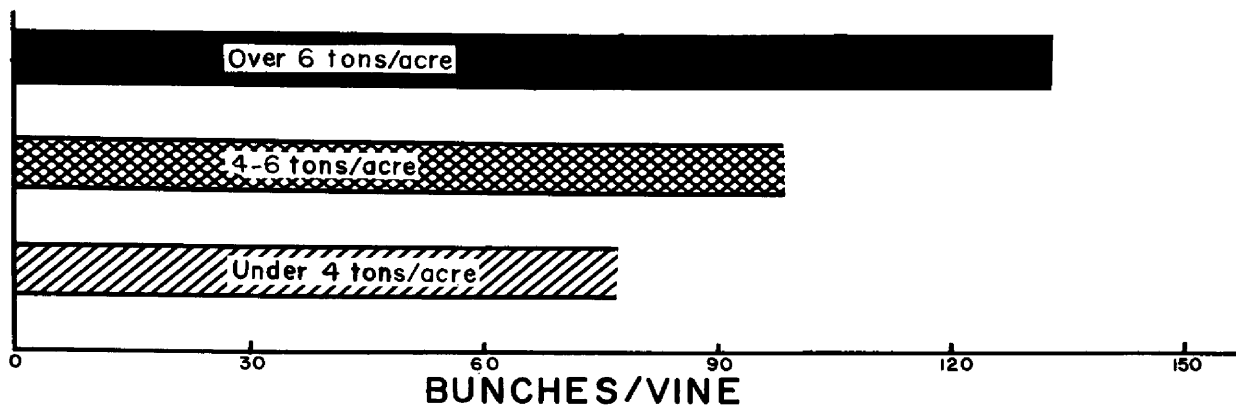


indicate that the potassium of the soil was more influential in the absorption of calcium and magnesium than the soil content of these two elements.

Active and reserve potassium and active calcium as obtained by soil tests were found to be closely correlated with exchangeable potassium and calcium. This relationship was not true for active magnesium and exchangeable magnesium. The phosphorus values were extremely variable and seemingly showed no trend with any other relationships.

Figure 6 shows the relation of yield to the number of bunches per vine, weight per bunch, and soluble solids of the fruit. The number of bunches per vine was more closely associated with yield than was the weight of the individual bunches. Yield increased progressively with an increase in the number of bunches. The average weight per bunch was also considerably higher for the highest yield class than for the lowest yield class, but there was little apparent difference in average bunch weight between the two higher yield classes. There was a significant decrease in percent soluble solids as yield increased. However, this relationship did not hold true for vineyards exhibiting severe potassium deficiency symptoms. In such vineyards, yields were usually low and the grapes failed to ripen fully, resulting in low percent soluble solids.

Figure 6. Number of bunches per vine, weight per bunch, and fruit soluble solids in relation to yield. Survey vineyards, 1953 and 1954.

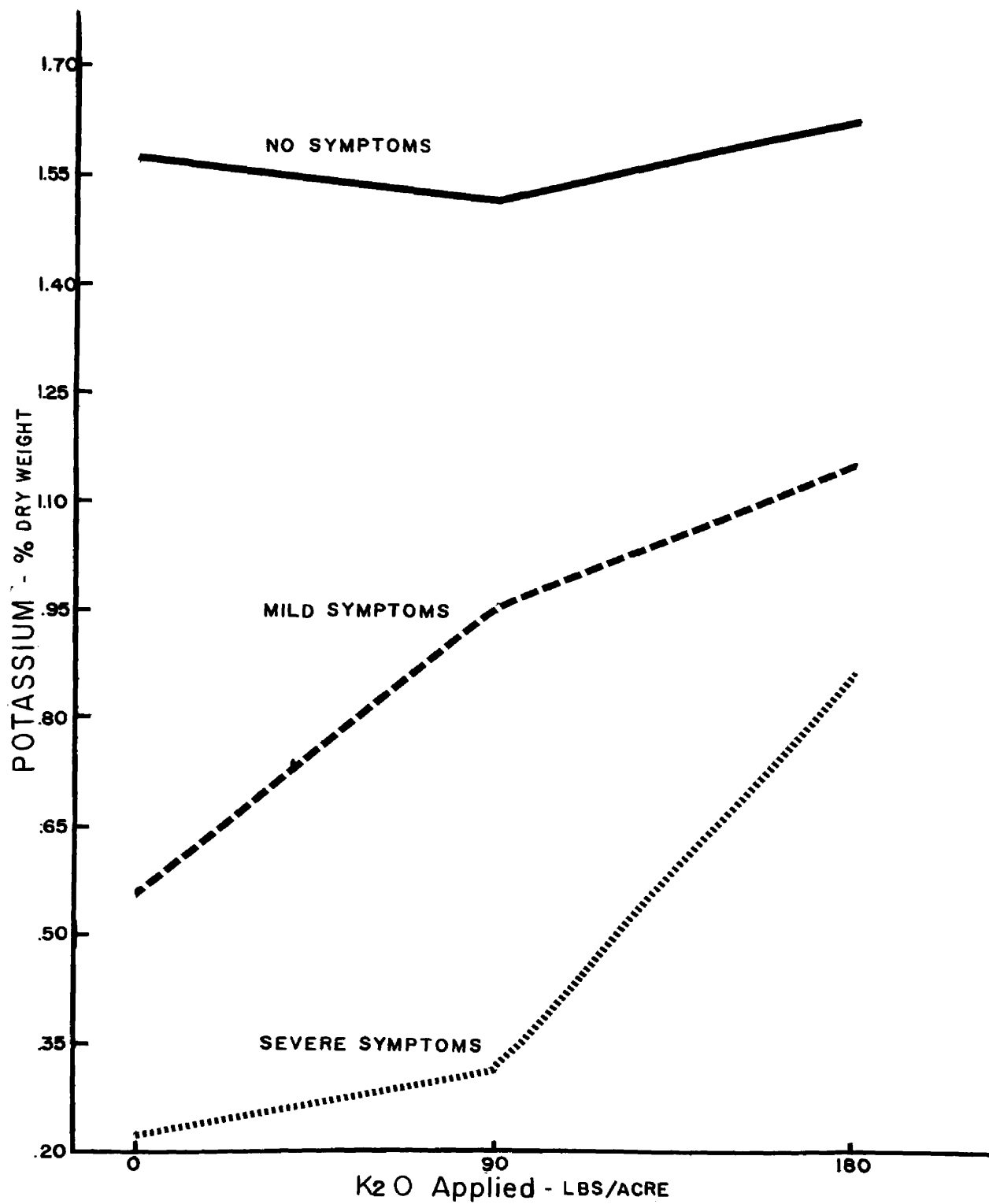


Fertilizer Trials

The effects of varying amounts of applied potash on yield and petiole composition of the individual vineyards are shown in Appendix Table VII. Considerable variation existed between individual vineyards and their yield and nutrient composition as a result of the potash applications. In general, however, the influence of the potash applications on both yield and petiole composition appeared to be proportional to the amount of available potash at the beginning of the experiment. The vineyards which were very deficient in potassium prior to the potash applications responded rather markedly; whereas the two vineyards which previously showed no potassium deficiency symptoms responded only slightly, if at all, to the potash applications. There was little apparent difference in response between the two forms of potassium used. The plots receiving the sulfate salt showed a slightly larger yield increase than the plots receiving the chloride salt; however, this difference was not true for individual vineyards and was not statistically significant.

The response to potash applications was found to be associated with the severity of potassium deficiency prior to applications (Figure 7). In vineyards that did not show any symptoms, there was little or no increase in petiole potassium when potash was applied. Potash applications resulted in a marked increase in petiole potassium when there were severe symptoms. The response was intermediate when the

Figure 7. Effect of potash application on petiole potassium as influenced by potassium deficiency. Grape fertilizer trials, 1954.



symptoms were moderate. General response in vigor and appearance of the vines was closely related to the influence of potash applications upon petiole potassium. However, there appeared to be a reduction in influence of potash applications on petiole potassium as "optimum" was approached and, conversely, less influence until deficiency symptoms had been eliminated.

Figure 8 shows the effect of the different levels of potash on the growth and appearance of vines in Vineyard No. 5. The vines of the no potash treatment exhibited pronounced symptoms of potash deficiency which became progressively worse as the season advanced toward the harvest period. With no potash there was little growth, and in most cases the grape bunches and individual berries were smaller than on the vines receiving high levels of potash. The vines receiving 90 pounds K_2O per acre had moderate potassium deficiency symptoms, and vigor and bunch size were better than the checks but not as good as those in the plots which received 180 pounds K_2O . Plots which received the high levels of potash (180 pounds K_2O per acre) had no visual symptoms of potassium deficiency, were vigorous in growth, and usually had large well-formed bunches of grapes.

Differences in growth between vines which received no potash and those which received 180 pounds K_2O per acre of Vineyard No. 3 are shown in Figure 9. As in the previous example, the check vines showed severe potash deficiency

Figure 8. Effect of different levels of potash on growth and appearance of vines in Vineyard No. 5. Grape fertilizer trials, 1954.

Center left -- no potash treatment resulted in pronounced potassium deficiency symptoms, little growth, small immature grapes.

Upper right -- 90 pounds K_2O per acre resulted in moderate potassium deficiency symptoms, increased growth and bunch size.

Lower right -- 180 pounds K_2O per acre resulted in no deficiency symptoms, vigorous growth, and large well formed bunches of grapes.



Figure 9. Effect of applied potash on growth and appearance of vines in Vineyard No. 3. Grape fertilizer trials, 1954.

Top -- no potash treatment resulted in potassium deficiency symptoms, poor growth, small immature grapes.

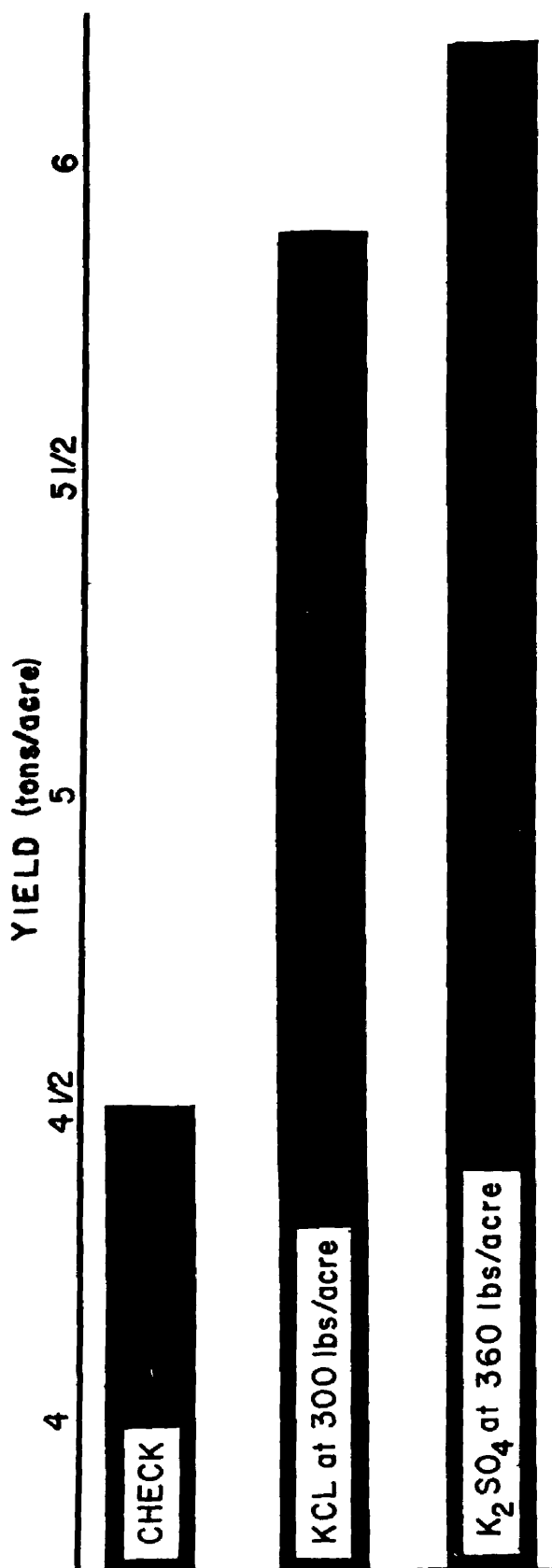
Bottom -- 180 pounds K_2O per acre resulted in no deficiency symptoms, vigorous growth, and large well formed bunches of grapes.



symptoms, were low in vigor, and had rather small bunches which did not ripen properly. Plots which received the high levels of potash were very vigorous in growth, showed no potash deficiency symptoms, and had large well-formed bunches with yield being increased from one to one and one-half tons per acre (Figure 10). The soluble solids content of the grapes was increased from 15.1 percent on the check plot to 16.6 percent on the high potassium chloride plot.

There was a decrease in accumulation of nutrient elements other than potassium as a result of potash applications. Figure 11 shows the influence of different levels of potash on potassium, calcium, and magnesium accumulation and yield of the treated vines of a rather typical vineyard (Vineyard No. 2). This vineyard was located on soils rather high in potassium but which exhibited mild potassium deficiency symptoms on the leaves, probably due to excessive soil saturation with calcium and magnesium. Its response to potash applications was not as marked as the two vineyards which were severely deficient; however, there was a definite response to the treatments, particularly at the higher levels. In addition to the regular treatments, one plot in this vineyard was treated with 1,000 pounds of potassium sulfate (500 pounds K_2O per acre) in order to tentatively determine effects of very high amounts of potash on vine growth and yield. The performance (growth, vigor, and yield) of the vines receiving this high level of potash differed but little from those which

Figure 10. Yield increased about one and one-half tons per acre by application of 180 pounds K_2O per acre. Vineyard No. 3. Grape fertilizer trials, 1954.

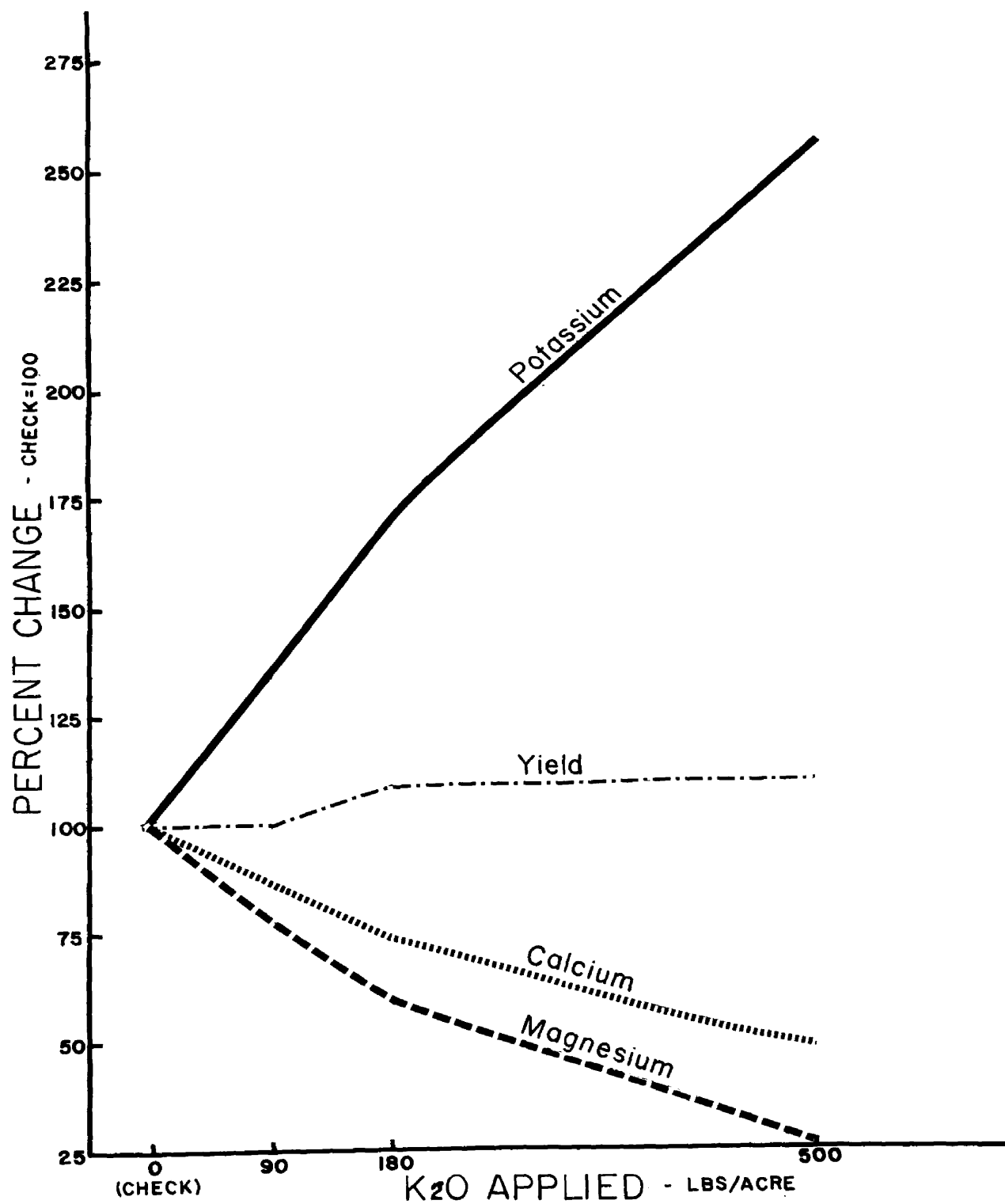


received 180 pounds of K_2O per acre; however, there were very obvious differences in nutrient element accumulation.

The potassium content of the petioles increased almost directly and proportional to the amount of potash applied (Figure 11). An opposite effect was found for calcium and magnesium. If the check plots are considered as 100 percent, potassium was increased to 257 percent with the addition of 500 pounds of K_2O per acre, while calcium was reduced to 49 percent and magnesium to 26 percent. In this vineyard, yield was not affected by the low rate of potash (90 pounds K_2O). There was an eight percent increase in yield by the addition of 180 pounds K_2O per acre, but there was no further increase by the application of 500 pounds K_2O per acre.

Although not shown in Figure 11, the accumulation of nitrogen, boron, and copper was depressed very similarly to calcium by different increments of applied potash. The accumulation of phosphorus, manganese, and iron was depressed even more, closely resembling that of magnesium (Appendix Table VII).

Figure 11. Effect of potash applications on yield and on potassium, calcium, and magnesium content of leaf petioles. Vineyard No. 2. Grape fertilizer trials, 1954. Shown as percent change with check as 100.



DISCUSSION

According to Goodall and Gregory (14), a plant is deficient in a certain element if supplying that element to the plant in a suitable form causes an increase in the yield. Using this concept, standard values of nutrient element composition were selected from the vineyards in the highest yield class (over six tons per acre). The standard value for each of the nine elements was determined as the average petiole analysis for vineyards having the highest yield. Coefficients of variation were calculated for each standard value using the individual vineyard analyses (Table III).

In order to show the relative composition of all vineyards sampled, a deficiency index for each value of each vineyard was calculated. Each deficiency index was determined by obtaining the percent of the standard for each value and then adjusting this figure by the coefficient of variation of that standard (Kenworthy, 17). This procedure classifies the deficiency indexes as follows: Less than 56 indicates deficiency, 56 to 84 - hidden deficiency, 84 to 116 - normal, 116 to 142 - approaching excess, and over 142 - excess. Using all of the vineyards sampled, the deficiency indexes were classified according to the above groupings (Table IV).

Potassium and manganese were the only elements which appeared to be deficient to an appreciable extent. According

TABLE III. Standard Values for Petiole Composition.
Survey of Concord Vineyards, 1953 and 1954

Nutrient element	Value	Coefficient of variation
Nitrogen - %	0.82	2.6%
Phosphorus - %	0.20	39.5%
Potassium - %	2.01	32.1%
Calcium - %	1.75	14.6%
Magnesium - %	0.44	42.5%
Manganese - %	0.065	19.7%
Iron - ppm	30	46.3%
Boron - ppm	23	34.3%
Copper - ppm	41	54.8%

TABLE IV. Nutritional Conditions of Concord Vineyards
in Michigan. Shown as Percent of Vineyards
Used in Survey, 1953 and 1954

	Deficiency	Hidden	Normal	Approaching	Excess
	percent	deficiency	percent	excess	percent
	percent	percent	percent	percent	percent
Nitrogen	0	3	80	15	2
Phosphorus	0	22	52	11	15
Potassium	18	32	35	13	2
Calcium	0	21	49	25	5
Magnesium	1	17	36	13	33
Manganese	11	20	34	13	22
Iron	0	18	38	21	23
Boron	1	23	48	19	9
Copper	0	23	55	10	12

to the calculated deficiency indexes, 18 percent of the vineyards were deficient in potassium and 11 percent in manganese. Magnesium and boron were the only other elements in which any vineyards were deficient. These two elements were deficient in one percent of the vineyards.

If it is assumed, however, that the vineyards in either the deficiency or hidden deficiency columns would show a response to applications of the nutrient concerned, then 3 percent should respond to applications of nitrogen, 22 percent to phosphorus, 50 percent to potassium, 21 percent to calcium, 18 percent to magnesium, 31 percent to manganese, 18 percent to iron, 24 percent to boron, and 23 percent to copper. The rapidity of response to nutrient element applications are related to the degree of deficiency (Figure 7). Thus a rapid response would be expected in the case of potassium where 50 percent of the vineyards were shown to be low in potassium, and possibly in the case of manganese where 31 percent of the vineyards were low. Data from the fertilizer plots showed marked response to applications of potassium by vines low in this element. Increases in growth and yield were obtained by applying potassium to vines which were mildly or severely deficient in potassium. Deficiency symptoms were usually present in vines containing less than .75 percent potassium in the petioles.

Also from the data shown in Table IV, it is possible that some vineyards might respond to applications of some of

the other nutrient elements. The fact that no deficiency symptoms were evident does not eliminate the possibility that improved growth and yields might result from additions of elements where shortages were shown. The supply of nitrogen was less variable than the other elements, and there appeared to be adequate nitrogen present in the plantings. However, applications of nitrogen have been made in practically all vineyards sampled so its value should not be underestimated.

Excesses were also noted in all of the elements concerned. The excesses were particularly noticeable for phosphorus, magnesium, manganese, iron, boron, and copper. These excesses may have been due, in part, to either luxury consumption, caused by a shortage of other elements, i.e. potassium; or, in the case of iron or copper, incomplete removal of spray residue from the petioles. Excesses are not usually considered to be of serious consequence unless toxicities are suspected and no deficiencies are present. There were no known cases of toxicity in the vineyards sampled.

When compared to the average of the high yielding vineyards, the vineyard soils were relatively high in calcium, magnesium, phosphorus, percent base saturation, and pH but were relatively low in potassium and cation exchange capacity. The close relationship that existed between cation exchange capacity and yield indicates the need for larger amounts of organic matter or humus in many vineyard soils.

The soils data confirms the field observations and petiole analysis data that a rather high percentage of the Concord vineyards in Michigan are growing under conditions of mild to severe potassium shortages. Active and reserve soil tests as well as soil analysis indicated that at least 50 percent of the vineyards are low in potassium. Yields were no doubt being limited in many instances by this shortage. As exchangeable potassium of the soil increased from .09 m.e. per 100 grams of soil to .25 m.e. per 100 grams, yield increased from less than four tons per acre to over six tons per acre.

Yield was not related to either the total percent base saturation or the percent saturation of the individual elements (calcium, magnesium, potassium); however, when the ratio of potassium to calcium + magnesium was computed there was a direct relationship with yield. The highest yields were obtained when the sum of calcium and magnesium was about 11 times as high as potassium, and the lowest yields occurred when this difference was increased to about 18 times. These relationships of yield to percent saturation and ratio of potassium to calcium + magnesium show the value of a balanced supply of nutrients in the soil. The ratio of one element to another appeared to be more important than the percent saturation of the exchange capacity.

The effects of potassium applications on the analyses for other elements were in agreement with other reports

(6, 25, 42, 46). The survey vineyards had rather constant nitrogen levels regardless of the potassium status. In the fertilizer plots, the nitrogen content of the petioles was reduced slightly, on an average, by applications of potash. Increased potassium in the petioles resulted in decreased accumulation of phosphorus, calcium, magnesium, manganese, iron, and boron. This depression was particularly noticeable for phosphorus, magnesium, manganese, and iron and to a lesser extent for calcium and boron. Copper, although seemingly depressed by potash applications in the fertilizer trials, followed no consistent pattern. The decrease in accumulation of the nutrients as a result of increased potassium may have been due to decreased absorption of the nutrient elements, increased utilization because of more growth, or both.

Yield was found to be correlated to both the number of bunches per vine and the weight of the individual bunches on the vine. The degree of correlation, however, was closer between yield and number of bunches than between yield and weight per bunch. This was in agreement with the findings of Partridge (31). Thus, yield would appear to be more closely related to the growing conditions and their effect on cane growth the preceding year than to growing conditions and their effect on shoot growth the current year.

Soluble solids, on an average, were highest in the lowest yielding vineyards at the time the samples were harvested.

This difference was probably due to the earlier maturation of the lower yielding vineyards. All the samples were harvested at the first part of the harvest season at which time the grapes of the higher yielding vineyards had probably not had sufficient time to fully mature. Potash deficient vineyards, however, usually had low yields and low soluble solids content. Applications of potash in severely deficient vineyards increased both yield and soluble solids.

SUMMARY

A survey of Concord vineyards conducted during 1953 and 1954 revealed that potassium shortages were prevalent in a high percentage of Michigan vineyards and that these shortages are appreciably reducing grape yields in many instances. Although deficiency symptoms were not apparent, petiole analysis indicated that manganese may be deficient in several vineyards. Except in isolated instances, other nutrients were apparently in satisfactory supply.

Applications of either potassium sulfate or potassium chloride at rates of 180 pounds per acre of actual potash resulted in good growth and increased yields of fruit during the year of initial application. Potash applied at 90 pounds per acre materially reduced deficiency symptoms but was not sufficient to increase yields.

Cation exchange capacity of the soil and soil potassium were both related to yield, indicating that additions of organic matter as well as potash might be of value in many of the vineyards located on sandy soils. The ratio of potassium to calcium + magnesium appeared to be more important in relation to yield than the percent saturation of the three cations either individually or collectively.

High levels of potassium in the petioles were associated with low levels of other nutrients, except nitrogen, in the

petioles. Applications of potash to the soil resulted in decreased accumulation of all elements, except potassium. Because of this effect of potassium, high amounts of potash fertilizers could result in deficiencies of other elements, particularly magnesium.

Yield was more closely related to the number of bunches per vine than to the weight per bunch indicating the importance of the preceding season's growth on yield. Soluble solids content of the fruit was low under conditions of either potash deficiency or high yields associated with good vigor. Applications of potash increased the soluble solids content of fruit from the deficient vines.

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APPENDIX TABLE I. Nutrient Element Content of Grape Leaf Petioles from Vineyards which Produced over Six Tons per Acre

	Vineyard Number							Average
	1	2	3	4	5	6	7	
Yield - lbs./vine								
1953	23	20	21	19	20	16	18	20
1954	45	42	37	34	32	33	30	36
Average	34	31	29	26	26	24	24	28
Nitrogen - %								
1953	0.73	0.74	0.85	0.85	0.93	0.80	0.78	0.81
1954	0.80	0.90	0.88	0.78	0.91	0.85	0.74	0.84
Average	0.76	0.82	0.86	0.81	0.92	0.82	0.76	0.82
Phosphorus - %								
1953	0.25	0.17	0.14	0.22	0.08	0.16	0.42	0.21
1954	0.21	0.14	0.20	0.21	0.20	0.12	0.17	0.19
Average	0.23	0.15	0.17	0.21	0.14	0.14	0.29	0.20
Potassium - %								
1953	0.97	1.94	2.44	1.69	1.27	2.86	2.25	1.92
1954	1.12	2.32	2.12	1.46	2.02	3.13	2.54	2.11
Average	1.04	2.13	2.28	1.58	1.64	2.99	2.39	2.01
Calcium - %								
1953	1.72	1.78	2.12	1.48	1.42	1.75	1.75	1.72
1954	2.18	1.47	2.12	1.73	1.85	1.63	1.44	1.78
Average	1.95	1.62	2.12	1.61	1.63	1.69	1.59	1.75
Magnesium - %								
1953	0.55	0.45	0.36	0.37	0.39	0.28	0.38	0.40
1954	0.98	0.38	0.38	0.52	0.57	0.27	0.21	0.48
Average	0.76	0.41	0.37	0.44	0.48	0.28	0.29	0.44

APPENDIX TABLE II. Nutrient Element Content of Grape Leaf Petioles
from Vineyards which Produced Four to Six Tons per Acre

	Vineyard Number						Average
	8	9	10	11	12	13	14
Yield - lbs./acre							
1953	16	23	18	20	19	19	15
1954	30	23	25	21	17	13	18
Average	23	23	21	20	18	16	16
Nitrogen - %							
1953	0.81	0.84	0.69	0.82	0.79	0.64	0.67
1954	1.03	0.78	0.84	0.93	0.90	0.76	1.03
Average	0.91	0.82	0.76	0.87	0.84	0.70	0.85
Phosphorus - %							
1953	0.20	0.19	0.44	0.09	0.44	0.73	0.27
1954	0.37	0.39	0.12	0.23	0.52	0.42	0.40
Average	0.28	0.29	0.12	0.23	0.52	0.42	0.40
Potassium - %							
1953	1.73	0.56	2.65	1.46	0.56	1.45	0.34
1954	2.42	0.69	2.71	2.02	0.78	2.32	0.34
Average	2.07	0.62	2.68	1.74	0.66	1.88	0.34
Calcium - %							
1953	1.88	2.12	1.20	1.35	2.23	1.97	1.89
1954	2.13	3.52	1.37	2.05	2.12	1.12	1.06
Average	2.00	2.82	1.28	1.70	2.17	1.54	1.47
Magnesium - %							
1953	0.46	1.32	0.22	0.31	1.02	0.54	0.80
1954	0.46	2.22	0.28	0.98	1.26	0.25	0.90
Average	0.46	1.77	0.25	0.64	1.14	0.39	0.85

Appendix Table II Cont'd.

	Vineyard Number						
	8	9	10	11	12	13	14
Manganese - %							
1953	.065	.038	.048	.046	.088	.092	.058
1954	.089	.033	.054	.070	.229	.085	.051
Average	.077	.035	.051	.058	.158	.088	.054
Iron - ppm							
1953	41	58	19	44	53	31	31
1954	58	58	14	71	107	38	38
Average	49	58	16	57	80	34	35
Boron - ppm							
1953	27	34	24	24	36	28	31
1954	30	37	9	48	40	11	25
Average	28	35	16	36	38	19	28
Copper - ppm							
1953	19	23	49	35	16	85	21
1954	25	27	64	96	79	21	38
Average	22	25	56	65	47	53	29
							Average
							.062
							.087
							.074
							40
							55
							47
							29
							29
							29
							35
							50
							42

APPENDIX TABLE III. Nutrient Element Content of Grape Leaf Petioles
from Vineyards which Produced Less than Four Tons per Acre

	Vineyard Number								Average
	15	16	17	18	19	20	21		
Yield - lbs./acre									
1953	12	16	12	15	13	7	10	12	
1954	18	15	17	11	14	10	5	13	
Average	15	15	14	13	13	8	7	12	
Nitrogen - %									
1953	0.95	0.67	0.73	0.76	0.80	0.64	0.92	0.78	
1954	0.98	0.67	0.93	0.86	0.80	0.67	1.21	0.87	
Average	0.96	0.67	0.83	0.81	0.80	0.65	1.06	0.83	
Phosphorus - %									
1953	0.80	0.52	0.43	0.24	0.24	0.74	0.53	0.50	
1954	0.95	0.57	0.29	0.20	0.26	0.35	0.79	0.48	
Average	0.86	0.54	0.36	0.22	0.25	0.54	0.66	0.49	
Potassium - %									
1953	0.23	1.78	1.00	0.15	0.90	1.37	0.16	0.80	
1954	0.19	2.41	1.71	0.41	2.52	1.34	0.23	1.26	
Average	0.21	2.09	1.35	0.28	1.71	1.35	0.19	1.03	
Calcium - %									
1953	2.42	1.30	2.12	2.23	2.42	1.96	2.30	2.11	
1954	2.82	0.98	2.27	1.65	1.24	1.02	2.55	1.79	
Average	2.62	1.14	2.19	1.94	1.83	1.49	2.42	1.95	
Magnesium - %									
1953	2.06	0.41	0.93	1.45	0.89	0.62	1.91	1.18	
1954	3.05	0.28	0.97	1.08	0.21	0.38	2.72	1.24	
Average	2.55	0.34	0.95	1.26	0.55	0.50	2.31	1.21	

Appendix Table III Cont'd.

	Vineyard Number							Average
	15	16	17	18	19	20	21	
Manganese - %								
1953	.069	.046	.100	.099	.183	.062	.048	.087
1954	.105	.068	.113	.108	.330	.058	.051	.119
Average	.087	.057	.106	.103	.267	.060	.049	.104
Iron - ppm								
1953	62	48	58	65	46	32	56	52
1954	100	58	69	61	62	41	93	69
Average	81	53	63	63	54	36	75	61
Boron - ppm								
1953	42	33	35	35	31	29	43	35
1954	79	16	36	25	13	16	15	29
Average	60	24	35	30	22	22	29	32
Copper - ppm								
1953	47	20	14	20	21	77	31	33
1954	94	25	30	89	18	19	35	44
Average	70	22	22	52	19	48	33	38

APPENDIX TABLE IV. Soil Composition of Vineyard Soils
from Vineyards which Produced over Six Tons per Acre

	Vineyard Number						
	1	2	3	4	5	6	7
Cation exch. capacity m.e./100 gm.							
1953	6.75	9.10	5.29	9.98	9.95	9.80	5.55
1954	7.17	10.41	4.61	11.91	12.04	9.22	5.00
Average	6.96	9.75	4.95	10.94	10.99	9.51	5.27
Exch. Ca - m.e./100 gm.							
1953	2.16	3.75	1.15	2.78	3.15	2.88	1.09
1954	2.00	4.06	1.10	3.09	2.47	2.05	1.28
Average	2.08	3.90	1.12	2.93	2.81	2.46	1.16
Exch. Mg - m.e./100 gm.							
1953	0.42	0.62	0.25	0.61	0.67	0.52	0.31
1954	0.37	0.67	0.18	0.77	0.62	0.31	0.25
Average	0.39	0.64	0.21	0.69	0.64	0.41	0.28
Exch. K - m.e./100 gm.							
1953	0.12	0.31	0.26	0.15	0.21	0.31	0.15
1954	0.15	0.45	0.22	0.33	0.37	0.28	0.21
Average	0.13	0.38	0.24	0.24	0.29	0.29	0.18
Percent base sat.							
1953	40.0	51.5	31.4	35.6	40.5	37.9	27.9
1954	35.0	49.7	32.4	35.1	28.6	28.6	33.8
Average	37.5	50.6	31.9	35.3	34.5	33.2	30.8
Percent Ca sat.							
1953	32.0	41.3	21.8	28.0	31.7	29.4	19.6
1954	27.8	39.0	23.8	25.9	20.5	22.2	24.6
Average	29.9	40.1	22.6	26.9	25.6	25.8	21.5

APPENDIX TABLE V. Soil Composition of Vineyard Soils from
Vineyards which Produced Four to Six Tons per Acre

	Vineyard Number						
	8	9	10	11	12	13	14
Cation exch. capacity m.e./100 gm.							Average
1953	8.31	4.65	6.60	4.30	3.96	2.85	5.64
1954	7.30	4.61	5.56	4.91	4.50	2.72	6.85
Average	7.80	4.63	6.08	4.60	4.23	2.78	6.24
Exch. Ca - m.e./100 gm.							
1953	3.02	3.08	1.31	1.38	1.26	0.46	3.20
1954	2.02	3.10	1.65	1.70	1.93	0.48	3.43
Average	2.52	3.09	1.48	1.54	1.59	0.47	3.31
Exch. Mg - m.e./100 gm.							
1953	0.42	0.64	0.42	0.45	0.25	0.16	0.68
1954	0.13	1.07	0.45	0.62	0.22	0.18	0.62
Average	0.27	0.85	0.43	0.53	0.23	0.17	0.65
Exch. K - m.e./100 gm.							
1953	0.30	0.12	0.18	0.35	0.05	0.08	0.09
1954	0.22	0.09	0.23	0.42	0.08	0.12	0.12
Average	0.26	0.10	0.20	0.38	0.06	0.10	0.10
Percent base sat.							
1953	45.0	82.6	29.1	50.7	39.4	24.6	70.7
1954	32.4	92.3	41.8	55.6	49.4	28.6	60.7
Average	38.7	87.5	35.4	53.1	44.4	26.6	65.7
Percent Ca sat.							
1953	36.4	66.2	20.0	32.2	31.8	16.2	57.0
1954	27.6	67.2	29.6	34.6	42.8	17.6	50.0
Average	32.0	66.7	24.3	33.5	37.6	16.9	53.0

Appendix Table V Cont'd.

	Vineyard Number						
	8	9	10	11	12	13	14
Percent Mg sat.							
1953	5.0	13.8	6.4	10.4	6.3	5.6	12.1
1954	1.8	23.2	8.1	12.5	4.9	6.6	9.0
Average	3.5	18.3	7.1	11.5	5.4	6.1	10.4
Percent K sat.							
1953	3.6	2.6	2.7	8.1	1.3	2.8	1.6
1954	3.0	1.9	4.1	8.5	1.7	4.4	1.7
Average	3.3	2.2	3.3	8.3	1.4	3.6	1.6
							Average
							8.5
							9.4
							8.9
							3.2
							3.6
							3.4

APPENDIX TABLE VI. Soil Composition of Vineyard Soils from
Vineyards which Produced Less than Four Tons per Acre

	Vineyard Number								Average
	15	16	17	18	19	20	21		
Cation exch. capacity m.e./100 gm.									
1953	7.00	3.31	4.65	3.41	2.85	3.11	3.96	4.04	
1954	6.89	3.91	4.89	3.41	3.93	2.50	4.22	4.25	
Average	6.95	3.61	4.77	3.41	3.39	2.80	4.09	4.14	
Exch. Ca - m.e./100 gm.									
1953	3.24	0.70	1.86	0.57	0.18	0.38	1.41	1.19	
1954	3.50	1.01	2.34	0.56	0.51	0.48	1.65	1.44	
Average	3.37	0.85	2.10	0.56	0.34	0.43	1.53	1.31	
Exch. Mg - m.e./100 gm.									
1953	0.54	0.13	0.52	0.14	0.05	0.17	0.25	0.26	
1954	0.42	0.25	0.56	0.27	0.20	0.22	0.47	0.34	
Average	0.48	0.19	0.54	0.20	0.12	0.20	0.36	0.30	
Exch. K - m.e./100 gm.									
1953	0.07	0.09	0.18	0.03	0.08	0.06	0.04	0.08	
1954	0.05	0.18	0.13	0.03	0.14	0.11	0.06	0.10	
Average	0.06	0.13	0.15	0.03	0.11	0.08	0.05	0.09	
Percent base sat.									
1953	55.0	27.8	55.1	21.4	10.8	19.8	43.0	33.3	
1954	57.5	36.8	61.5	25.1	21.5	32.4	51.6	40.9	
Average	56.2	33.3	56.3	22.2	16.1	26.1	47.6	37.1	
Percent Ca sat.									
1953	46.3	21.2	40.0	16.4	6.3	12.4	35.6	25.4	
1954	50.7	25.8	47.8	16.4	12.9	19.2	39.0	30.2	
Average	48.5	23.5	44.0	16.4	10.0	15.3	37.3	27.8	

Appendix Table VI Cont'd.

	Vineyard Number							
	15	16	17	18	19	20	21	Average
Percent Mg sat.								
1953	7.7	3.9	11.2	4.1	1.7	5.5	6.3	5.8
1954	6.1	6.4	11.1	7.9	5.1	8.8	11.2	8.0
Average	6.9	5.3	11.1	5.9	3.5	7.1	8.7	6.9
Percent K sat.								
1953	1.0	2.7	3.9	0.9	2.8	1.9	1.1	2.0
1954	0.7	4.6	2.6	0.8	3.5	4.4	1.4	2.5
Average	0.8	3.6	3.2	0.8	3.2	2.8	1.2	2.2

APPENDIX TABLE VII. Petiole Composition in Relation to Potassium Applications

Vineyard No.	Check	Pounds K ₂ O per Acre				
		KCl		K ₂ SO ₄		500
		90*	180	90*	180	
Yield - lbs./acre						
1	14	14	13	13	15	-
2	23	22	23	23	27	26
3	18	-	24	-	25	-
4	18	18	20	19	19	-
5	5	8	7	5	6	-
6	25	24	27	27	26	-
Average	17	17	19	18	20	26
Nitrogen - %						
1	0.88	0.83	0.81	0.82	0.82	-
2	0.76	0.80	0.79	0.76	0.80	0.80
3	1.03	-	0.85	-	0.87	-
4	0.97	0.99	0.99	0.93	0.93	-
5	1.24	0.99	1.09	1.04	1.02	-
6	0.88	0.85	0.88	0.80	0.82	-
Average	0.96	0.89	0.90	0.87	0.88	0.80
Phosphorus - %						
1	0.32	0.24	0.40	0.23	0.32	-
2	0.30	0.16	0.16	0.33	0.25	0.07
3	0.62	-	0.26	-	0.16	-
4	0.33	0.47	0.64	0.36	0.32	-
5	0.65	0.31	0.37	0.52	0.33	-
6	0.26	0.22	0.21	0.19	0.24	-
Average	0.41	0.28	0.34	0.32	0.27	-
Potassium - %						
1	1.58	1.63	1.99	1.50	1.88	-
2	0.73	1.08	1.37	0.88	1.14	1.88
3	0.23	-	1.17	-	1.06	-
4	0.38	1.07	0.90	0.81	1.21	-
5	0.22	0.33	0.42	0.29	0.82	-
6	1.57	1.51	1.42	1.46	1.24	-
Average	.78	0.99	1.21	0.88	1.22	1.88

*Results were not obtained from plots of Vineyard No. 3 which received 90 pounds K₂O per acre because of inadvertent treatment by the grower.

Appendix Table VII Cont'd.

		Pounds K ₂ O per Acre				
Vineyard		KCl		K ₂ SO ₄		
No.	Check	90	180	90	180	500
Calcium - %						
1	2.09	1.69	2.01	1.77	2.00	-
2	2.63	1.53	1.57	2.88	2.34	1.30
3	1.78	-	2.02	-	1.35	-
4	1.06	1.60	1.98	1.25	1.41	-
5	1.94	1.48	1.38	1.63	1.82	-
6	2.44	2.07	2.23	1.69	2.00	-
Average	1.99	1.67	1.86	1.84	1.82	1.30
Magnesium - %						
1	0.69	0.48	0.49	0.55	0.54	-
2	1.55	0.76	0.68	1.66	1.19	0.43
3	1.85	-	0.99	-	0.74	-
4	0.89	0.80	1.20	0.91	0.75	-
5	1.96	1.33	1.48	1.78	1.32	-
6	0.96	0.72	0.84	0.60	0.82	-
Average	1.32	0.85	0.94	1.12	0.89	0.43
Manganese - %						
1	.244	.151	.257	.157	.234	-
2	.036	.030	.030	.042	.024	.008
3	.077	-	.104	-	.104	-
4	.049	.085	.110	.051	.061	-
5	.043	.046	.058	.056	.060	-
6	.057	.050	.078	.049	.076	-
Average	.084	.072	.106	.070	.093	.088
Iron - ppm						
1	42	41	60	47	49	-
2	38	15	15	41	20	4
3	53	-	27	-	21	-
4	44	55	78	24	34	-
5	64	43	43	46	52	-
6	39	69	37	49	33	-
Average	47	43	43	40	35	4

Appendix Table VII Cont'd.

Vineyard No.	Check	Pounds K ₂ O per Acre				
		KCl		K ₂ SO ₄		
		90	180	90	180	500
Boron - ppm						
1	32	27	28	26	28	-
2	32	19	23	32	26	11
3	37	-	30	-	26	-
4	28	36	36	27	23	-
5	12	10	8	9	11	-
6	30	27	30	29	30	-
Average	28	30	26	30	24	11
Copper - ppm						
1	20	18	17	19	20	-
2	24	18	17	22	21	16
3	88	-	78	-	91	-
4	40	30	40	38	33	-
5	41	42	40	37	42	-
6	40	38	36	27	25	-
Average	42	38	38	36	39	16