BORON DEFICIENCY IN CALIFORNIA VINEYARDS

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Instances of boron deficiency in vineyards have been reported from many of the grape growing areas of the world: Australia (14), New Zealand (1), Portugal (9), Japan (7, 16), France (5), Germany (10, 12, 19) and southeastern USA (18). The Japanese and German workers in particular have illustrated the symptoms thoroughly; investigated the role of boron in vine growth and fruitfulness, and discussed conditions of variety, soil type, and weather conditions affecting the incidence of deficiency symptoms.

Certain areas in California have long been known to have problems of excess or toxic levels of boron in the soil and/or the irrigation water. Perhaps, for this reason the possibility of boron deficiency was not suspected in California vineyards, and it has been only in the last few years that such deficiency has been found, identified, and corrected. The present paper shows by illustrations and tissue analyses how boron deficiency in grapes may be recognized and how fruit yields in such cases can be greatly increased with proper boron treatment.

DIAGNOSIS OF BORON DEFICIENCY

The symptoms of boron deficiency most characteristic in grapes—dieback of the shoot tips, chlorosis of terminal leaves, and poor fruit set—were first identified in a Carignane vineyard near Hopland, in Mendocino County, in the summer of 1956. Tissue analysis and response to treatment with soil-applied borax confirmed the diagnosis.

Various visual symptoms of boron deficiency are illustrated in figures 1 through 6. The foliage or vegetative symptoms, not all of which are always found, include: (a) death of the primary growing point, with subsequent pushing of many lateral shoots that may appear normal (Figures 1 and 2); (b) abnormally short internodes near the shoot tip; (c) noticeable brittleness of shoots; (d) a characteristic chlorosis initially almost white but later turning to red in some varieties; (e) necrotic areas in the tendrils; and (f) swollen areas in the terminal portion of the stem that sometimes appear as lesions as in figures 1 and 2. When the immature stem is slit, these swollen areas are corky, as seen in figure 3. The foliage symptoms are most noticeable in early summer—two weeks before the bloom period until two weeks after. After this, particularly when soil moisture is satisfactory, new and more vigorous growth from lateral buds may obscure the chlorotic foliage, giving the casual observer the impression that any chlorotic leaves that are visible are basal; actually, they are terminal on the primary shoots.

Corkiness of fruit has not been observed in California vineyards, though it has been reported by two workers (1, 5) as one of the symptoms. Abnormal fruit set, with accompanying severe loss of crops, is a very characteristic symptom, listed consistently in all reports. Gärtel (10) for example, estimated general crop reductions of 50 per cent in vineyards of the Moselle Valley, with some losses as great as 80 per cent of potential normal production.

The nature of the abnormal fruit set varies with variety and/or severity of the deficiency (5, 16, 18). Symptoms observed in the present studies include the complete drying up and falling off of many flower clusters at bloomtime or very shortly thereafter; a very light set of mostly normal berries, resulting in extremely straggly clusters; full clusters of uniform but small seedless berries that persist and ripen; and intermediate set of abnormally shaped berries that shatter in midsummer, as with Thompson Seedless (Figures 1, 5, and 6).

A limited but continuing survey of California grape-growing areas has been made during the past few years in efforts to locate areas or conditions where boron

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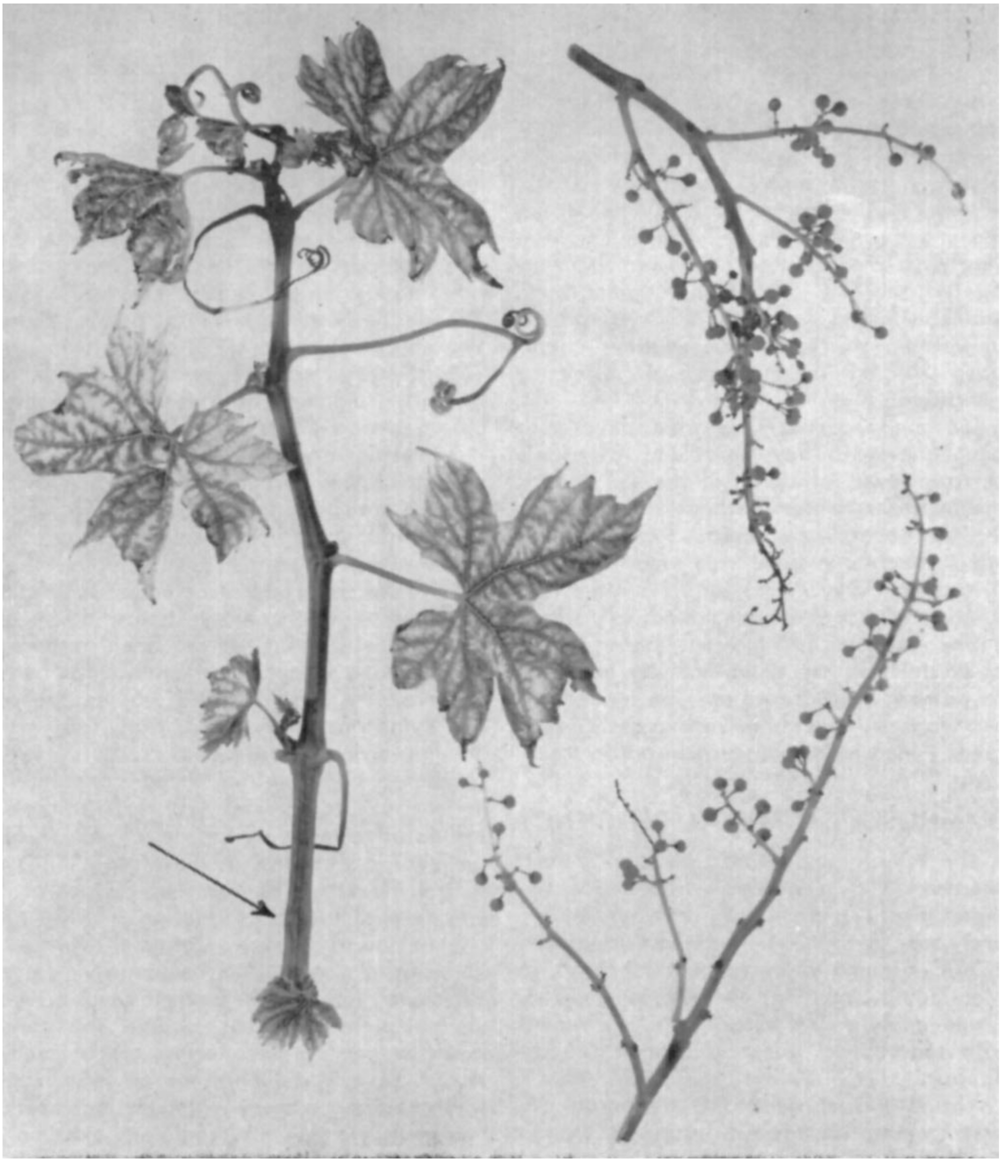

Figure 1. Terminal portion of Thompson Seedless shoot and fruit clusters, mid-June, Merced county, showing symptoms of severe boron deficiency. Note death of growing point, necrosis of tendrils, and swollen area in oldest internode of the shoot. Blackness of the node near tip is due to shadow effect. Notice the poor set, and drying of the cluster framework.

deficiency exists or is likely to be found. County farm advisors reported observed symptoms and collected samples for analysis, and many tissue samples already on hand from other investigations have been analyzed. Boron was determined by the simplified curcumin method (8).

Conclusions indicate that boron deficiency is usually found where vines are planted in soils subject to severe leaching with water of very low boron content. Severe symptoms have been found near irrigation outlets and low areas in sandy, alluvial soils of granitic origin along the east side of San Joaquin Valley in San Joaquin, Stanislaus, Merced, and Fresno counties. In high-rainfall coastal regions, unirrigated, deficient vineyards have been at well-drained high elevations in Santa Clara, Napa, Sonoma and Mendocino counties; the most common occurrences were found in Redwood Valley north of Ukiah. Table I lists some boron levels for various foliage tissues of the Carignane and Thompson Seedless varieties from these miscellaneous vineyards, all showing visual symptoms at time of sampling.

Many of these findings were localized areas, often only one or two acres at most, and variable in severity of symptoms. Further, the obvious great reduction in crop, the wide buffer areas required to protect control vines, and the ease of correction ruled out replicated comparative fertilizer trials in most cases. However, overall treatment and single demonstration plots with

TABLE I

Some Boron Levels (ppm dry weight) of Various Foliage Tissues of Grapevines Having Symptoms of Boron Deficiency

Date sampled	Vineyard	Tissue	B
			ppm
		Carignane Variety	
5/28/58	1	leaf blades adjacent to clusters	26
	1	leaf petioles adjacent to clusters	28
	1	chlorotic shoot tips (6 to 10 in. long)	20
	2	chlorotic shoot tips (6 to 10 in. long)	15
6/9/58	3	petioles adjacent to clusters at end of bloom period	26
6/13/58	4	petioles adjacent to clusters at end of bloom period	20
6/13/58	5	petioles adjacent to clusters at end of bloom period	20
	6	petioles adjacent to clusters at end of bloom period	24
	7	petioles adjacent to clusters at end of bloom period	26
	8	petioles adjacent to clusters at end of bloom period	26
6/27/57	9	whole chlorotic leaves (blades + petioles) from shoot terminals	9
	10	whole chlorotic leaves (blades + petioles) from shoot terminals	5
	11	whole chlorotic leaves (blades + petioles) from shoot terminals	7
	12	whole chlorotic leaves (blades + petioles) from shoot terminals	8
7/31/59	13	chlorotic leaf blades from shoot terminals	8
	13	petioles from shoot terminals	10
	14	chlorotic shoot tips (6 to 10 in. long)	9
8/13/58	15	whole leaves with no symptoms; taken from middle of chlorotic shoots	8
	15	whole chlorotic leaves from shoot terminals	5
		Thompson Seedless Variety	
5/22/58	16	chlorotic shoot tips (6 to 10 in. long)	9
	16	petioles adjacent to clusters at bloomtime	25
5/16/56	17	petioles adjacent to clusters at bloomtime	23
5/28/56	18	petioles adjacent to clusters at bloomtime	26
5/29/56	19	petioles adjacent to clusters at bloomtime	28
6/11/58	20	petioles adjacent to clusters at bloomtime	22
9/1/55	21	petioles from chlorotic shoot terminals	24
	22	petioles from chlorotic shoot terminals	18
	22	blades from above petioles	8

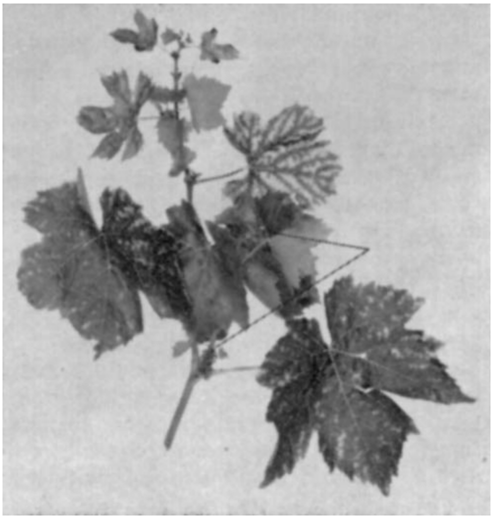

Figure 2. Terminal portion of Thompson Seedless shoot in mid-July, Merced county, showing symptoms of boron deficiency. Note the death of the main growing point, the short internodes near the tip, that the chlorosis of the primary leaves becomes progressively worse near the tip, and that the leaves on the lateral or secondary shoot seem normal.

borax at rates of 30 to 40 pounds per acre gave very striking vine recovery and yield increases. In one Thompson Seedless vineyard, for example, the crop was increased 10-fold in the first season—to ten pounds of fruit per vine on the treated row and no foliage symptoms versus **one** pound per vine and the illustrated symptoms on controls.

EXPERIMENTAL PLOTS

Replicated comparative fertilizer trials were permitted by growers for one year in three San Joaquin Valley vineyards: at Selma and Sanger, in Fresno county, and near Escalon, in San Joaquin county.

Selma: This 20-year-old Thompson Seedless vineyard, own-rooted, was planted at spacing of 8 by 12 feet on a well-drained soil classed as Delhi sand. The vineyard had a history of excessive irrigation, was weakened by heavy nematode damage, and showed both foliage and fruit-set symptoms of boron deficiency.

Sanger: This Thompson Seedless vineyard, with a spacing of 7 x 10 feet in a low-lying area also on Delhi sand, suffered from such severe boron deficiency that the grower did not bother to harvest the very light crop in 1957, the year before treatment.

In mid-January, 1958, one ounce per vine of a material equivalent to 44 per cent boric oxide was surface-applied in the old irrigation furrows in these two vineyards. Two-row buffers, 24 feet wide, were allowed between treated and control plots. Seasonal rainfall was unusually heavy for the area, a total of 15.4 inches for the period January through May, with nearly 6 inches falling in March alone. No supplementary irrigation water was applied in either vineyard until immediately after bloomtime petioles adjacent to flower clusters were collected on May 22. At sampling time symptoms were present in control plots at both locations, but none were detected in treated plots.

Table 2 summarizes the data for these two trials. At Selma, although the borax gave a 34 per cent increase in crop, the treated vines produced an average of only 20.5 pounds per vine, about one-half the production of an average Thompson Seedless vineyard. Nematode damage, and perhaps incomplete recovery from boron deficiency, restricted both production and vine growth. The greater boron level in treated petioles at Selma than at Sanger may be a concentration effect in the lesser vine growth at Selma. At Sanger the treated vines produced an average of ten pounds per vine (about three tons per acre), well below the state average of about eight tons. Thus, in spite of the high percentage yield increases on the boron plots, it seems that complete correction should not be expected the first year of treatment.

Escalon: This four-year-old Grenache vineyard was planted at 10 by 10 foot spacing on Hanford loamy sand adjacent to a raised irrigation ditch. The crop in 1959 was light throughout this 10-acre vineyard. Few clusters were present, and these were extremely straggly from poor

TABLE 2

Thompson Seedless Vineyard Trials with Boron Application
Results for 1958 after Treatment During Winter of 1957-58

Location (Fresno Co.)	Replications and vines/plot	Boron in bloomtime petioles Controls ppm	Treated ppm	Yield increase compared with controls %
Selma	11 x 40 V.	26	88	+ 34
Sanger	4 x 182 V.	24	41	+ 67

set. The most extreme crop loss and most prevalent foliage symptoms of boron deficiency were in a 600-foot strip about 100 feet wide, parallel to the irrigation ditch. The symptoms were most severe in fanlike areas around the gates in the ditch bank through which the vineyard was flood-irrigated. Fruit yields in this area in 1959 averaged 4.4 pounds per vine, about 25 per cent of normal. Leaf samples taken adjacent to clusters at early harvest time, September 26, 1959, showed boron values of 14 ppm for petioles and 10 ppm for the leaf blades.

In mid-October, borax was broadcast around treatment vines at a rate of $1\frac{1}{2}$ ounces of 34 percent boric oxide per vine. Again, two-row buffers, but only 20 feet wide, were provided for the control plots, which by grower request were only three in number. No rainfall occurred until more than two months later, December 23, when 0.40 inch was recorded. The total for December was only 6.0 inches, so that a flood-type irrigation was applied in early spring.

Figure 7 shows the plot layout and the pertinent data. Boron values are shown for petioles at cluster position taken at the end of bloomtime, May 23, 1960. Yields per vine are graphed for both 1959 and 1960. It can be readily seen that there was a striking, five-fold increase in crop in 1960, but that the control (untreated) plots showed the same great crop increase as those that were treated. Although buffer distances at Selma and Sanger were similar to those here, with no suggestion of boron pickup by controls, the vineyard conditions differed in several respects. The Thompson Seedless vineyards were trellised so that cultivation across the plots was prevented, irrigation was by furrows, and high ridges were present in the vine rows; also, 0.90 inch of rainfall occurred only ten days after the borax application. At Escalon, in contrast, the soil surface was per-

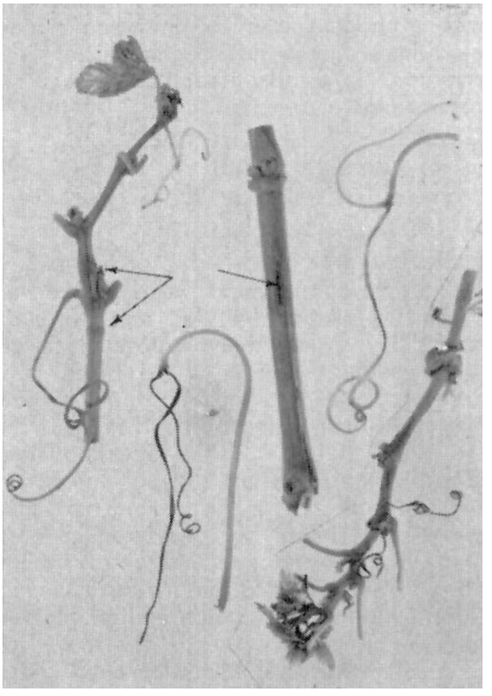

Figure 3. Symptoms of boron deficiency in various tissues of Thompson Seedless in mid-June. Leaves have been removed to show stem swellings, open lesion, short internodes, and necrosis of tendrils.

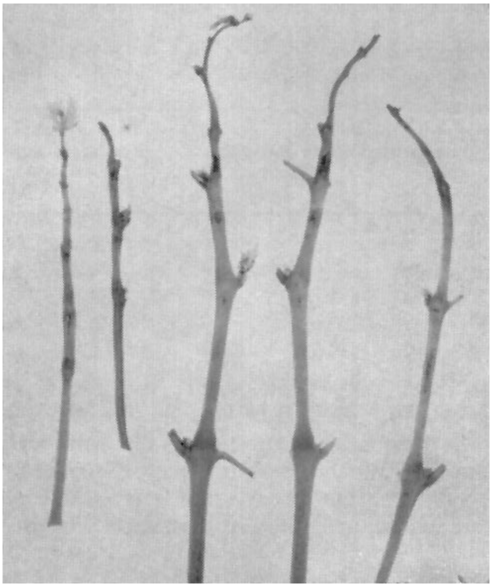

Figure 4. Longitudinally-bisected terminal tips from boron-deficient Carignane vine at beginning of bloom when associated leaves were just beginning to show chlorosis. Note corky areas that correspond to swellings and lesions.

fectly flat and smoothed by wind action at the time of treatment; weed growth was practically absent, and fall rains were so long delayed that in the exposed location some wind movement of the borax may have occurred. Additional horizontal spread may have been aided by cultivation across the plots (no trellis) and by the flood system of irrigation. Thus, although the boron levels are greater for the treated plots and are at what might be considered at least borderline deficiency in the controls, there seem to be justifiable reasons for assuming some boron pickup by the control plots—perhaps enough to provide the maximum crop recovery that the weakened vines could make in the first year. At least, very careful observation at sampling and harvest times in 1960 revealed no visual signs of boron deficiency in any of the plots, whereas in 1959 symptoms were obvious throughout the trial area.

DISCUSSION AND CONCLUSIONS

The various foliage symptoms of boron deficiency described herein are in close, detailed agreement with those reported from other grape-growing areas of the world. One symptom, internal browning of the flesh or pulp of the berries, as reported by Askew (1) and Branas (5), was not observed; instead, swellings and lesions of terminal stems were caused by the development in the immature pith tissue of spongy cork areas reminiscent of the internal corkiness of the fruit associated with boron deficiency in apples (6).

The characteristic loss of crop associated with boron deficiency has been shown to be due to poor pollen germination (7, 10, 16). Gärtel (10) reported that with extreme deficiency the pollen does not germinate at all, and that set of fruit is therefore scant; with higher but still deficient boron levels, the pollen may germinate into weak tube growth that may stimulate fruit set but without true fertilization of the ovule and subsequent seed formation. In such cases fruit set may consist of full clusters of small seedless berries set by stimulative parthenocarpy.

Whether one symptom or the other will be more prominent in a boron-deficient vineyard will depend not only on the variation and severity of deficiency but also on the variety involved. Varieties subject to naturally weak pollen development, such as Muscat of Alexandria, may react to boron deficiency more frequently by extremely straggly clusters, whereas varieties with pollen of normally high-percentage germination or those with parthenocarpic tendencies may react more often with a fairly well-filled cluster of abnormal fruit. In Thompson Seedless the stimulation of the pistil by pollen tube growth alone (stimulative parthenocarpy) is not sufficient for normal berry development; the pollen tube must enter the ovule, and double fertilization of both egg and endosperm nuclei occurs, although the seed embryo aborts after only rudimentary development (17). The round, non-elongated berries of boron-deficient Thompson Seedless support Müller-Thurgau's statement (15) that berry elongation is associated with fertilization (and the resulting stimulation on ovary tissue development), and also gives indirect support to the relation of boron supply and pollen germination.

Scott (18) showed a wide range of susceptibility to boron deficiency among the group of 33 American varieties in his study. Some exhibited extreme foliage symptoms and almost complete crop failure, whereas four or five varieties in the same planting showed little or no effects; susceptibility was not correlated with the inherent vigor of the variety. Furthermore, the response to borax treatment was varied: foliage improvement and crop response, not necessarily in the same order. Fruit yield was increased in 28 of the 33 varieties, some of which had been practically fruitless before treatment. Some of the largest increases were with varieties that are normally self-sterile and with some varieties that showed only slight foliage symptoms.

Wilhelm (19) concluded from his field trials and observations that Sylvaner was perhaps the most susceptible of the varieties grown in south-eastern Germany. Branas (5) noted that Grenache, Carignane, and Alicante Bouschet were among the more susceptible varieties in France. In California, symptoms have been observed and verified by tissue analysis on Sylvaner, Gamay, and Zinfandel, but Carignane or Thompson Seedless have been involved most commonly. Data are too limited, however, to indicate whether this is just coincidental with the greater acreage of these

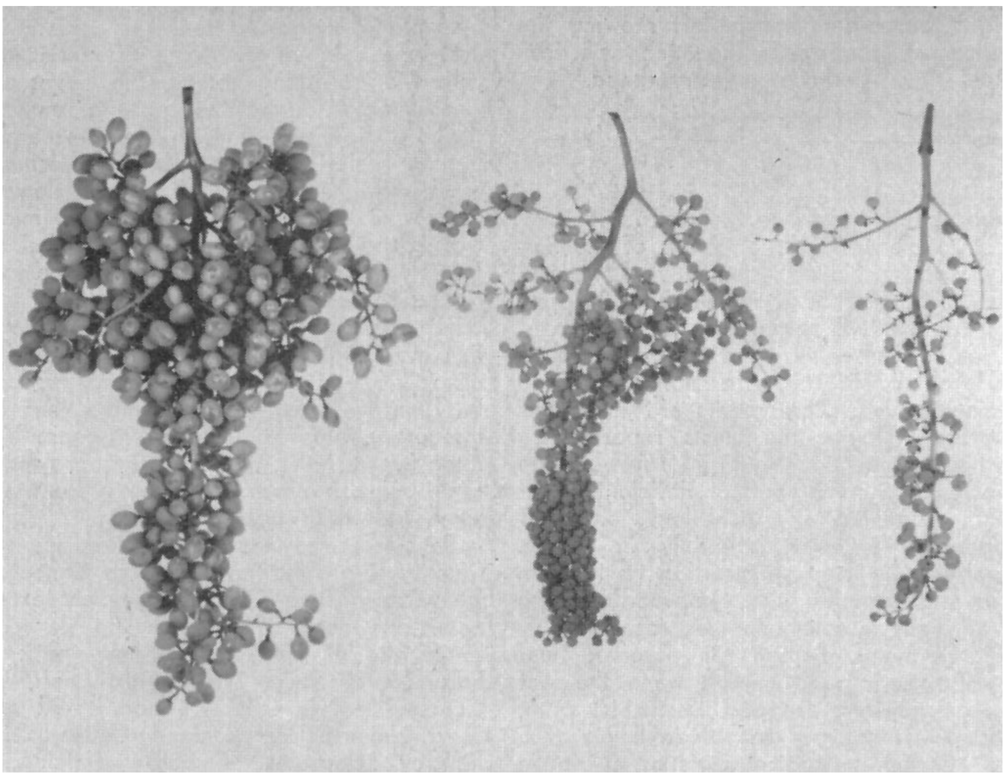

Figure 5. Thompson Seedless clusters from boron plots in mid-July, 1957. The cluster at left is from treated row. The other two show variations from boron-deficient vines; clusters like the center one begin to shatter at about this stage and end up like the one at the right.

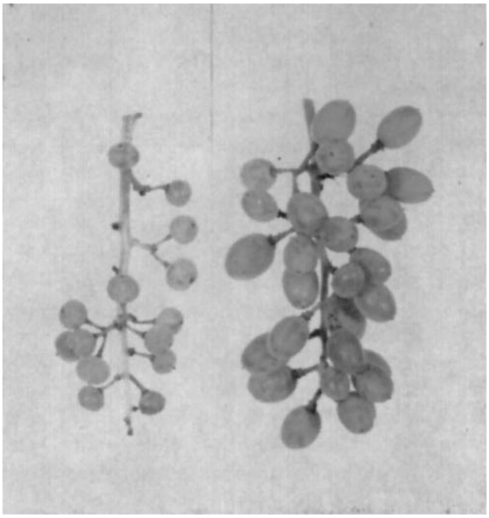

Figure 6. Close-up of Thompson Seedless berries from figure 5. Boron-treated on right, boron-deficient in left showing the poor set, the smaller size, and particularly, the difference in berry shape.

two varieties in suspect regions.

In table I the boron levels of the miscellaneous chlorotic tissues vary from a low of 5 ppm, for whole leaves, to 24 ppm, for petioles of terminal, affected leaves. Even so, the values tend to group around a level of 7 to 9 ppm for both blades and whole leaves. These results are in general agreement with the levels reported by others. Ono and Yoshida (16) obtained values of 5 to 9 ppm for deficient leaves and suggested a critical level of 12-13 ppm for leaves in late July in Japan. Gärtel (12) listed values of 5 to 14 ppm for leaf samples with symptoms ranging from light to severe in the Moselle Valley of Germany. Benson (3) observed leaf symptoms in sand culture when the leaf boron content dropped below 10 ppm; Askew (1) showed leaf blade levels of 5 to 12 ppm in control plots of a trial in which boron treatment corrected the disorder.

Although the uniform agreement among the above reports might suggest tissue analysis as an easy means of diagnosis, Scott's more extensive analyses emphasize just the opposite (18). His data show that boron content of leaves was not necessarily in accord with the variety response to boron application. The lowest boron level in almost-mature, bloom-period leaves was 7.8 ppm for the control vines of the variety Bailey, which showed 0.9 pound yield vs. 22.8 for treated vines. Corresponding data for the variety Lenoir showed 21.2 ppm boron in leaves from control vines producing 2.2 pounds of fruit, vs. 22.5 for the treated vines; control vines of the variety Extra with a leaf boron value of 34 ppm produced 7.5 pounds per vine, whereas borax-treated vines yield 18.2 pounds.

The very limited data of table I support Scott's findings that the boron level in leaves decreases toward the shoot tip. His results show further that, in general, leaf levels were lowest in early season, but this trend was not consistent among varieties. He suggested that the variations may be accounted for by the difficulties involved in collecting comparable leaves at various times during the growing season.

The primary aim of much of the research by the senior author has been to establish bloomtime petioles adjacent to flower clusters as a reference tissue for the mineral needs in general of grapes. Table I lists the boron content of such tissue for 6 Carignane and 4 Thompson Seedless boron-deficient vineyards. The two varieties show similar, rather narrow ranges in boron value—from 20 to 28 ppm. Thus, on this limited basis, it is suggested that a temporary threshold level for response by these two varieties might be 30 ppm, symptoms being quite likely to be present at levels below 25 ppm.

Petioles of most-recently matured leaves were used in a nutrient survey of Concord vineyards in Ohio (2). These samples, taken about one month after bloomtime, showed 29 of the 83 vineyards to have petiole boron levels below the lowest seasonal Concord leaf level of 7.4 ppm listed by Scott. Nevertheless, no clearly defined deficiency symptoms of boron deficiency were recognized and there appeared to be no correlation of boron level with crop production. Scott observed that some varieties showed yield response to borax treatment even though control vines show-

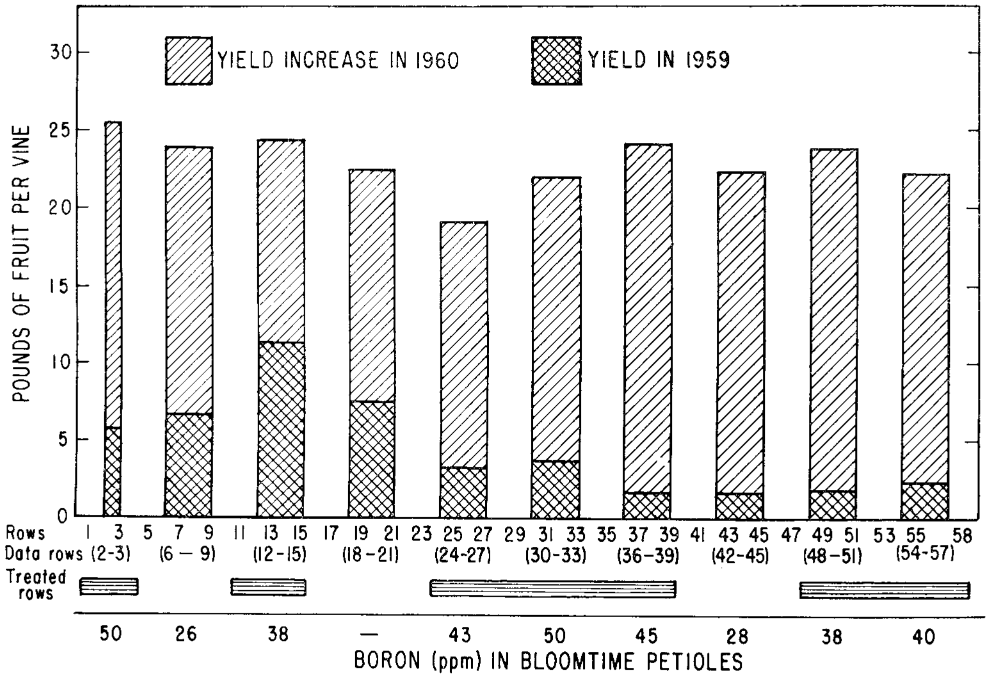

Figure 7. Plot layout and summary data from boron treatment trial with Grenache variety near Escalon, California. Except for the first (two-row) plot, yield data are four-row averages and boron levels are from four-row, composite samples.

ed no foliage symptoms. Gärtel (13) suggested symptomless boron deficiency in that fruit production is generally improved by addition of borax. Thus, it seems likely that yield responses to boron application might be found in the Concord vineyards of Ohio.

In addition to differential variety susceptibility other factors are known to affect the incidence and intensity of symptoms. The nature and timing of symptom development have suggested to several investigators—Scott (18), with grapes, and Boynton (4), with apples—that plants may have difficulty in either storing adequate reserve boron or transferring it rapidly enough to meristematic tissue in adequate amounts at times of greatest need. Therefore, if boron supply to the vine is reduced by low available soil boron or restricted by poor root deveopment, temporary boron deficiency might occur, especially during periods of very rapid growth, and because of its transient nature, might be rather difficult to detect except as reduced yields when it takes place near bloomtime. The clear relationship of drought to boron deficiency development in the apple is well-documented by Boynton (4); the effect of excess water, or waterlogged soil is also noted. With grapes, both Ono and Yoshida (16) and Gärtel (11) associated drought conditions during bloom with outbreaks of symptoms. Similarly, low moisture conditions and unseasonably warm weather are not unusual in the unirrigated coast-county vineyard regions of California where boron deficiency has been located. Also, the greater severity of symptoms in phylloxerated own-rooted vineyards has been reported (16), and has also been observed in several instances in the present California investigations.

Thus, upland coastal vineyards, particularly those on shallow soils or on own-roots, should be observed carefully during unusally dry springtime periods for effects of boron deficiency. Or better yet, considering the frequent short-time duration of the deficiency symptoms, the drastic effect on fruit yields that might occur even without other visual symptoms of lack of boron, and the low per-acre cost of treatment, it might be advisable to apply borax to all such above areas as a precautionary measure.

SUMMARY

Boron deficiency has been found in certain California vineyards leached by excessive seasonal rainfall in the unirrigated coastal region, and by low-boron irrigation water on sandy alluvial soils of granitic origin along the east side of the San Joaquin Valley. The foliage symptoms and effects on fruit production are descriped and illustrated by six photographs; they are in complete agreement with symptoms described in reports from other grape-growing regions of the world.

Boron levels of representative foliage tissue are presented. Chlorotic leaves have values averaging about 7 to 9 ppm. Bloomtime petioles adjacent to clusters, taken from deficient Carignane and Thompson Seedless vines, show boron levels of 20 to 28 ppm. It is suggested that vineyards of these two varieties may respond to borax treatment (using any of several available materials at rates equivalent to 10 pounds of boric oxide per acre) when bloomtime petioles drop below 30 ppm, and that visual symptoms are likely if values are 25 ppm or less.

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