THE INFLUENCE OF ENVIRONMENTAL AND INDUCED CULTURAL STRESSES ON THE WINTER SURVIVAL-VINE PRODUCTIVITY COMPLEX IN *VITIS LABRUSCA* L. VAR. CONCORD VINES

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ABSTRACT

THE INFLUENCE OF ENVIRONMENTAL AND INDUCED CULTURAL STRESSES ON THE WINTER SURVIVAL-VINE PRODUCTIVITY COMPLEX IN VITIS LABRUSCA L. VAR. CONCORD VINES

By

Basil G. Stergios

Cold hardiness and its association with the productivity of Vitis labrusca L. var. Concord vines was studied in the field and in the laboratory. Various methods for testing the viability of cold-stressed grape tissue were evaluated. Lowest bark temperature survival was adequately assessed by specific conductivity analysis for small sample sizes, and by tissue browning for large sample sizes. Tissue browning was the most practical method to assess cane and bud viability.

The effect of site-induced air temperature on cold acclimation and deacclimation in Concord grape vines was assessed in southwestern Michigan. High and low vineyard sites generated distinct temperature-induced microclimatic environments where differences in intracultivar adaptation were possible. Changes in bark and bud hardiness were directly related to air temperature changes. These changes affected primary buds most, then the secondary buds, followed by the bark. Concord grape vines on the low

site produced bark and primary and secondary buds which were hardier during acclimation and deacclimation than bark and buds from high site vines.

Evaluation of previous studies led to the concept that cultural stress could determinately influence cold hardiness. Since vine management is a complex of cultural practices, it was determined that evaluation of cultural stresses should include both hardiness and productivity measurements.

Concord grape plants were culturally stressed by complete defoliation, pruning severity, cluster thinning, and trellis height from 1971 to 1973. Defoliation, pruning severity, and cluster thinning influenced bark and bud hardiness. The effect of trellis height on bark hardiness was inconclusive. Some increased hardiness was noted for low trellis buds. Defoliation resulted in delayed acclimation in the fall and more rapid deacclimation in the spring. Effects of defoliation on bark and bud hardiness were more pronounced during the second year of treatment. Balance (30 + 10) pruning maximized the bark and bud hardiness of nondefoliated plants. Cluster thinning increased hardiness levels otherwise depressed by 60 + 10 pruning, particularly when the vines were defoliated. Thus, the greater hardiness sensitivity of under-pruned vines seems to be a result of over production. The tertiary bud was usually as hardy or slightly hardier than the secondary

bud with most treatments. The cultural stresses individually and collectively influenced vine size, and productivity as measured by yield, fruitfulness, berry size, soluble solids, clusters per vine, clusters per node, total vine sugar, berries per cluster, and cluster size. Leaf removal caused a reduction in all factors of productivity, particularly total vine sugar (59%), yield (50%), fruitfulness (37%), cluster number per node (23%), soluble solids (22%), and vine size (22%). Light (60 + 10) pruning increased the number of nodes retained which decreased vine fruitfulness. Yields were initially higher from lightly pruned vines than from balance pruned vines even though fruitfulness was low. Later, however, balance pruned vines yielded as much fruit and total vine sugar as lightly pruned vines while still maintaining a higher level of fruitfulness.

Although cluster size and the number of nodes per vine increased on cluster thinned vines, fruitfulness, cluster number per node, and total vine sugar was reduced. Defoliation and cluster thinning interacted most frequently to lower vine productivity.

The differential hardiness and productivity of primary and secondary buds led to a desire to determine the reason for their difference. A pilot study was undertaken to assess the effect of primary bud kill and removal on secondary shoot growth and productivity. A field technique was developed for primary bud destruction.

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Field death of dormant primary buds of Concord grape was effectively simulated by *in situ* puncture with an aluminum needle super-cooled by liquid nitrogen. This allowed the subsequent development of the secondary buds for study.

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DEDICATION

This dissertation is dedicated to two individuals. To my advisor, Stan Howell, who always shared and taught, both as a personal friend and as a scientist; and to my wife, Anita, who always worked hard and remained dedicated.

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I wish to express my sincere appreciation to the members of my committee: Drs. Stan Howell, David Dilley, Robert Olien, Eugene Mielke, Norman Good, Donald Ramsdell, Frank Dennis, and Robert Andersen for their guidance and critical inputs. I wish to thank William Grevelding, Robert Van Vleck, and Richard Haynor of the National Grape Cooperative; Dr. Nelson Shaulis of the Geneva Experiment Station; Robert Rogers, William Cronenwett, and Walter Spiech of Lawton, Michigan; Stephen Stackhouse and Maureen Myers of Michigan State University, for their continual help and guidance both in and out of the field. I wish to express my gratitude to fellow students and friends who aided, guided, and provided moral support in my research: Marie Ross, Loudes Alvarez, the De-La-Garza family, the Mendoza family, the Gonzales family, the Garcia family, the Gomez family, Skip Bittenbender, Susan (Engstrom) Bittenbender, Michael Byrne, and John Stuurwold.

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PREFACE

PREFACE

Introduction

Since cultivated woody plants are immobile, their distribution, survival, and productive capacity are controlled by their ability to adapt to conditions imposed upon them by the environment and by man. Such conditions include topography, soil conditions, drought, photoperiod, cold, and cultural practice.

Cold stress appears to be one of the most important factors regulating the distribution of cultivated plant populations (9, 22). Freezing damage to economically important plants presents problems of economic concern in both temperate and subtropical regions. Coping with environmental stresses, in particular cold stress, constitutes an important part of the plant's survival strategy.

Strategically, cold may be dealt with by the plant in several ways. One involves the advantageous use of low temperature. Seeds of Hieracium aurantiacum L. deposited late in the growing season will not germinate as readily as those deposited early unless they are subjected to a cold period (34). Seedlings arising from early deposited seed would be sufficiently developed to successfully overwinter, while those arising late would not. Cold is probably

utilized to break seed dormancy, affording the seedling an entire growing season for establishment. Another strategem for plant survival involves protection from injury and death from cold stress. Less hardy woody plants may be physically protected by a low growth habit when overwintering in areas with deep snow cover (8).

External protection against cold stress is largely unavailable for larger woody plants. They avoid cold injury by using metabolic energy (20) to initiate the biologically active (42) process of acclimation in response to natural rhythms (8, 42).

In cold climates, the cold hardiness and fruit productive capacity of cultivated woody plants are inextricable. Their capacity to produce fruit is important primarily for economic reasons. Often, however, the productive plant parts are the most susceptible to cold injury. The strategy thus requires back-up mechanisms to assure survival: via enhanced vegetative growth, apomixis, or the activation of secondary plant parts.

Freezing Injury and Death in Woody Plants

There appear to be two general approaches to the question of freezing injury in woody plants. The first approach involves primary direct injury (18), where injury and death always result from intracellular ice formation (18, 19), usually occurring when tissues are rapidly

frozen (41, 42). The lethality of intercellular ice also depends on the amount of recrystalization occurring during warming, with slow warming producing the greater amount (19, 29). Since intracellular ice formation in woody plants is rarely observed in nature, the mechanism of primary direct injury remains obscure. However, it seems reasonable that physical disruption of the protoplasm, or rupture of the cell membrane itself by large ice crystals may be involved (18, 19). Olien et al. (21) observed that when hardened winter barely was damaged during cold weather following a mid-winter thaw, large ice masses formed which ruptured the xylem vessels in the crown.

Injury and death in woody plant cells most commonly occurs as a result of slow-freezing stress. Many theories concerning this process have been proposed and are discussed at length by Levitt (18), Vasil'yev (41), Mazur (19), Tumanov and Krasavtsev (39), and by Weiser (42). Freeze-induced dehydration of the protoplast appears to be the most reasonable theory to explain injury and death in hardy woody plants, and the steps of this process as proposed by Weiser (42) are outlined in Figure 1.

Environmentally Induced Acclimation and Deacclimation

Woody plants adapted to temperate regions are resistant to freezing stress (1, 42) because of their ability to acclimate (18, 19, 42). Alden and Herman (1)

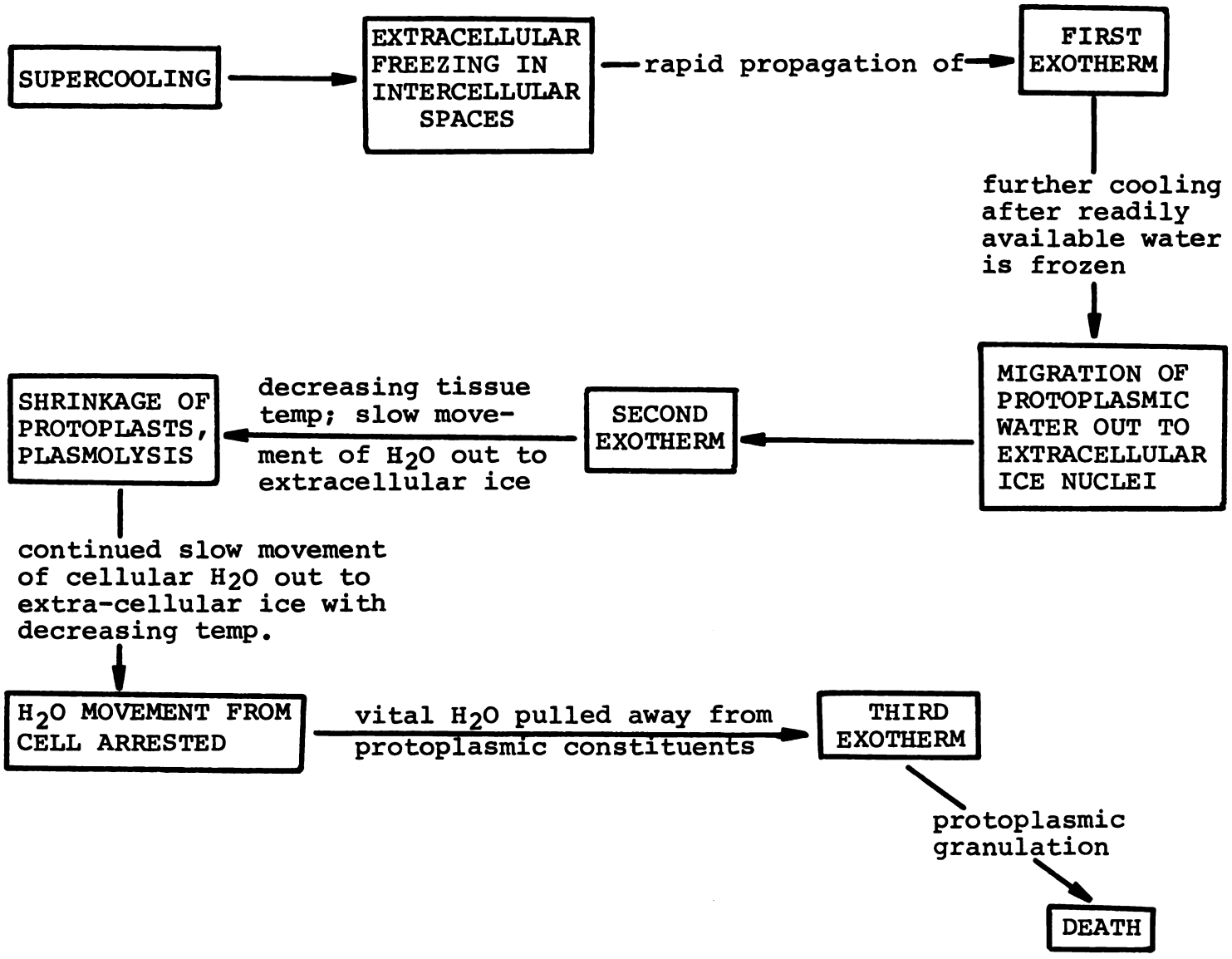

Fig. 1. Schematic view of sequential development of slow-freezing death in woody plant tissue. After Weiser, 1970.

point out that the ability of plants to withstand cold stress depends on an inherent annual rhythm of complex metabolic functions that has evolved through plant-environment interaction.

It is widely reported that cold acclimation in nature is a two-phase, sequential process (5, 10, 15, 32, 40, 42) dependent upon active metabolic processes in the early stages (5, 42). Investigations have shown (5, 10, 13, 40) that the first phase of acclimation is not temperature dependent, rather is initiated by a photoperiodic response induced by short-day perceptors in the leaves. Woody plants will begin to acclimate with a short day stimulus even when temperatures remain high (10). However, either low temperatures or short days can induce acclimation in the absence of the other inductive factor (5).

Growth cessation appears to be a necessary prerequisite to cold acclimation (5, 10, 40, 42) and the induction of growth cessation is probably one of the prime functions of short days in the natural cold acclimation of plants (5). Plants will not acclimate even if they are chilled to 0°C while they are actively growing (6, 26). Weiser (42) suggests that short days probably function as a natural early warning system. He further suggests that the first stage of acclimation appears to involve two distinct events, growth cessation and the initiation of metabolic changes which facilitate the plant's response to

low temperatures during the second phase of acclimation. The key factor in photoperiodic acclimation appears to be growth cessation rather than rest induction because low temperature can stop growth and bring about acclimation without inducing rest (10).

Studies suggest that the light stimulus results in the production of a translocatable hardiness factor(s) (4, 16, 32, 33) which causes acclimation. Long-day induced leaves are the source of a translocatable factor(s) which inhibits cold acclimation (16), while short-day induced leaves are the source of translocatable hardiness promoting factor(s) (5, 10, 16). Although investigators agree that a translocatable hardiness promoter(s) exists, the nature of the promoter(s) is still being debated. Opinions appear to be divided along two lines. Weiser (42) and his associates (10), Irving and Lanphear (17), and Roberts (26) have suggested that the promoter(s) is a hormone. Steponkus (32), however, suggests the hardiness promoter is most likely sucrose. He argues that sucrose is necessary during the second phase of acclimation because frost sensitive proteins alter their configurations when subjected to low temperature, and their subsequent stabilization is dependent upon the binding of sucrose. This is accomplished when the protein assumes a new configuration or composition which provides sites which bind with the hydroxyl groups of sucrose. This stabilization is manifested as an increase

in hardiness. Steponkus (32) supports his argument from his finding that sucrose will replace the light requirement for initiating acclimation in Hedra helix.

Once acclimation is underway, and the hardiness promoter(s) has been activated, the second phase of acclimation begins. The second phase of acclimation appears to be induced by low temperatures. Howell and Weiser (10) found that young Haralson apple trees failed to acclimate beyond a certain point in the absence of frost. The second phase of acclimation was always initiated when the trees were exposed to frost. In addition, they found that the second, or low temperature induced phase of acclimation does not involve a translocatable factor(s) (10).

A third phase of acclimation has also been described (39, 42), where prolonged exposure to very low temperatures causes the woody tissue to attain hardiness not found in nature. This type of hardiness is quickly lost (39).

Dehardening and rehardening processes in woody plants appear to be related to the state of dormancy. Two phases of dormancy have been identified: rest and quiescence (42). Plants apparently are at rest immediately following the onset of acclimation, and during this stage they tend to maintain hardiness even when subjected to higher air temperatures (14). After the cold requirement is satisfied, rest gives way to quiescence and the plants may then loose hardiness (deharden) readily when

air temperatures rise (3). During the quiescent period, woody plant tissue may also reharden after loss of hardiness, when exposed to fluctuating air temperatures (3, 7, 10, 11, 25). Howell and Weiser (11) found that dehardening of living apple bark is only partially reversible. Once dehardening had begun, the bark did not reharden beyond the killing temperature on the day preceding the final day of dehardening. This lethal temperature increased with each successive day of dehardening.

Cold Hardiness and Plant Productivity

Low temperatures and a short growing season, which are characteristic in cold climates, enhance the importance of the cold hardiness-productivity complex in cultivated woody plants such as Vitis labrusca L. var. Concord. Cultural stresses induced by vineyard management techniques directly influence the cold hardiness of the vine (36). Cultural stresses can have a synergistic effect on vine productivity. While they can exert a direct influence on productivity (37), reduced cold hardiness by improper vine management will in turn result in reduced yield, fruitfulness, and fruit quality (30, 31, 37). It is evident, then, that vine management for cold hardiness cannot and should not be separated from other management techniques. The vine must accomplish three physiological functions if it is to be economically satisfactory to the grower (12): (a) it

must mature the grape crop it is carrying; (b) it must initiate and carry out the differentiation and ontogeny of shoots and flower clusters for the following season; and (c) it must mature the canes to insure acclimation and adequate cold hardiness. These functions can be adequately achieved if vineyard cultural practices are implemented with both cold hardiness and production in mind.

The sexual back-up mechanism for survival in Concord grape vines is not only part of the survival strategy, but also can be of economic importance to growers. The primary bud (35) which is the most productive (2, 24, Appendix) part of the compound bud, is also the least cold hardy (23, 36, 38). However, the secondary bud, which will usually develop in the absence of a viable primary bud, is hardier (23, 36, 38) and can produce up to 70% of the normal crop (43, Appendix) under ideal circumstances.

Thesis Objectives

Cultural stresses like defoliation, pruning severity, and cluster thinning have a synergistic effect on vine productivity. That is, while cultural stresses can exert a direct influence on vine productivity, reduced cold hardiness by improper vine management will, in turn, result in reduced yield, fruitfulness, and fruit quality. Therefore, I suggest that vine management for hardiness cannot and should not be separated from other management techniques.

When viticultural stresses are minimized, both vine hardiness and vine productivity are simultaneously improved. Improved hardiness increases productivity by increasing vine fruitfulness, and increased productivity stimulates proper vine vigor. A proper vine balance encourages maximum hardiness.

The purpose of this thesis was to provide a broader understanding of the cold hardiness-vine productivity complex in culturally stressed Concord grape plants. The following studies were undertaken in an attempt to elucidate the manner in which vine hardiness and productivity are related.

The specific goals of the research were five-fold: (a) to evaluate and determine the reliability of several viability tests for Concord grape vines. In order to effectively evaluate cold hardiness in grape vines, a suitable test for viability had to be determined. What effectively determines viability in one type of plant may not do so for another; (b) to determine the effect of site-induced air temperature on cold acclimation and deacclimation in Concord grape vines. In order to obtain a basic understanding of the nature of cold hardiness in Concord grape canes and buds, the effect of air temperature on acclimation and deacclimation under natural conditions necessitated elucidation. Differences in site elevation provided the distinct temperature regimes necessary for

this purpose; (c) to determine the effects of hand defoliation, pruning severity, cluster thinning, and trellis height on the cold hardiness of Concord grape vines; (d) to determine the individual and combined effects of hand defoliation, pruning severity, and cluster thinning on the size and productivity of Concord grape vines. Cold hardiness and vine productivity are inextricably associated and are influenced by cultural stresses imposed upon the vine by vineyard management practices. The studies in sections 3 and 4 were designed to gain some insight into the nature of the hardiness-vine productivity complex; and (e) to design and implement a workable method for simulating freezing death of the primary bud in the field without injuring the secondary bud of Concord grape vines. The differential hardiness and productivity of primary and secondary buds led to a desire to determine the reason for their difference. In order to assess the effect of primary bud kill and removal on secondary shoot growth and productivity, an effective field technique had to be developed for primary bud destruction. The technique described in section 5 allowed the subsequent development of the secondary buds for study.

This dissertation is presented as three manuscripts prepared to meet the literary requirements of the American Journal of Enology and Viticulture, to which each will be submitted; and two published articles.

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SECTION ONE

EVALUATION OF VIABILITY TESTS FOR COLD STRESSED PLANTS

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Evaluation of Viability Tests for Cold Stressed Plants[1]

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Abstract. The reliability and convenience of 5 viability tests were evaluated. Growth and tissue browning were the most reliable tests, but they required considerable time and were qualitative. Triphenyl tetrazolium chloride (TTC) reduction and specific conductivity were satisfactory for grape, but TTC was not as reliable as specific conductivity for cherry and raspberry. Neither test proved satisfactory for strawberry.

A second exotherm always indicated living stems and the absence of a second exotherm accurately predicted stem death. Freezing curves for raspberry showed the stems to be 5 degrees hardier than the control growth tests indicated.

Interest in stress physiology of horticultural plants has increased in recent years. The understanding of cold hardiness is rapidly expanding (1, 11, 21). Parker (17) reported the difficulty of determining whether a small sample of tissue or entire organism is still alive after a stress treatment. Dexter et al. (3) recognized the necessity for rapid methods of measuring viability of plant tissue and were among the first to develop a test for this purpose. Steponkus and Lanphear (19) pointed out that a prerequisite to conducting research in cold hardiness is a reliable method to determine tissue viability. They stated that the method should "eliminate bias associated with visual observations, be based on a quantitative system that can be analyzed statistically, utilize small quantities of tissue, be relatively quick, and be capable of predicting the future performance of the plant" (19).

The purpose of the present study was: 1) to determine the reliability of several viability tests, and 2) evaluate these tests under the same conditions on different plant species. A test was considered reliable if it effectively distinguished between living and dead tissue. Convenience was assessed based on the time lag between stress and evaluation, amount of effort involved, and the need for specialized equipment to evaluate the material under test.

Materials and Methods

Growth, tissue browning, triphenyl tetrazolium chloride (TTC) reduction, specific conductivity, and double freezing point were used to evaluate viability of cold stressed plants of 4 different species: 'Montmorency' sour cherry (*Prunus cerasus* L.), 'Concord' grape (*Vitis labrusca* L.), 'Latham' raspberry (*Rubus strigosus* Michx.), and 'Midway' strawberry (*Fragaria* sp.). The tissue evaluated consisted of excised stems of current season's growth obtained from plants under cultivation in the field. Three-node sections from the mid-portion of cherry shoots and raspberry canes were used. Single-node stem sections, cut in the mid-point of the internode, were made from the mid-portion of 10 to 20-node grape canes. Strawberry crowns were taken from 2-year-old plants and the crowns stripped of all leaves and petioles. The sections of cherry, grape, and raspberry were cut to 12 cm in length. Care was taken to insure that the samples for a particular species were of comparable caliper.

Hardiness was determined on May 2 and May 10, 1971 by subjecting the material to a controlled freezing stress as described by Howell and Weiser (9). Three test samples per treatment were labeled and placed immediately into a series of vacuum flasks which were then cooled in a deep freeze at approximately 10°C/hr. A 26-gauge thermocouple was inserted in the pith of 1 stem in each flask to monitor sample temp. Flasks were removed from the freezer at 5°C intervals and allowed to warm slowly to ambient temp.

Growth and tissue browning. The tissue browning test for viability has been used both for direct determination of injury (6, 8, 9) and as a control for evaluating the responses of more quantitative tests (5, 20). The growth test has been used in a similar manner (4, 19).

Cold stressed stems were placed in sand on a mist propagation bench in a 23.9°C (75°F) greenhouse for 1 month. Stems were considered alive if root growth, callusing, or bud break occurred. The stems were also considered alive if the tissue appeared green in the absence of growth after 30 days. Both the percentage of cuttings showing growth, and the percent survival were recorded. Additional material was placed in a humid chamber and incubated at ambient temp for 14 days, after which it was dissected and visually inspected for injury. The stems were recorded as dead if the cambium and the phloem were brown. The results were tabulated as a percentage of the stems surviving at each temp.

Specific conductivity. Dexter et al. (3, 4) were among the first to describe a workable procedure for the use of specific conductance to relate change in electrolyte concentration to levels of low temp injury in plant tissues. Wilner (22 23) improved the test by expressing the specific conductivity of diffused electrolytes as a percent of the total extracted by boiling water.

The method used was similar to that used by Wilner (22, 23). Freeze stressed cherry, grape, raspberry, and strawberry material was cut into 1 cm sections, halved, weighed, and placed in large culture tubes with distilled water (3 ml/g of tissue). The reliability of the specific conductivity test for grape was enhanced by removing the non-living bark before sectioning. The material was incubated for 24 hr at ambient temp, the initial conductivities (reciprocal ohms) measured, and the samples autoclaved at 121°C for 1 hr. The final conductivities were measured after an additional 24 hr at ambient temp. The specific conductance was calculated as initial conductivity x 100 divided by final conductivity.

Triphenyl tetrazolium chloride (TTC). The triphenyl tetrazolium chloride test was refined and meaningfully adapted as a tissue viability test by Steponkus and Lanphear (19), and the procedure they reported was utilized. Cold hardiness was expressed as optical density (recorded at 530 mμ on a Bausch and Lomb 340 spectrophotometer) of solutions from stressed tissue x 100 divided by the optical density of solutions from controls. High percentages of TTC reduction indicated living tissue, low percentages indicated dead tissue.

Data for specific conductivity and TTC reduction were processed statistically using an analysis of variance, and the means were compared across dates using Tukey's w procedure (18).

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Multiple freezing points. When water forms ice, heat is given off (exotherm) and tissue temp rises temporarily (15, 21). Two exotherms normally are observed in living tissue, only 1 in dead tissue (10, 14, 15, 16, 21). The multiple freezing point technique described by McLeester et al. (15) was used. Samples were frozen at a rate of 10°C/hr, thawed, and then refrozen at the rate of about 60°C per hr. The resultant freezing curves were then compared and evaluated.

Specific conductivity and TTC reduction values depicted graphically show the viability status of the 4 plant mate evaluated. The first range (solid line) indicates non-lethal te The last range (dotted line) indicates the lethal range, i.e. te at which sufficient injury occurred to prevent growth. middle, or critical range (broken line) indicates that de occurred somewhere within that 5°C interval based on growth test.

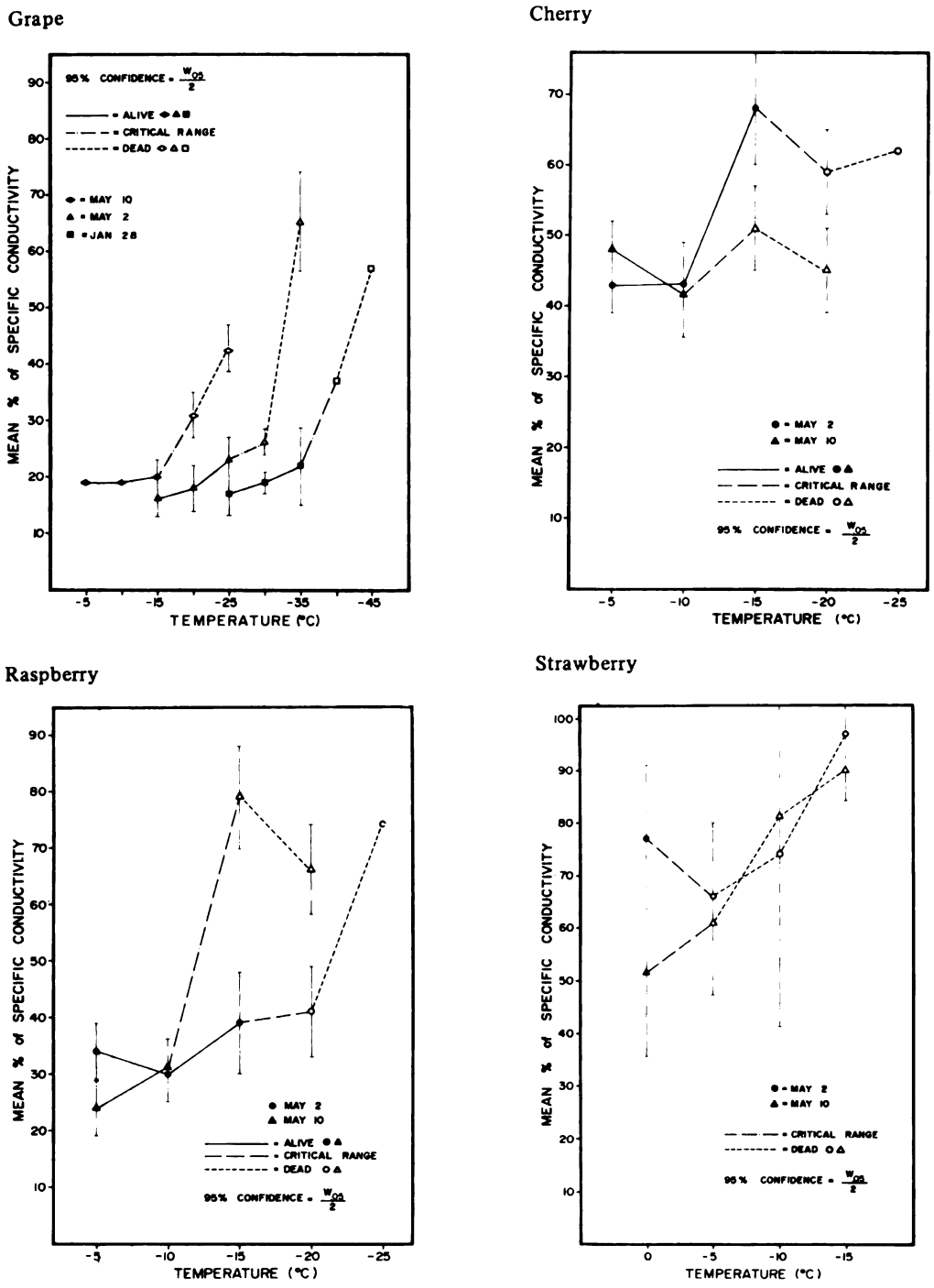

Fig. 1. Effect of low temp stress on stem tissue viability as determined by specific conductivity. Means between dates are compared using the Tukey statistic.

Table 1. Effects of freezing temp upon growth and tissue browning of cuttings of 4 species. Values indicate percent of cuttings showing growth or browning.

Temp °C	Growth			Browning		
	Jan. 28	May 2	May 10	Jan. 28	May 2	May 10
			Grape			
− 5	100	100	100	0	0	0
−10	100	100	80 (100)	0	0	0
−15	100	100	20 (80)	0	0	0
−20	100	40 (60)	20	0	0	100
−25	100	0	0	0	33	100
−30	50 (67)	0	0	0	100	100
−35	50 (67)	0	0	0	100	100
−40	0	0	0	100	100	100
			Cherry			
− 5		100	100		0	0
−10		100	70 (100)		0	0
−15		60 (100)	0		0	100
−20		0	0		100	100
−25		0	0		100	100
			Raspberry			
0		100	60		0	0
− 5		100	40 (60)		0	0
−10		60 (100)	0 (100)		0	0
−15		0 (100)	0		0	100
−20		0	0		100	100
−25		0	0		100	100
			Strawberry			
0		100	100		0	0
− 5		0	0		100	100
−10		0	0		100	100

[z]Values in parentheses indicate percent surviyal.

dehardening of 5°C between May 2 and May 10 in agreement with the browning test (Table 1). Although the range of specific conductivity seemed reasonably small for living tissue (Fig. 1), it varied considerably in dead tissue. Further, only a slight increase in specific conductivity occurred between living and dead tissue on May 2. However, values differed acceptably between living and dead tissue on May 10. Also, specific conductivity of living and dead tissue between May 2 and May 10 was significantly different. The reliability of this test was low as judged by its inconsistent performance. Analysis of hardiness by TTC reduction for raspberry proved unsatisfactory (Fig. 2), because consistent responses could not be obtained. Dead tissue, as indicated by growth, from stressed material collected on May 10, effectively reduced the TTC, but on May 2, the TTC was not reduced by similarly stressed tissue. The appearance of double freezing points in raspberry cane tissue was unpredictable, and sometimes indicated that the tissue was about 5°C hardier than was shown by the growth test (Fig. 3).

Strawberry. The hardiness of strawberry crowns could be evaluated effectively by the tissue browning test (Table 1). No change in hardiness occurred between May 2 and May 10, and 0°C was the lowest survival temp. Values for TTC reduction and specific conductivity at the higher temperatures were variable (Figs. 1 and 2) between the dates even though there was no difference in hardiness, emphasizing the unpredictability of TTC reduction and specific conductivity responses in strawberry tissue.

Double freezing point curves were more reliable in strawberry than either specific conductivity or TTC reduction (Fig. 3). As expected, 2 exotherms appeared in curves from the living tissue. In dead tissue the "second" exotherm appeared as a wide deflection in the curve, while there was no evidence of a first exotherm. This might be expected since a large portion of the crown consists of parenchyma (pith) tissue, with large intercellular spaces. These tissues contain a larger amount of water than do woody tissues, resulting in slower cooling.

Discussion

Even though growth and tissue browning were slow and qualitative, these tests were the most reliable. Although the labor needed is minimal, 1 to 2 weeks of incubation is necessary for the browning test, and up to 1 month for the growth test. These 2 factors coupled with the qualitative nature of the results are their major weaknesses. Results of both tests were in perfect agreement (Table 1) and growth was used as the control for the other methods evaluated. This agreement between growth and browning is consistent with the findings of McLeester et al. (16) on dogwood.

Both specific conductivity and TTC reduction would be suitable for evaluating grape stem hardiness, although specific conductivity was more critical. The unreliable performance of the specific conductivity test in cherry, raspberry, and strawberry due to excess variability might be explained in part

Table 2. General summary of the advantages and disadvantages of viability tests for evaluation of woody plant hardiness.

Test	Advantages	Disadvantages	Species suited to test
Growth and browning	– Accurate in determining death – Can be used as a control for other tests – Best for large samples	– Time required – Slow – Unless data coded, can be biased	Cherry Grape Raspberry Strawberry
Specific conductivity	– Variability usually small – More rapid than browning or growth – Best test with few samples when good standard response curve has been established	– Requires large amounts of material per sample – Slower than TTC reduction or multiple freezing point tests – Not practical for large number of samples	Grape
TTC reduction	– Requires small amount of material per sample – Best to use when quantitative data necessary for larger sample sizes	– Considerable labor required – Refinement of technique critical to success of test – Variances large among replicates – Not practical for large number of samples	Grape
Multiple freezing points	– Very rapid – Responses tend to be the same; 2 exotherms when alive, 1 when dead – Accurate	– Not quantitative – Second freezing point may not occur in same tissues – Will occasionally indicate that a dead tissue is alive	Cherry Strawberry

by the onset of metabolic activity in the stems during May. Wilner (23) has suggested that electrical conductivity varies according to changes in permeability of living cells due to seasonal periodicity in vegetative growth. Harris (7), however, claimed success with the specific conductivity test when his data on specific conductivity of strawberry crowns showed an inverse relationship with known field hardiness. The disappointing performance of the TTC test in general might be explained in part by: 1) the need for specific techniques for specific tissues, and 2) cellular retention of the reductant $NADPH_2$ in varying amounts after the cell dies.

In the species studied, the presence of a single exotherm always indicated death of the tissue. Two exotherms, however, were observed in raspberry even though the stem was dead. This was the most important weakness of the double freezing point test.

The continued drop in TTC reduction or rise in specific conductivity after the stem was killed is of interest. The cambium is necessary for whole plant survival. When this has been killed, the other tissues may still be alive. As low temp stress increases these tissues are ultimately killed. However, any cells which remain alive will still reduce the TTC dye. Likewise, as more tissue is killed, increasing amounts of electrolytes are released which increases specific conductivity.

The viability tests compared in this study are listed and evaluated in Table 2. The data collected in this comparison were taken on dates during the dehardening period and on all sampled dates the rest period (physiological dormancy) had been satisfied. It is possible that a physiological condition such as rest could modify the relationships reported here. That possibility brings us to the central point to be derived from the study. The fact that a viability test has worked effectively on 1 plant under specific conditions is no guarantee that it will perform in a similar fashion on a different plant or even on the same plant under different conditions. Any researcher wishing to use a viability test should carefully determine specific responses on that plant and compare it to a less quantitative but reliable test such as the growth test.

In discussions with some scientists, it is apparent that there is growing use of an arbitrary amount of percent specific conductivity or percent O.D. for the TTC reduction evaluations as a breaking point for viability and death. The most frequently suggested is 50%. Our data show such usage to be without scientific merit. Further, to use these tests in such a way results in both tests losing their status as quantitative.

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SECTION TWO

EFFECT OF SITE ON COLD ACCLIMATION AND DEACCLIMATION IN *Vitis labrusca* L. var. Concord Vines

EFFECT OF SITE ON COLD ACCLIMATION AND DEACCLIMATION IN *Vitis labrusca* L. var. Concord Vines[1]

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Abstract

The effect of site on cold hardiness of *Vitis labrusca* L. var. Concord vines was investigated in southwestern Michigan. Air temperatures from a low, poorly air-drained site were consistently lower than temperatures from a nearby high, well air-drained site. Seasonal hardiness changes followed seasonal changes in air temperature. Living bark from low site vines acclimated faster and to a greater degree of hardiness than bark from high site vines. Both site, as well as compound (primary vs. secondary) bud polymorphy were important in determining bud hardiness differences. High site buds tended to be less hardy than

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low site buds, and secondary buds from either site tended to be hardier than primary buds. The early spring deacclimation status indicated that bud hardiness differences were due to site-induced differences in air temperature, while inherent differences between the primary and secondary bud were solely responsible for late spring bud hardiness differences. The two sites generated distinct temperature-induced microclimatics where differences in intracultivar adaptation was possible. Site-induced air temperatures, and bud differences appeared to interact to influence cold hardiness of Concord grape vines during acclimation and deacclimation. Concord grape vines apparently adapted to lower fall, winter, and spring air temperatures through exposure.

Introduction

Freezing damage has been a problem of major economic significance to native vegetation and crop plants (1, 28). Parker (15) stated that the reason cold became so acutely limiting to the success of plants in some areas was not only the excess of out-going radiation over incoming but also the fact that cold air tended to remain near the ground and produce a relatively static situation in which local temperatures fall below the surrounding levels. The existence of this phenomenon suggested that adaptation to local low temperature at low sites might have played a role in determining the cold hardiness of a cultivar.

Even though low temperature was estimated to be the most significant environmental factor causing direct plant injury in cold climates (3), quite severe injury from cold did not necessarily limit plant establishment and distribution in regions of annual subfreezing weather. (24). Once the initial acclimation phase in hardy woody plants was complete, the degree of freezing resistance of a species in winter may differ considerably depending on the air temperature at which the plants were wintering (20). Generally, increasing cold tolerance to decreasing winter temperatures has been recognized as an adaptive feature of the plant (13).

It has been commonly accepted among viticulturists that site selection was the most critical of vineyard establishment (4, 7, 21, 22, 23), in order to insure that there may be adequate solar radiation, drainage of potentially injurious cold air, acceptable soil type and water drainage (7, 21). Weak air drainage generates lower minimum air temperatures (5). Topographic depressions and an opening in a young pine stand were the sites of the lowest minimum temperatures. Minimum night temperatures during the spring near the soil surface were -90°C on a lodgepole pine flat site, and -6°C on an adjacent ponderosa pine slope in eastern Oregon (2). Locating a grape vineyard on sloping ground has been considered advantageous because these areas had higher night

temperatures and were less likely to have a freeze whenever the cold air drained onto adjacent low-lying areas (4).

Vineyard elevation, as it relates to air drainage, is recognized by scientists and growers to be important for frost protection. In the absence of good air drainage, adaptation of canes and buds to tolerate local lower air temperature becomes more important (9, 10, 24). This study was initiated to investigate the effect of site-induced air temperature on the acclimation and deacclimation patterns in Concord (Vitis labrusca L.) grape vines.

Methods and Materials

The Study Area

Two 4.9 ha Concord grape vineyards located in Van Buren County, Michigan (T3S, R13W, Sec. 32) were selected for the study. The first vineyard is located on a high (elev. approx. 277 m above sea level), well air-drained site. It is surrounded by other vineyards situated to the east and south, and open fields to the north. The second vineyard is located on a low (elev. approx. 256 m above sea level), poorly air-drained site directly west of the first site. It occupies a depression surrounded on the south and west by other vineyards and on the north by open fields. The two study sites are approximately 210 m apart, separated by a 6° slope containing a tart cherry (Prunus cerasus L.) orchard. The site topography is

fairly homogeneous while the low site tapers off gently into a pocket at the southwest corner.

The grape vines on both sites were planted in 1904 on Plainfield sand (29), and have since undergone intermittant renewal. They were planted in rows of 48 vines, spaced at 2.5 m, with 2.8 m between the rows.

Sampling Procedures

Samples were taken from 36 vines selected for uniformity in 1970 and balance (30 + 10) cane-pruned. A vine was balance pruned when 30 buds were left for the first pound of current cane growth removed (prunings), and 10 more buds left for each additional pound of removed prunings (16). The vines were trained to an umbrella kniffen system and constituted a 2.5 ha experimental plot at each site. Hardiness evaluations were made periodically during the fall and spring of 1971-1973. Single node stem sections, cut in the mid-point of the internode, were made from the mid-portion of 10 to 20 node mature canes chosen for their maturity as determined by cane color and diameter (16). The single node samples were sealed in small plastic bags and were transported within two hours to the laboratory without elevating their temperature. Bark (cambium and phloem) and compound bud samples were then evaluated for hardiness, which was determined as described below.

Hardiness and Air Temperature Measurements

Hardiness was determined on each sampling date by subjecting the material to a controlled freezing stress as described by Howell and Weiser (11). Test samples from the field were immediately labeled, wrapped in aluminum foil, and placed into a series of vacuum flasks which were then cooled in a controlled temperature freezer at approximately 5°C per hour. Each test sample consisted of 3 observations from 18 vines. A 26-gauge copper-constantan thermocouple was inserted in the pith of one cane section in each flask to monitor sample temperature. Previous unpublished data indicate that this freezing rate allowed sufficient time for all canes to equilibrate to the same temperature as the indicator cane. Flasks were removed from the freezer at 5°C intervals and allowed to warm in the flasks to ambient (approx. 21°C) temperature. Bark, primary and secondary buds were evaluated for viability with the browning test (25). Bark hardiness was recorded as the lowest survival temperature. With the 5°C intervals no differences among replicates were observed, and therefore each point on a figure represents both the mean and the observed range. Primary and secondary bud hardiness was determined using graphic methods to determine the 50% survival rate (T_{50}; 18, 19). The buds were judged alive when they were all green and dead when at least their center portions were browned (26).

Daily maximum and minimum air temperatures for the general study area were recorded during spring and September, 1971 from a nearby weather station (14). Beginning in November, 1971 maximum and minimum air temperatures were recorded daily from thermograph recorders in the vineyards. They were enclosed in conventional weather boxes and placed about 1.5 m from the ground at the highest and lowest point in each experimental plot. Air temperature readings from both recorders were averaged together at each site, and the resulting mean maximum and minimum values are given in Figures 1 - 4. Weekly mean maximum and minimum air temperatures and season minimal air temperatures for both sites are given in Table 1.

Results

Figures 1 - 4 show site differences in the seasonal hardiness changes of living bark and buds of Concord grape vines from 1971 to 1973. These hardiness patterns were associated with seasonal changes in air temperature (Fig. 1 - 4), and were generally similar to those described for peach buds (16, 17), Cornus stoloniferea Michx. (26), apple (10, 11, 12), and Forsythia intermedia Zabel (8). Site differences in air temperature were also evident. Seasonal mean maximum weekly temperatures were generally higher on the high site and minimum temperatures consistently lower on the low site (Table 1). Seasonal

minimum air temperatures were also always lower on the low site (Table 1), with a four-season grand mean minimum of -15.8°C.

Acclimation

Bark of low site vines had attained 10°C more hardiness than high site vines by mid-fall, 1971. By mid-December, the vines were at maximum hardinesses. At this stage low site bark was 5°C more hardy than high site bark (Fig. 1).

Results indicate that site, as well as compound bud polymorphy were important in determining bud hardiness differences. Both primary and secondary buds from high site vines were always less hardy than those from low site vines during fall and early winter acclimation in 1971 (Fig. 1). By mid-season, 1971, it became clear that primary buds were less hardy than secondary buds on both sites, with buds on the low site being hardier. In early winter, 1971, the primary buds were about as hardy as the secondary buds at each site, but high site buds were still less hardy than low site buds.

In 1972 (Fig. 2) bark hardiness followed the same general pattern of acclimation as in 1971 (Fig. 1). In the early fall of 1972 (Fig. 2) the bark of low site vines had attained 5°C more hardiness than high site vines. By mid-season, high site bark had attained the same hardiness

as low site bark (Fig. 2). Low site bark was again 5°C more hardy than high site bark by early winter (Fig. 2).

Bud hardiness differences between sites were less evident in 1972. By the middle of the hardening season, however, both primary and secondary buds were less hardy on the high site than their counterparts on the low site. Secondary buds were always more hardy than primary buds through the 1972 fall season regardless of site (Fig. 2).

Bark from low site vines was 10°C more hardy than high site bark by mid-acclimation 1971 (Fig. 1), but nearly the same hardiness as high site bark was during the same period in 1972. Bark from both sites had similar hardiness in early winter for both 1971 and 1972 (Figs. 1 and 2).

Bark from both sites acclimated at a faster rate than the buds and continued to harden longer. The buds reached a maximum hardiness in November, after which the hardiness normally leveled off (Figs. 1 and 2). However, the hardiness decreased when there was an early winter thaw (Fig. 1). That observation agreed with observations made by Proebsting (18) on Elberta peach buds.

Deacclimation

Bark tissue hardiness changed with fluctuating air temperatures in the spring of 1971 (Fig. 3). Bark from high site vines remained 5°C less hardy than bark from low site vines until mid-May, when air temperature

minimums were above freezing. At that time the bark attained equal hardiness on each site (Fig. 3).

As was the case during acclimation, both site-induced air temperatures and bud polymorphy appeared to influence deacclimation as they did acclimation. Site-induced bud hardiness differences were evident during early spring deacclimation. High site buds were less hardy than low site buds throughout the deacclimation period in 1971, and, regardless of site, primary buds were always less hardy than secondary buds (Fig. 3).

With warmer air temperature minimums in 1972 and 1973, bark tissue from both sites dehardened faster, and reached the same hardiness level earlier in the season (Figs. 2 and 4). In an apparent response to sudden increase in air temperature (Fig. 4), high site bark dehardened more rapidly than low site bark in 1972.

Primary buds from high site vines were less hardy during deacclimation than low site primaries in 1972 (Fig 4). The same relationship held for secondary buds, and the difference remained even after the primary buds had broken in late April. The deacclimation pattern of primary buds in 1973 (Fig. 2) was similar to that in 1972, and in 1973 secondary bud dehardening was as in 1971. However, differences between the hardiness of secondary buds from the two sites were smaller in 1973.

High late spring air temperatures hastened deacclimation to the point where site differences were no longer important. In general, secondary buds from both sites remained hardier than the primary buds (Figs. 1, 2, 3) during the dehardening period. In 1971 and 1972, when hardiness measurements were made later in the season than in 1973, primary buds had completely dehardened and begun to grow. Secondary buds remained dormant and retained hardiness during the same measurement period.

Discussion

Air temperatures in the low site would perhaps have been lower than indicated if it were not for the cherry orchard barrier between the two sites. Dethier and Shaulis (4) have pointed out that a dense woods above the vineyard can divert and/or reduce the flow of air down-slope into the vineyard, thus less of the warmer air is displaced upward. Nevertheless, air temperatures in the low site were consistently lower than in the high site. This would create a distinct microclimate allowing for greater vine adaptation to lower temperatures and greater vine hardiness. This was reasonable in the light of Parker's statement that, "Woody plants, as a result of their life-form, must grow year after year in the same location and they must, therefore, be able to withstand great temperature variations in some climates. Since these sessile organisms survive

only under conditions favorable to them, they become standing indicators of the environmental conditions to any particular place" (15). Sakai (20) found that the maximum and duration of freezing resistance of Salix babylonica L. Twigs differed considerably depending on the temperature regime in a given locality. Smithberg and Weiser (25) and Flint (6) found that plants from semi-tropical origins hardened more slowly than plants from temperate origins, and so were less hardy at specific times. However, all eventually hardened sufficiently to avoid low temperature injury.

Even though Concord grape vines responded to lower temperatures of the sites by developing greater hardiness, the risk of cold injury to low site plants was still great due to temperature fluctuations in early fall and late spring. Injury could have resulted to even the most hardy vines because their lowest survival temperatures were still higher than the lowest air temperatures.

The general effects of air temperature on hardening and dehardening, as documented earlier (8, 9, 10, 11, 12) have been supported by this study. Air temperature, site, and polymorphic differences between primary and secondary buds appear to simultaneously affect hardiness in Concord grape vines. Thus in early spring when air temperature was still low enough to maintain hardiness, site differences in bud hardiness were apparent. In late

spring, however, air temperatures were high enough to permit growth of the more dominant primary bud in both sites while the secondary bud in both sites did not grow and remained hardy. It was not possible to explain intra-site hardiness differences between the primary and secondary buds which occur consistently throughout acclimation and deacclimation. They could have been due to hormonal or other regulation of certain mechanisms favoring primary bud ontogeny and maturation. The strong apical dominance of grapevines may have been operating in the dormant bud. Primary and secondary bud hardiness and productivity differences in Concord grapes have already been recognized (17, 26).

Conclusions

Air temperatures in a low, poorly air-drained Concord grape vineyard were consistently lower than in a high, well air-drained vineyard site. High and low vineyard sites may generate distinct temperature-induced microclimatic environments where differences in intra-cultivar hardiness differences were possible.

Changes in bark and bud hardiness were related to air temperature changes. Generally, bark hardiness was least modified by sudden temperature changes; secondary buds more affected and primary buds most susceptible.

Concord grape vines growing on low sites produced bark and primary and secondary buds which were hardier during acclimation and deacclimation than bark and buds from high site vines.

In a given site, living bark was hardier than secondary buds which were generally hardier than primary buds.

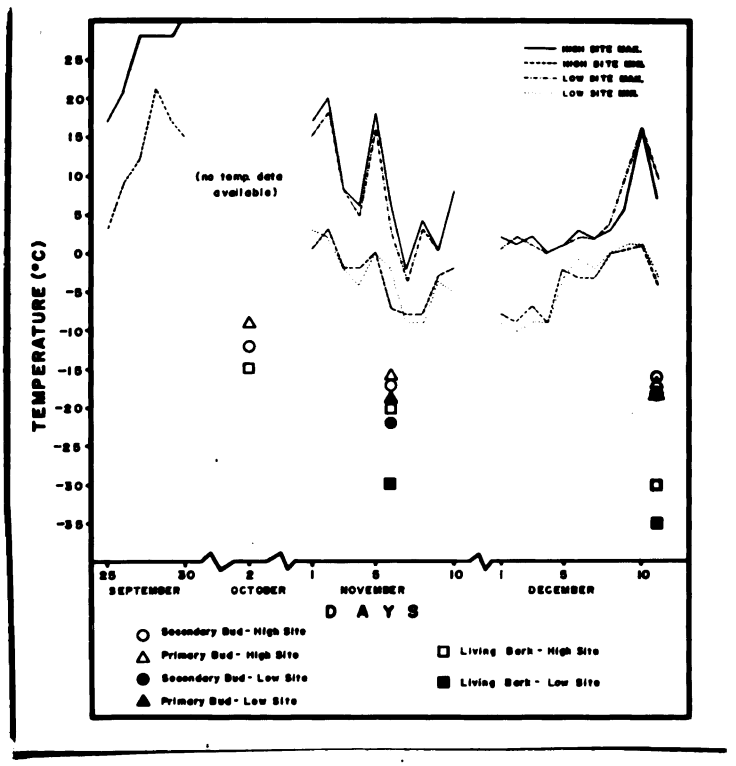
The high site microclimate induced greater bud hardiness fluctuation than did the low site microclimate.

Thus site-induced air temperature and bud differences collectively influenced hardiness patterns in Concord grape vines during the periods of acclimation and deacclimation investigated.

Table 1. Weekly mean maximum (max.) and minimum (min.) air temperatures (°C) for a high (H), well air-drained and a nearby low (L), poorly air-drained Concord grape vineyard in Van Buren Co., Michigan from fall, 1971 to spring, 1973.

Date	H-max.	L-max.	H-min.	L-min.
1971				
Nov. 1-5	14.0	12.5	0	0
" 6-10	2.5	2.0	-5.5	-6.0
Dec. 1-5	1.0	1.0	-7.0	-8.0
" 6-11	6.0	7.5	-3.0	-0.5
Fall seasonal minimum			-9.0	-10.0
1972				
Mar. 21-25	4.0	4.0	-8.0	-9.0
" 26-31	5.0	5.0	-5.5	-6.0
Apr. 1-7	5.0	6.0	-6.0	-8.5
" 8-14	13.0	13.5	-2.5	-3.0
" 15-21	16.5	16.0	3.0	2.0
" 22-30	12.5	13.0	0.5	0
Spring seasonal minimum			-14.0	-20.0
Oct. 5-11	15.0	15.5	3.5	4.5
" 12-18	9.5	9.5	-1.5	-1.5
" 19-25	11.5	9.5	3.0	0.5
Nov. 15-21	1.5	1.0	-7.0	-7.0
" 22-30	2.0	1.5	-3.5	-5.5
Dec. 5-11	-4.5	-4.5	-10.5	-12.0
" 12-18	-4.5	-4.5	-9.5	-11.5
" 19-25	0.5	0	-2.0	-3.5
Fall seasonal minimum			-17.0	-19.0
1973				
Mar. 21-25	5.0	4.0	-8.5	-9.0
" 26-31	12.5	11.0	-3.5	-2.5
Apr. 1-7	12.5	11.5	3.5	2.5
" 8-14	7.0	6.0	-5.5	-5.0
" 15-20	19.0	19.5	5.0	7.0
Spring seasonal minimum			-13.0	-14.0

Fig. 1. Acclimation of living bark, and of primary and secondary buds from balance pruned Concord grape vines in a high (elev. 277 m), well air-drained site and a low (elev. 256 m), poorly air-drained site in 1971 in Van Buren Co., Michigan. Symbols indicate lowest survival temperatures (expressed as T_{50} for buds). Daily maximum and minimum temperatures are recorded for the general vicinity, and within experimental plots for November and December.


TEMPERATURE (°C)
25
20
15
10
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-10
-15
-20
-25
-30
-35
(no temp. data available)
25
SEPTEMBER
30
2
OCTOBER
1
6
NOVEMBER
10
1
6
DECEMBER
10
D A Y S
Secondary Bud - High Site
Primary Bud - High Site
Secondary Bud - Low Site
Primary Bud - Low Site
Living Bark - High Site
Living Bark - Low Site

Figure 1

Fig. 2. Acclimation and deacclimation of living bark, and of primary and secondary buds from balance pruned Concord grape vines in a high (elev. 277 m), well air-drained site and a low (elev. 256 m), poorly air-drained site during 1971 and 1972 in Van Buren Co., Michigan. Symbols indicate lowest survival temperatures (expressed as T_{50} for buds). Daily maximum and minimum experimental plot air temperatures are recorded.

TEMPERATURE (°C)

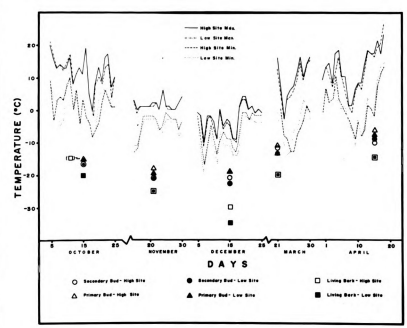
High Site Max.
Low Site Max.
High Site Min.
Low Site Min.
TEMPERATURE (°C)
10
0
-10
-20
-30
OCTOBER
NOVEMBER
DECEMBER
MARCH
APRIL
DAYS
Secondary Bud - High Site
Secondary Bud - Low Site
Living Bark - High Site
Primary Bud - High Site
Primary Bud - Low Site
Living Bark - Low Site

Figure 2

Fig. 3. Deacclimation of living bark, and of primary and secondary buds from balance pruned Concord grape vines in a high (elev. 277 m), well air-drained site and a low (elev. 256 m), poorly air-drained site in Van Buren Co., Michigan in 1972. Symbols indicate lowest survival temperatures (expressed as T_{50} for buds). Daily maximum and minimum temperatures for the general vicinity are recorded.

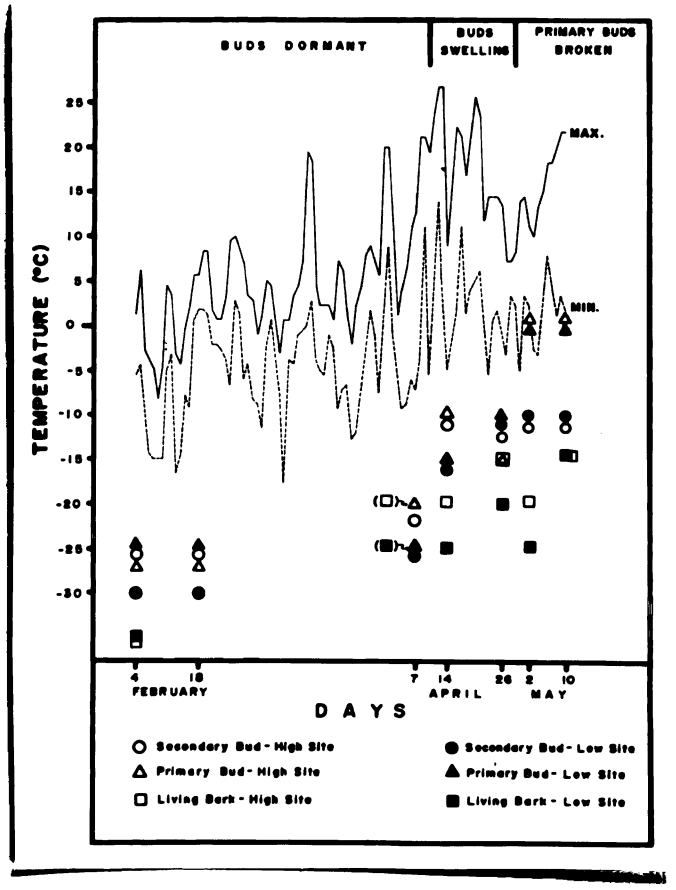
BUDS DORMANT
BUDS SWELLING
PRIMARY BUDS BROKEN
MAX.
MIN.
TEMPERATURE (°C)
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
4
18
FEBRUARY
7
14
APRIL
26
2
10
MAY
DAYS
Secondary Bud - High Site
Primary Bud - High Site
Living Bark - High Site
Secondary Bud - Low Site
Primary Bud - Low Site
Living Bark - Low Site

Figure 3

Fig. 4. Deacclimation of living bark, and of primary and secondary buds from balance pruned Concord grape vines in a high (elev. 277 m), well air-drained site and a low (elev. 256 m), poorly air-drained site in 1973 in Van Buren Co., Michigan. Symbols indicate lowest survival temperatures (expressed as T_{50} for buds). Daily maximum and minimum experimental plot air temperatures are recorded.

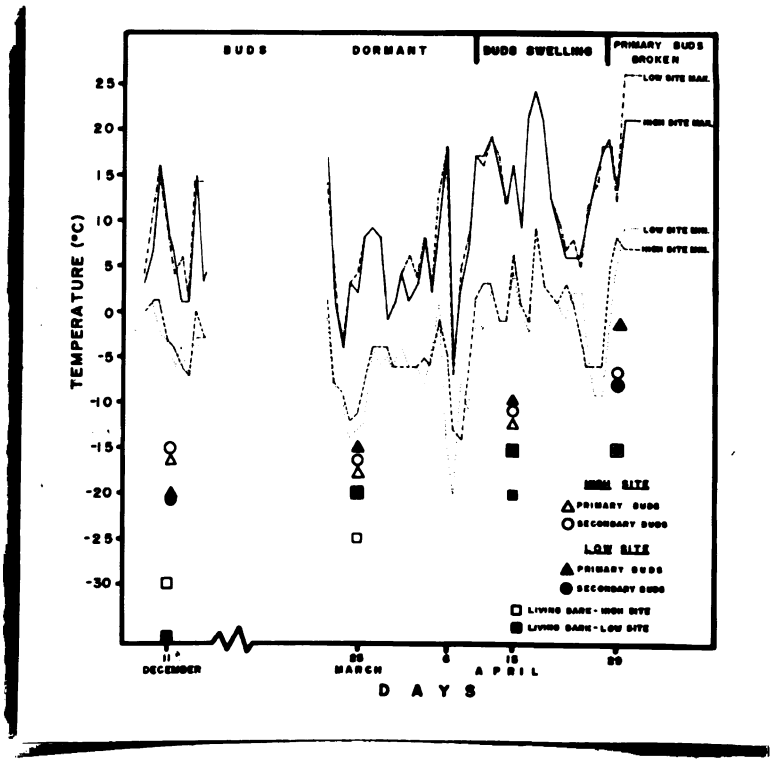
BUDS
DORMANT
BUDS SWELLING
PRIMARY BUDS BROKEN
TEMPERATURE (°C)
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
HIGH SITE
PRIMARY BUDS
SECONDARY BUDS
LOW SITE
PRIMARY BUDS
SECONDARY BUDS
LIVING BARK - HIGH SITE
LIVING BARK - LOW SITE
11
DECEMBER
29
MARCH
6
APRIL
19
29
DAYS

Figure 4

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SECTION THREE

EFFECTS OF DEFOLIATION, TRELLIS HEIGHT, AND CROPPING STRESS ON THE COLD HARDINESS OF *Vitis labrusca* L. var. Concord Vines

EFFECTS OF DEFOLIATION, TRELLIS HEIGHT, AND CROPPING STRESS ON THE COLD HARDINESS OF *Vitis labrusca* L. var. Concord Vines[1]

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Abstract

Cold hardiness of the bark and compound buds of culturally stressed Concord grape (*Vitis labrusca* L.) vines was investigated in southwestern Michigan. Results showed that defoliation, pruning severity, and cluster thinning influenced bark and bud hardiness. The effect of trellis height on bark hardiness was inconclusive but some increased hardiness was noted for low trellis buds. Complete defoliation by hand in August resulted in delayed acclimation in the fall and more rapid deacclimation in the spring. Effects of defoliation on bark and bud

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hardiness were more pronounced during the second year of treatment. Pruning severity was the most important factor influencing bark and bud hardiness in the nondefoliated plants. Field observations emphasized the importance of balance (30 + 10) pruning, as opposed to light (60 + 10) pruning for greater hardiness. Cluster thinning increased hardiness levels depressed by 60 + 10 pruning particularly when vines were defoliated. The greater sensitivity of under-pruned vines seemed to be a result of the over-production of fruit. The tertiary bud was usually as hardy or slightly hardier than the secondary bud with most treatments.

Introduction

Woody plants in a dormant condition are injured by low temperature to some extent in most winters (28), and also when early fall or spring low temperature fluctuations occur (10, 28, 29, 31, 32, 44).

Excessively low temperatures in late fall, early winter or in the spring have been associated with cold injury in grape plants (2, 3, 26, 27, 44). Low temperature stress was determined to be a limiting factor in grape production in the states of Washington (3), New York (4, 34, 37), Pennsylvania (9), and Michigan (44). Economic losses due to low temperature have been extensive in Michigan where average Concord (Vitis labrusca L.) grape production

for the past 5 years was 6046 kg/ha (19). Production in milder New York (20, 21) and Washington (6) for the same period was about 10,783 kg/ha and 16,135 kg/ha respectively.

Olien (22) pointed out that winter hardiness was a complex plant property involving many interacting factors and many types of stress. Such stress could not only be environmentally induced (11, 32, 33, 44), but also culturally induced (5, 12, 36, 37). This study was initiated to investigate the effects of hand defoliation, pruning severity, cluster thinning, and trellis height on the cold hardiness of Concord grape vines.

Materials and Methods

The Study Area

A 4.9 ha Concord grape vineyard located in Van Buren County, Michigan (T3S, R13W, Sec. 32) was selected for the study. It had a high (elev. approx. 277 m above sea level), well air-drained site with other vineyards situated to the east and south, open fields to the north and a tart cherry (Prunus cerasus L.) orchard to the west which slopes 6° downward for 210 m away from the study area. The topography of the study area is fairly homogeneous.

The grape vines were planted in 1904 on Plainfield sand (47), and have since undergone intermittant renewal. They were planted in rows of 48 vines, spaced at 2.5 m,

with 2.8 m between the rows. Two additional wires (high trellis), one about 40 cm above the other were placed directly above the top of the original trellis for the entire length of each row. The space from the top of the original trellis to the bottom additional wire was 1.5 m. The top of the original trellis was 2 m above the ground. The vines of each plant were trained onto the high trellis during the 1971 growing season by extending the trunk vertically from the low originally trellised growth. No shoots were allowed to grow in the 1.5 m space between the high and the low trellis.

Experimental Design and Sampling Procedures

Samples were taken from both the high and low trellis positions of 288 vines selected initially for uniformity in 1970. All vines were trained to an umbrella kniffen system and constituted a 2.5 ha observational plot. The plot was completely randomized and consisted of 8 treatments, with 36 vines per treatment available for sampling. One half of the treatment vines were sampled for fall hardiness, and the other half were sampled in the spring. Each treatment consisted of a combination of the three variables: defoliation, pruning severity, and cluster thinning, and are ranked in order from the least stress to the most stress as follows:

Not defoliated, 30 + 10 pruned, thinned

Not defoliated, 60 + 10 pruned, thinned

Not defoliated, 30 + 10 pruned, not thinned

Not defoliated, 60 + 10 pruned, not thinned

Defoliated, 30 + 10 pruned, thinned

Defoliated, 60 + 10 pruned, thinned

Defoliated, 30 + 10 pruned, not thinned

Defoliated, 60 + 10 pruned, not thinned

The vines were either balance pruned at 30 + 10 (17, 23) or pruned less severely at 60 + 10 during the mid-winter of 1971, 1972, and 1973. A vine was balance pruned when 30 buds were left for the first pound of current season's cane growth (prunings) removed and 10 more buds were left for each additional pound of prunings (17, 23). Designated vines were hand cluster thinned to one cluster per shoot at anthesis (around the second week of June in 1971 and 1972). Designated vines were hand defoliated (all the leaves were removed) at verasion (initiation of fruit coloring) which occurred during the third to fourth week of August in 1971, 1972, and 1973.

Hardiness evaluations were made periodically during the fall and spring of 1971-1973. Single node cane sections, cut in the mid-point of the internode, were made from the mid-portion of 10 to 20 node mature canes chosen for maturity as determined by cane color

and diameter (1, 23). The single-node samples were sealed in small plastic bags and were transported within two hours to the laboratory without elevating their temperature. The samples were then evaluated for hardiness as described below.

Hardiness Measurements

Hardiness was determined on each sampling date by subjecting the material to a controlled freezing stress (10, 42). Test samples from the field were immediately labeled, wrapped in aluminum foil, and placed into a series of vacuum flasks which were then cooled in a controlled temperature freezer at approximately 5°C per hour. Each test sample consisted of one observation from each of the 18 treatment vines. A 26-gauge copper-constantan thermocouple was inserted in the pith of one cane section in each flask to monitor sample temperature. Previous unpublished data indicate that this freezing rate allowed sufficient time for all canes to equilibrate to the same temperature as the indicator cane. Flasks were removed from the freezer at 5°C intervals and allowed to warm in the flasks to room (approx. 21°C) temperature. Bark, primary and secondary buds were tested for viability with the browning test (42). With the 5°C intervals, no differences among replicates were observed for bark hardiness, and therefore each point on a figure represents both the mean and the observed range. Bark hardiness was recorded

as the lowest survival temperature. Primary and secondary bud hardiness was determined with graphic methods to determine the temperature at which there was 50% survival (T_{50}; 29, 30). The buds were judged alive when they were all green, and dead when their center portions browned (43). The term "cane hardiness," as used in this paper, will be synonomous with bark hardiness.

Results

Seasonal descriptive differences in the hardiness of Concord bark and buds which were culturally stressed are shown in Figures 1 - 4, and are discussed below.

Bark Hardiness

Defoliation had the greatest effect on bark hardiness during both seasons evaluated (Figs. 1 and 2). Leaf removal, while causing only a moderate hardiness reduction during the first season, markedly reduced bark hardiness during the second season (Fig. 2). Hardiness losses resulting from cropping stress (light pruning seventy and no cluster thinning) and trellising were not evident during the second season. In December and March of the first season, however, light pruning of defoliated vines reduced high trellis bark hardiness (Fig. 1, Treatments G and H). During early acclimation (October 2), high trellis bark of defoliated, balance pruned vines was as hardy as bark from nondefoliated vines (Fig. 1). Bark acclimation was

favored by the high trellis position in October of the first season (Fig. 1). The high trellis position also favored bark acclimation of both nondefoliated balance pruned vines in November, and nondefoliated vines stressed by light pruning on April 29.

Low trellising favored bark hardiness only during the first season (Fig. 1) but the results were inconclusive. High trellising favored bark hardiness in December (Fig. 1) for some treatments (A, B, D).

Primary Bud Hardiness

Since the buds (particularly the primary buds) are more responsive to factors influencing hardiness than the bark (44), even small changes and fluctuations in bud hardiness can be a valid manifestation of treatment effect. Defoliation had a pronounced effect during both seasons as it did with the bark (Figs. 1 and 2). However, hardiness differences resulting from trellising and cropping stress were not as obvious during the second cold season as they were during the first.

Light pruning generally retarded bud hardiness on foliated plants in October 1971. However, hardiness was greater on plants with less fruiting stress (thinned) whether or not they had leaves (Treatments B, D, and F). Trellising and cropping stress did not appear to have an appreciable affect on bud hardiness in October of the

second season. Bud acclimation for all treatments had proceeded further by November, and hardiness was somewhat retarded as the treatment-stresses were increased (Fig. 1, Treatments A to H). Cropping stress did not influence hardiness in November of the next season and trellis height did not influence bud hardiness during October and November of either season.

During the December thaw in 1971, high trellis buds dehardened more than the low trellis buds (Fig. 1). Low trellis buds were hardiest on foliated, balance pruned vines. When the buds were at maximum hardiness in December of 1972, foliated canes with less fruiting stress had superior bud hardiness (Fig. 2, Treatment B) when they were balance pruned.

As dehardening began in late March of the first season evaluated, buds on balance pruned, foliated canes with least fruiting stress (Treatment B) were the hardiest. Buds of defoliated canes lost hardiness but, when they were balanced pruned (Treatments E and F), low trellis buds remained hardy. Both high and low trellis buds lost less hardiness when cluster thinned (Treatment H) than when fruit-stressed (Treatment G). In March of the second season, high trellis bud hardiness was favored by balance pruning on foliated vines (Treatments A and B). Cluster

thinning delayed bud dehardening on lightly pruned, foliated canes and on balance pruned, defoliated canes (Treatments D and F).

The buds had dehardened considerably by April 15 of the first season. Buds which were on low trellis, balance pruned canes retained the most hardiness (Treatments A and B). Low trellis bud dehardening was also retarded more when cluster thinning was combined with balance pruning (Treatment B). Buds from defoliated canes were killed between April 15 and April 29. In April of the second season (Fig. 2), the buds showed continued dehardening, but there were no apparent hardiness differences caused by the eight treatment combinations.

Secondary Bud Hardiness

Observations indicated that cultural practice treatments affected secondary bud hardiness during the 1971-1972, and 1972-1973 acclimation and deacclimation periods (Figs. 3 and 4).

Defoliation had a greater effect on secondary bud hardiness than any other treatment during both seasons evaluated. This effect was more pronounced during the second cold season than during the first. Bud hardiness was favored by the low trellis position in October of the first season and also, to a lesser extent, in October of the second season (Fig. 4, Treatments A to D). Light

pruning retarded bud acclimation on foliated, high trellis canes in October of the first season, and on all foliated trellising in October of the second season (Fig. 3, Treatments C and D).

Buds from all treatments had acclimated further in both 1971 and 1972 by November. Hardiness differences were slight in 1971. Cluster thinning enhanced the acclimation of defoliated buds when they were located on balance pruned vines (Treatment F). Balance pruning, and to a lesser degree cluster thinning, increased bud hardiness on foliated canes in 1972. High trellis bud hardiness was reduced in most of the treatments during the December thaw in 1971 (Fig. 3). The buds attained maximum hardiness in December of the second, and only leaf removal was observed to reduce hardiness (Fig. 4).

High trellis buds (Treatments E - H) and fruit-stressed low trellis buds (Treatment G) from the defoliated canes had begun to deacclimate by late March of the first season. Low trellis buds from balance pruned, cluster thinned canes (Treatment B) retained the most hardiness. Buds from leafed canes showed delayed deacclimation in March of the second season (Fig. 4, Treatments A - D). As in the first cold season, buds from Treatment B retained greatest hardiness during initial deacclimation. On April 15 in both 1972 and 1973, buds from the balance pruned, foliated treatments were hardiest. Balance

pruning enhanced low trellis bud hardiness among the defoliated treatments on April 15 of the first season. Buds from defoliated canes had either completely dehardened, or were dead by April 29 (Fig. 3), except those which were cluster thinned (Treatments F and H). Buds from balance pruned, foliated canes remained the hardiest. When canes were lightly pruned, low trellis buds retained more hardiness than high trellis buds (Treatments C and D).

Tertiary Bud Hardiness

Acclimation and deacclimation observations of tertiary buds during 1971-72 and 1972-73 are given in Figures 3 and 4. They indicate that tertiary bud hardiness was affected by the cultural stress treatments in a manner similar to the secondary bud responses. The tertiary bud was usually just as hardy or occasionally hardier than the secondary bud, but specific differences appear too small for practical comparison.

Discussion

Recent research has implicated leaves as the source of substances which promote hardiness in deciduous woody plants (12, 13, 39). It has been suggested that substances act as growth (hardiness) regulators (7, 11, 14, 39) and as energy sources (7, 8, 12, 16, 18, 33, 39, 41) on being translocated from the leaves to the woody tissues and buds (7, 14, 15, 40).

Whether grape leaves produce growth regulator type hardiness promoters is unknown. However, the importance of foliage for good wood maturity and hardiness has been recognized as a factor in grape culture (18, 35, 38). The defoliated and foliated high-trellis treatments investigated during the study represent extremes of maximum and minimum leaf area available for manufacturing hardiness promoting substances whether regulatory or metabolic in nature.

Regardless of mode of action, observations recorded in this paper indicate that the combined cultural stresses of leaf area loss, light pruning, and nonthinning delayed fall acclimation and caused early loss of hardiness in Concord grape vines in the spring.

Defoliation

Summer leaf removal at verasion was effective in inhibiting cold acclimation of Concord grape canes and buds in the fall, and hastening deacclimation of canes and buds in the spring. Similar results were reported by Howell and Stackhouse (12) as a result of early leaf loss from tart cherry (*Prunus cerasus* L.) trees. Fuchigami *et al.* (7) reported that container grown *Cornus stolonifera* Michx. plants which were completely defoliated on August 8 failed to acclimate and were dead by November 14 when exposed to -4°C.

Loss of leaf area by defoliation can be analogous to excess shading within the vine canopy (18). Excess shading, caused by improper vine management, could result in hardiness situations in bark and buds similar to those already described for defoliation of Concord grape vines. A reduction in cold hardiness by leaf area loss triggered losses in vine productivity, vine fruitfulness (fruit production per node), and vine size (45). When vine productivity is reduced, the vine may become over-stressed by subsequently excessive vegetative growth, resulting in loss of hardiness (35, 37).

Pruning Severity

After defoliation, pruning severity was the dominant factor influencing bark and bud hardiness in the non-defoliated plants. Light (60 + 10) pruning decreased vine size while increasing the number of nodes retained on the vine. The increase in node number increased the fruiting stress on the vine (45). Bark and buds on such a plant may not have had proper hardiness (35), either because excessive fruit depleted plant reserves, or too much vegetation retarded growth cessation in the fall.

Balance pruned (30 + 10) vines, however, had less fruiting stress than 60 + 10 pruned vines while maintaining greater vine fruitfulness (45). Also, since vine size was greater for balance pruned vines than for lightly

pruned vines, a proper balance was maintained on the vine between fruit production and vegetative growth. This condition enhanced the potential for maximum hardiness.

Cluster Thinning

Observations from this study indicate that cluster thinning occasionally raised hardiness levels lowered by light (60 + 10) pruning particularly when the vines were defoliated. Since developing fruit clusters compete successfully for vine reserves (24, 25, 46, 48), their removal would make additional reserves available for more effective bark and bud maturation and thus for greater hardiness.

Trellis Height

Solid trends in bark and bud hardiness resulting from trellis height were absent. However, mid-winter (1971) and early spring (1972) bud hardiness was occasionally favored by the low trellis. This could be most reasonably explained as follows. A significant air temperature gradient was present from the top of the high trellis to the ground. Field measurements have indicated that air temperatures at the top of a conventional 2 m high trellis can be as much as 20°F warmer than at ground level on a still, cold night (data not shown). Buds consistently exposed to low temperatures would be more hardy than buds exposed to higher temperatures (43).

It is reasonable to suggest that viticultural stresses such as leaf area loss (defoliation; shading), light pruning, and a heavy fruit load on the vine acted together to influence vine cold hardiness. Since vineyard practices influence vine productivity (45), and since productivity and cold hardiness can be directly associated, vine hardiness must ultimately be affected. Good hardiness and productivity complimented each other and resulted in well-balanced vines (vegetative growth vs. fruit production) with optimal cropping conditions and fruit quality.

Fig. 1. Acclimation and deacclimation patterns of living bark and primary buds of Concord grape (Vitis labrusca L.) vines from October 2, 1971 to April 29, 1972. Values indicate lowest survival temperatures (expressed as T_{50} for buds).

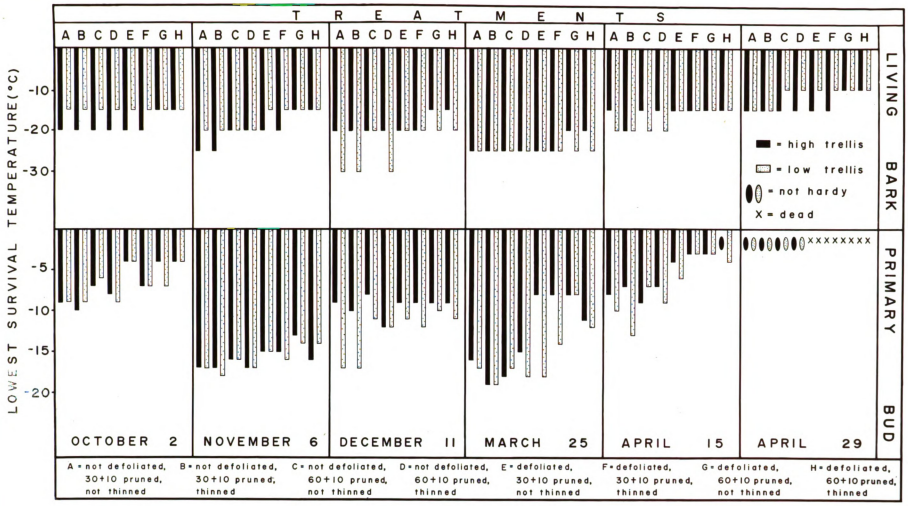
TREATMENTS
A B C D E F G H
LOWEST SURVIVAL TEMPERATURE (°C)
-10
-20
-30
-5
-10
-15
-20
LIVING BARK
PRIMARY BUD
= high trellis
= low trellis
= not hardy
X = dead
XXXXXXXX
OCTOBER 2
NOVEMBER 6
DECEMBER 11
MARCH 25
APRIL 15
APRIL 29
A = not defoliated, 30+10 pruned, not thinned
B = not defoliated, 30+10 pruned, thinned
C = not defoliated, 60+10 pruned, not thinned
D = not defoliated, 60+10 pruned, thinned
E = defoliated, 30+10 pruned, not thinned
F = defoliated, 30+10 pruned, thinned
G = defoliated, 60+10 pruned, not thinned
H = defoliated, 60+10 pruned, thinned

Figure 1

Fig. 2. Acclimation and deacclimation patterns of living bark and primary buds of Concord grape (Vitis labrusca L.) vines from October 5, 1972 to April 15, 1973. Values indicate lowest survival temperatures (expressed as T_{50} for buds).

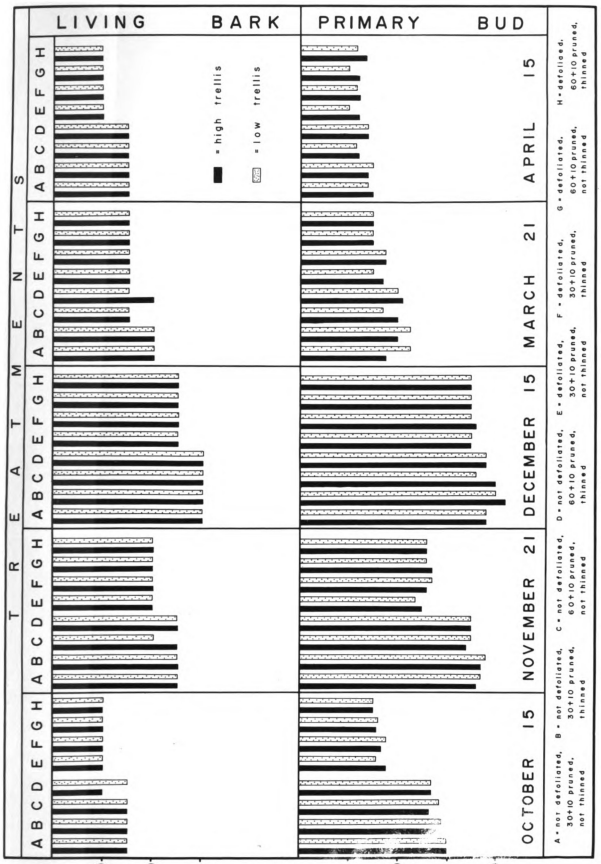
LIVING BARK
PRIMARY BUD
TREATMENTS
A B C D E F G H
= high trellis
= low trellis
LOWEST SURVIVAL TEMPERATURE (°C)
-10
-20
-30
-5
-10
-15
-20
OCTOBER 15
NOVEMBER 21
DECEMBER 15
MARCH 21
APRIL 15
A = not defoliated, 30+10 pruned, not thinned
B = not defoliated, 30+10 pruned, thinned
C = not defoliated, 60+10 pruned, not thinned
D = not defoliated, 60+10 pruned, thinned
E = defoliated, 30+10 pruned, not thinned
F = defoliated, 30+10 pruned, thinned
G = defoliated, 60+10 pruned, not thinned
H = defoliated, 60+10 pruned, thinned

Figure 2

Fig. 3. Acclimation and deacclimation patterns of secondary and tertiary buds of Concord grape (Vitis labrusca L.) vines from October 2, 1971 to April 29, 1972. Lowest survival temperatures are expressed as T_{50}.

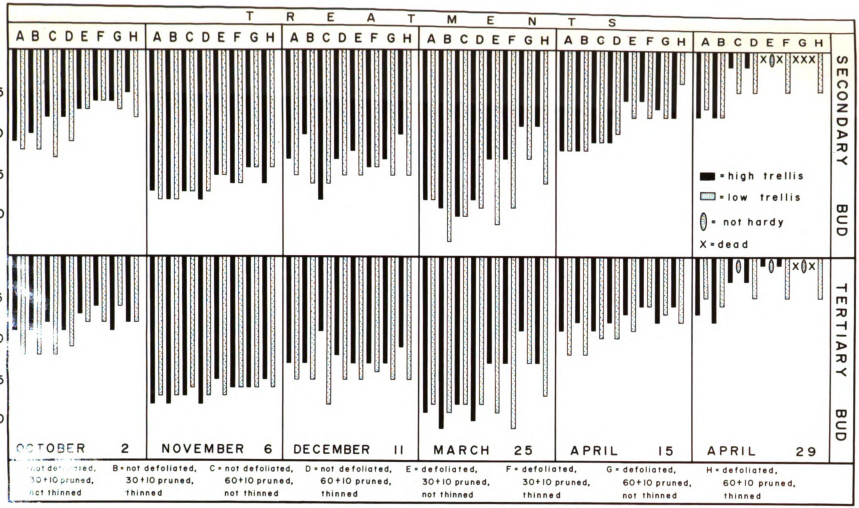
TREATMENTS
A B C D E F G H
SECONDARY BUD
TERTIARY BUD
LOWEST SURVIVAL TEMPERATURE (°C)
-5
-10
-15
-20
= high trellis
= low trellis
= not hardy
X = dead
OCTOBER 2
NOVEMBER 6
DECEMBER 11
MARCH 25
APRIL 15
APRIL 29
A = not defoliated, 30+10 pruned, not thinned
B = not defoliated, 30+10 pruned, thinned
C = not defoliated, 60+10 pruned, not thinned
D = not defoliated, 60+10 pruned, thinned
E = defoliated, 30+10 pruned, not thinned
F = defoliated, 30+10 pruned, thinned
G = defoliated, 60+10 pruned, not thinned
H = defoliated, 60+10 pruned, thinned

Figure 3

Fig. 4. Acclimation and deacclimation patterns of secondary and tertiary buds of Concord grape (Vitis labrusca L.) vines from October 5, 1972 to April 15, 1973. Lowest survival temperatures are expressed as T_{50}.

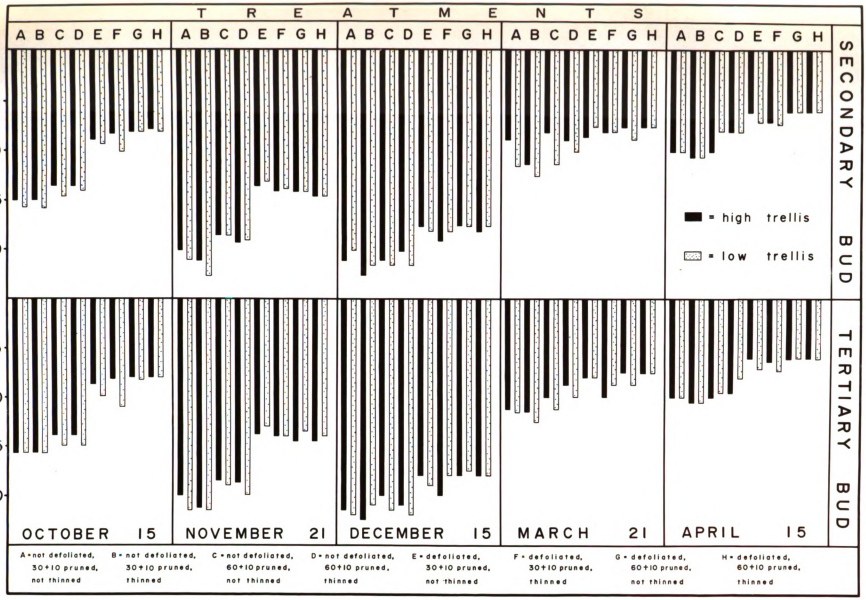
TREATMENTS
A B C D E F G H
SECONDARY BUD
TERTIARY BUD
LOWEST SURVIVAL TEMPERATURE (°C)
-5
-10
-15
-20
= high trellis
= low trellis
OCTOBER 15
NOVEMBER 21
DECEMBER 15
MARCH 21
APRIL 15
A - not defoliated, 30+10 pruned, not thinned
B - not defoliated, 30+10 pruned, thinned
C - not defoliated, 60+10 pruned, not thinned
D - not defoliated, 60+10 pruned, thinned
E - defoliated, 30+10 pruned, not thinned
F - defoliated, 30+10 pruned, thinned
G - defoliated, 60+10 pruned, not thinned
H - defoliated, 60+10 pruned, thinned

Figure 4

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SECTION FOUR

EFFECTS OF DEFOLIATION AND CROPPING STRESS ON THE SIZE AND PRODUCTIVITY OF *Vitis labrusca* L. var. Concord Vines

EFFECTS OF DEFOLIATION AND CROPPING STRESS ON THE SIZE AND PRODUCTIVITY OF *Vitis labrusca* L. var. Concord Vines[1]

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Abstract

Vine size and productivity of culturally stressed Concord (*Vitis labrusca* L.) grape vines were investigated in southwestern Michigan from 1971 to 1973. Defoliation, pruning severity, and cluster thinning individually and collectively influenced vine size, and productivity as measured by yield, fruitfulness, berry size, soluble solids, clusters per vine, clusters per node, total vine sugar, and cluster size. Leaf removal caused a reduction in all factors of productivity, particularly total vine sugar (59%), yield (50%), fruitfulness (37%), clusters per node

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(23%), soluble solids (22%), and vine size (22%). Light (60 + 10) pruning increased the number of nodes retained which decreased vine fruitfulness. Yields were initially higher from lightly pruned vines than from balance (30 + 10) pruned vines even though fruitfulness was low. Later, however, balance pruned vines yielded as much fruit than lightly pruned vines while still maintaining a higher level of fruitfulness and total vine sugar. Although cluster size and the number of nodes per vine increased on cluster thinned vine, fruitfulness, cluster number per node, and total vine sugar was reduced. Defoliation and cluster thinning interacted most frequently to lower vine productivity.

Introduction

A vineyard will give highest returns only if it can produce maximum amounts of fruit of the desired quality over a long period of time (9). In order to achieve this goal, the various cultural stresses affecting vine growth and productivity must first be examined. Previous studies have demonstrated certain effects that cultural practices can have on vine size, productivity (yield and fruit quality), and cold hardiness. The reduction of functional leaf area by defoliation, thus simulating vine shading, has resulted in reduced vine productivity (9). Pruning severity has been investigated in relation to vine size

(1, 2, 5, 16, 17, 21) and vine productivity (5, 7, 16, 17, 21). The relationship of cluster thinning to vine size (1, 17) and productivity (1, 3, 12, 13, 17) has also been investigated. Shaulis and Steel (17) investigated the effect of pruning severity, cluster thinning, rootstock, and weed control on vine size and certain productivity factors of Concord grape vines. However, information regarding the combined effects of leaf removal and cropping stress on vine size and productivity incomplete.

Cold hardiness of Concord grape buds was reduced by defoliation and cropping stress (20). But cold hardiness and vine productivity were closely associated when they were influenced by cultural stress, and the response was synergistic (20).

Cultural stresses induced by vineyard management techniques could influence the vine size and productivity of grape vines, either indirectly by reducing vine hardiness, or by the direct reduction of yield and fruitfulness. This study was initiated to investigate the individual and combined effects of hand defoliation, pruning severity, and cluster thinning on the size and productivity of Concord (Vitis labrusca L.) grape vines.

Methods and Materials

The Study Area

Two 4.0 ha Concord grape vineyards located in Van Buren County, Michigan (T3S, R13W, Sec. 32) were selected

for the study. The first vineyard is located on a high (elev. approx. 277 m above sea level) site. It is surrounded by other vineyards situated to the east and south, and open fields to the north. The second vineyard is located on a low (elev. approx. 256 m above sea level) site directly west of the first site. It occupies a depression surrounded on the south and west by other vineyards and on the north by open fields. The two study sites are approximately 210 m apart, separated by a 6° slope containing a tart cherry (Prunus cerasus L.) orchard. The high site topography is fairly homogeneous while the low site tapers off gently into a pocket at the southwest corner.

The grape vines on both sites were planted in 1904 on Plainfield sand (22), and have since undergone intermittant renewal. They were planted rows of 48 vines, spaced at 2.5 m, with 2.8 m between the rows.

Experimental Design and Sampling Procedures

Fruit samples and vine size data were obtained from 288 vines which were selected for uniformity in each site in 1970. The vines were trained to umbrella kniffen and constituted a 2.5 ha experimental plot at each site. Each plot was designed independently as a randomized block experiment with 6 blocks. There were 8 treatments per block and 6 vines were used for each treatment. Each

treatment consisted of a combination of the three variables: defoliation, pruning severity, and cluster thinning and are ranked in order from the least to the most treatment stress as follows:

Not defoliated, 30 + 10 pruned, thinned
Not defoliated, 60 + 10 pruned, thinned
Not defoliated, 30 + 10 pruned, not thinned
Not defoliated, 60 + 10 pruned, not thinned
Defoliated, 30 + 10 pruned, thinned
Defoliated, 60 + 10 pruned, thinned
Defoliated, 30 + 10 pruned, not thinned
Defoliated, 60 + 10 pruned, not thinned

The vines were either balance pruned at 30 + 10 or pruned less severely at 60 + 10 during the mid-winter of 1971, 1972, and 1973. A vine was balance pruned when 30 buds were left for the first pound of current cane growth removed (prunings), and 10 more buds were left for each additional pound of removed prunings (6, 10). Designated vines were cluster thinned by hand to one cluster per shoot at anthesis (around the second week in June for all three years). Designated vines were completely defoliated by hand at verasion (initiation of fruit coloring) which occurred during the third to fourth week of August in 1971, 1972, and 1973.

Main effects (the effect of any single variable on vine size and productivity) and treatment effects (the combined effects of two or more interacting variables) were evaluated by means of a factorial analysis of the variance by means of individual degrees of freedom (18). The means were compared using the Tukey statistic (18). Results generated from the high site experiment were analyzed independently from the low site results. Vine measurements for each experiment were made at harvest time (late September to early October) in 1971, 1972, and 1973 for the following factors involving vine productivity (17):

A. Yield of fruit in Kg per vine

B. The percent soluble solids content of the fruit

C. Berry size (g per berry)

D. The number of clusters per vine

E. The number of nodes per vine

The vine size in each experiment was measured as the amount of cane prunings kg per vine (3, 5, 17, 21) obtained during the winter of 1971, 1972, and 1973. The number of nodes retained (5, 17) after the vines were either balance (30 + 10) pruned or more lightly (60 + 10) pruned was also recorded. Vine fruitfulness was expressed as the kg of fruit produced per node retained, and calculated as follows.

$$\text{Fruitfulness} = \frac{\text{Yield (kg)}}{\text{Number of nodes retained}}$$

Total vine sugar (kg sugar per vine) was determined from the soluble solids of the fruit and vine yield as follows:

$$\text{kg sugar} = \frac{[\text{soluble solids}]\ [\text{yield (Kg)}]}{100}$$

The number of clusters per node were calculated as follows:

$$\text{No. clusters/node} = \frac{\text{No. clusters per vine}}{\text{No. nodes per vine}}$$

Cluster size (g per cluster) was calculated as follows:

$$\text{Cluster size} = \frac{[\text{Yield (Kg)}]\ [1000]}{\text{No. clusters per vine}}$$

The number of berries per cluster were determined as follows:

$$\text{No. berries/cluster} = \frac{\text{Cluster size (g)}}{\text{Berry size (g)}}$$

Results

The effects of defoliation, pruning severity, and cluster thinning on vine size and productivity from both the high and the low experimental plots in 1971, 1972, and 1973 are shown in Tables 1 - 6. Only those results which were statistically significant have been mentioned.

Vine Size and Nodes Retained

Vine size was not influenced by defoliation and cropping stress in 1971. The number of nodes retained in 1971 was not affected by defoliation and fruiting stress, but was higher on the lightly (60 + 10) pruned vines (Table 1). While both leaf removal and cropping stress reduced the size of high site vines in 1972, only leaf removal reduced vine size in the low site (Table 2). Defoliation reduced the number of nodes retained in both sites in 1972, but the number of retained nodes on prune-stressed and cluster thinned vines was higher. Defoliation reduced vine size again in 1973. Cropping stress affected vine size only in the low site where cluster thinned vines were larger (Table 3). Defoliation and light pruning reduced the number of retained nodes again in 1973, but fruiting stress had no effect. Low site vines were generally bigger than high site vines in 1971 and 1972. But this was reversed in 1973.

Yield

Fruit production was reduced by leaf removal in all three years (Tables 4, 5, and 6). However, light pruning increased fruit production in 1972. Treatment effects were evident in 1972. The 1972 high site yield was greater from lightly pruned vines than from balance pruned vines when the leaves were retained (Table 5).

Upon defoliation, the yield declined sharply for both balance pruned and lightly pruned vines, but the latter still produced a higher yield (Fig. 1). On the low site in 1972, the yield was greater from nonthinned vines than from thinned vines. The yield from nonthinned vines declined more when the leaves were removed than it did when the vines were thinned (Figs. 2 and 3).

Although light pruning produced higher yields in 1973, the differences were not significant (Table 6). Both leaf removal and cluster thinning decreased yield as they did in 1972. Treatment effects in 1973 revealed that high and low site yields were influenced by defoliation and cluster thinning as they were in 1972, except that nonthinned vines retained higher yields even when defoliated (Figs. 4 and 5).

We observed that low site yields were generally higher than high site yields in 1971 and 1972, but lower than high site yields in 1973.

Fruitfulness and Clusters Per Node

Leaf removal and light pruning reduced vine fruitfulness (kg fruit per node) and cluster number per node in 1971 (Table 4) and 1972 (Table 5). Fruitfulness was greater when the vines were not cluster thinned (Tables 4 and 5; Fig. 6). When the leaves were removed, however, fruitfulness declined sharply for both thinned and

nonthinned vines, but still remained greater for the nonthinned vines. Results in 1973 were similar to those obtained in 1971 and 1972, except that pruning severity had no effect on the number of clusters per node. A treatment effect on fruitfulness involving defoliation and cluster thinning as occurred in 1972 also occurred in 1973 (Fig. 7).

The number of clusters per node was greater in 1972 from nonthinned vines than from thinned vines when they were not defoliated. Upon defoliation, clusters per node declined more for nonthinned vines than for thinned vines, but still remained the greater of the two (Fig. 3).

High site vine fruitfulness was generally lower than low site vine fruitfulness in 1971 and 1972, but high site vines generally had more fruit per node than low site vines in 1973. Vine fruitfulness generally increased from 1971 to 1972, but no additional increases were evident in 1973.

Cluster Number and Size

Defoliation had no effect on cluster number in 1971 (Table 4), but cluster size was reduced (low site only). Light pruning increased cluster number as expected, but decreased cluster size (Table 4). Cluster size was increased by balance pruning (low site only), while cluster number was decreased. In 1972, leaf removal caused a

reduction in cluster number, but had no effect on cluster size (Table 5). By 1973, however, leaf removal had reduced the cluster size (Table 5). The cluster number was similarly affected (as in 1972). Light pruning reduced cluster size in 1972, (high site vines only) while increasing cluster number (Table 5). Cluster number and size response from vines stressed by cropping in 1973 was similar to the response from the first year evaluated.

Leaf removal and cluster thinning interacted to influence the cluster number of low site vines in 1972, and of both high and low site vines in 1973. The number of clusters was much greater on nonthinned than on thinned vines for the nondefoliated plants in 1972. Cluster production, however, declined on both nonthinned and thinned vines when the leaves were removed. In addition, nonthinned vines showed a much greater cluster number decline than thinned vines (Fig. 8). Leaf removal and cluster thinning had a similar effect on cluster number in 1973 as they did in 1972, except that the cluster number on defoliated vines remained greater on nonthinned vines than on thinned vines (Figs. 9 and 10). On high site vines in 1972, leaf removal and pruning severity had a combined effect on cluster number. The cluster number from nondefoliated vines was greater than from defoliated vines when the vines were balance pruned (Fig. 11). However, when the vines were lightly pruned, the number of

clusters on nondefoliated vines greatly increased, while those on defoliated vines increased only slightly.

Leaf removal and cluster thinning also interacted to determine cluster size of high site vines in 1973. Cluster size on nondefoliated vines was greater when they were thinned (Fig. 12). When the vines were defoliated, cluster size decreased more on nonthinned vines than on thinned vines.

Vine Sugar

Leaf removal decreased the sugar-yield/vine of vines from both sites in all three years evaluated (Tables 4, 5, and 6). Light pruning increased the sugar from vines from both sites in 1971, but only from high site vines in 1972 (Tables 4 and 5). In 1973, vine sugar was not significantly increased by light pruning (Table 6). Vine sugar increased in all three years evaluated when fruiting stress was heavy (Tables 4, 5, and 6).

Leaf removal and cluster thinning decreased the vine sugar of high site vines in 1971, and of all vines in 1973. In 1971 and 1973, sugar was much greater from nonthinned vines than from thinned vines when the vines were not defoliated (Figs. 13, 14, and 15). However, when the leaves were removed, the vine sugar decreased more for nonthinned vines than it did for thinned vines.

Pruning severity combined with leaf removal to affect high site vine sugar in 1972. Lightly pruned vines had more total sugar than balance pruned vines when they had leaves. When the vines were defoliated, however, the vine sugar of both 30 + 10 and 60 + 10 pruned vines was greatly reduced (Fig. 16).

Berry Size and Number of Berries Per Cluster

Both defoliation and fruiting stress reduced the berry size of low and high site vines in 1971 (Table 4). Berry size was also reduced by light pruning in 1971, but only on the low site vines. Leaf removal significantly increased berry number per cluster in 1971 (Table 1). but decreased it in 1973 (Table 3). Both balance pruning and cluster thinning increased the number of berries per cluster in 1971 and again in 1973. There was no effect in 1972 (Table 2).

Defoliation reduced berry size at both sites in 1972, but pruning severity combined with leaf removal to decrease the berry size of high site vines. Berry size was greater when balance pruned vines were not defoliated. However, when the vines were lightly pruned, berries from the nondefoliated vines showed a sharp size decrease (Fig. 17).

Leaf removal and cluster thinning combined to reduce berry size in 1973 (Table 6). Berries from high

site, nondefoliated vines were about the same size for thinned vines as for nonthinned vines (Fig. 18). But when the vines were defoliated, berry size was reduced much less when they were thinned than when they were not thinned.

Pruning severity effects also combined with the effects of fruiting stress to reduce berry size. Berry size was greater in 1973 when high site, balance pruned vines were thinned (Fig. 19). However, when the vines were lightly pruned, berries from the thinned vines showed only a slight size increase. At the same time, berries from the lightly pruned, nonthinned vines decreased in size.

Cluster thinning and leaf removal effects interacted to determine the number of berries per cluster in 1973 (Fig. 20). When the vines were not defoliated the number of berries per cluster was higher for thinned vines than for nonthinned vines. When the vines were defoliated, the number of berries per cluster for thinned vines declined only slightly, while the berry number per cluster for the nonthinned vines declined greatly.

Soluble Solids

Only leaf removal markedly reduced the percent of sugar in the fruit of high site vines in 1971 (Table 4). Leaf removal reduced fruit solids again in 1972 and in 1973 (Tables 5 and 6). Pruning and fruiting stress also

caused a reduction of fruit solids in 1972, as demonstrated by the lightly pruned, high site vines and the nonthinned, low site vines (Table 5).

The reduction of fruit solids from defoliated, high site vines in 1973 was also determined by pruning effects. The fruit solids of high site, nondefoliated vines was nearly the same for both balance pruned and lightly pruned vines. However, when the vines were defoliated, the fruit solids of lightly pruned vines decreased more than the fruit solids of balance pruned vines (Fig. 21).

Discussion

Leaf removal, pruning severity, and cluster thinning individually and collectively affected Concord grapevine size and productivity during the years evaluated. Some productivity differences which were not apparent during the first year appeared in 1972 and 1973. In high site vines, for example, defoliation had no effect on vine fruitfulness in 1971, but the fruitfulness of nondefoliated vines was significantly higher than the fruitfulness of defoliated vines in 1972, and again in 1973.

High and low site differences in productivity were not specifically compared. One possible explanation for the generally greater productivity in the low site in 1971 and 1972 may be less bud injury due to greater cold

hardiness (19). When severe freezes occur, however, the low site vines become susceptible to low temperature injury when air drainage is poor. Occurrences of such freezes in the late spring of 1973 were partially responsible for the general decline in low site vine productivity evident in 1973.

Defoliation

Leaf removal caused a reduction in all factors of productivity from 1971 to 1973 regardless of site. The average reduction in yield due to complete defoliation in 1972 and in 1973 was 50%. Other significant reductions in productivity due to defoliation were 37% for fruitfulness (yield/node), and 23% for clusters per node. In 1971, we found that the number of berries per cluster was significantly greater for defoliated vines than for non-defoliated vines. This was contrary to the findings of May et al. (9), who found that the number of berries per cluster decreased sharply upon defoliation. However, they were working with "Sultana" vines rather than "Concord." Interspecific differences (V. vinifera vs. V. labrusca) as well as differences in experimental procedures can account for the differing results. They (9) defoliated 4 to 6 weeks after anthesis at about the time the berries enter the lag phase of growth (4). They also reported the severity of productivity decline increased with

increased levels of defoliation (by removal of the non-fruiting shoots and defoliation of fruiting shoots). Later (1973), however, our results showed that a trend toward lower berry number for clusters of defoliated vines was significantly evident.

Next to yield, the most striking reduction in productivity due to defoliation was for total vine sugar (59%) which is the product of soluble solids and yield. May et al. (9) reported that on "Sultana" vines, vine fruitfulness (yield/node) and clusters per node were the best measurements of the defoliation effect, but primarily because they had found a significant drop in the number of berries per cluster.

While our results showed a significant reduction in soluble solids (22%) with loss of leaf area, such was not generally the case in the "Sultana" vine (8, 9, 15).

Our results demonstrated that defoliation significantly reduced "Concord" vine size by about 35%, while May et al. (9) reported a statistically nonsignificant vine size reduction of 23% when "Sultana" vines were defoliated. Shaulis and May (15) also reported an increase in vine size with a restricted canopy (increased shading) for "Sultana" vines, and argued that increased growth occurred in shaded canopies due to decreased fruitfulness. They had previously demonstrated (17) with "Concord" vines that a reduction of fruitfulness induced increased vine growth.

Shaulis et al. (14) had previously found, however, that the vine size of umbrella-trained "Concord" vines (10 nodes/cane) with their own roots was 10% less than the size of vines trained on the more exposed Double Curtain system with the same number of nodes per cane. Moreover, May's reported vine sizes occurred while obtaining an 81% decrease in fruitfulness due to defoliation (9).

Since the physiological consequences of leaf removal are ultimately associated with the reduction of leaf area exposed to light, internal vine shading could also cause a reduction of vine productivity in the same manner as defoliation (9). An earlier study by May and Antcliff (8) indicated the productivity of "Sultana" vines in Australia was reduced by shading if it occurred between mid-November and December. Development of the Double Curtain system at Geneva, New York for training "Concord" vines (14) increased yields by increasing the exposed leaf area. More recently, Shaulis and May (15) found that the productivity of "Sultana" vines was reduced by shading induced by a crowded (6 ft.) canopy.

Pruning Severity

Our data showed that light (60 + 10) pruning increased the number of nodes retained on the vine thereby decreasing fruitfulness, and in 1971 and in 1972, increasing yield and vine sugar. Initially, increased node

number directly caused higher yields even when fruitfulness was low. By 1973, it became evident that lightly pruned vines with a high node number and low fruitfulness had declined in yield and vine sugar to the point where they were no longer different from balance pruned vines, where yield was still increasing. Thus, balance pruned vines can yield as much fruit and total vine sugar as lightly pruned vines, while still maintaining a higher level of fruitfulness. Balance pruned vines can maintain greater vine size (pruning weight). Kimball and Shaulis (5) observed that declining exposure of leaf surface as vine size increases is a valid basis for the practice of balance pruning. It has been shown that improperly pruned vines were less productive because the amount of vegetative growth relative to fruit production was unbalanced (11, 16, 21).

The greater cluster size and greater number of clusters per node for balance pruned vines (as opposed to lightly pruned vines) observed in 1972 and in 1973 is in agreement with results obtained by Tompkins and Shaulis (21), and Shaulis and Steel (17).

Cluster Thinning

Early workers (3, 11, 12, 13, 17) have demonstrated that cluster thinning reduces the yield of grape vines. Partridge (11) and Ragland (12) argued that this

disadvantage would have been overcome for "Concord" vines by the large increase in cluster size, especially if the vines were "long pruned" (11). This seems unreasonable in the light of our results. They show that although the cluster size and number of nodes per vine increased with cluster thinning, the fruitfulness and number of clusters per node of nonthinned vines was greater for all years evaluated. It is unlikely that a lighter pruning severity (long pruning) would improve the situation, as our data indicate that fruitfulness and number of clusters per node are lower for lightly pruned vines than for balance pruned vines. The results further indicate the infeasibility of cluster thinning "Concord" grape vines, as total vine sugar was consistently lower for thinned vines than for non-thinned vines.

Treatment Effects

Defoliation and cluster thinning interacted most frequently to influence productivity. Greater rates of productivity decline were enhanced by a combination of more than one severe stress such as nonthinning or light pruning and leaf removal.

Table 1. Productivity and vine size of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1971. Values are main effect means on a per vine basis.

Site	Variable	Vine Size (Kg)	No. Nodes Retained	No. Clusters /node	No. Berries /cluster
HIGH	Not Defoliated	1.41	62.6	1.92	30.3
	Defoliated	1.39	62.7	1.30	34.1*
	30 + 10 Pruned	1.38	50.0	1.99*	32.5
	60 + 10 Pruned	1.42	73.3*	1.23	31.8
	Not Thinned	1.36	61.4	1.76*	30.6
	Thinned	1.44	63.8	0.96	33.8*
LOW	Not Defoliated	1.49	66.79	1.46	31.3*
	Defoliated	1.53	67.90	1.42	28.6
	30 + 10 Pruned	1.61*	55.34	1.47	31.4*
	60 + 10 Pruned	1.40	79.35*	1.41	28.4
	Not Thinned	1.49	66.93	1.96*	27.6
	Thinned	1.53	67.77	0.92	32.3*

* = main effect difference @ 5% level of significance.

Table 2. Productivity and vine size of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1972. Values are main effect means on a per vine basis.

Site	Variable	Vine Size (Kg)	No. Nodes Retained	No. Clusters /node	No. Berries /cluster
HIGH	Not Defoliated	1.39*	65.2*	1.43*	37.3
	Defoliated	1.13	58.3	0.98	38.5
	30 + 10 Pruned	1.34*	48.8	1.26	40.6*
	60 + 10 Pruned	1.18	74.7*	1.15	35.2
	Not Thinned	1.14	59.7	1.46*	36.0
	Thinned	1.38*	63.8*	0.96	39.8
LOW	Not Defoliated	1.23*	60.3*	1.82#	38.0
	Defoliated	0.99	55.6	0.92	43.0
	30 + 10 Pruned	1.15	45.7	1.55*	40.3
	60 + 10 Pruned	1.06	70.3*	1.19	40.7
	Not Thinned	1.03	55.8	1.62#	39.5
	Thinned	1.18	60.1*	1.13	41.5

* = main effect differences @ 5% level of significance.

= main effect differences @ 5% level of significance and defoliation x cluster thinning (Fig. 3).

Table 3. Productivity and vine size of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1973. Values are main effect means on a per vine basis.

Site	Variable	Vine Size (Kg)	No. Nodes Retained	No. Clusters /node	No. Berries /cluster
HIGH	Not Defoliated	1.64*	65.6*	1.53*	37.2#
	Defoliated	0.83	48.2	1.31	33.6
	30 + 10 Pruned	1.34	47.3	1.46	38.4*
	60 + 10 Pruned	1.13	66.5*	1.38	32.5
	Not Thinned	1.18	54.3	1.84*	31.8
	Thinned	1.29	59.4	1.00	39.0#
LOW	Not Defoliated	1.39*	61.6*	1.13*	45.1
	Defoliated	0.65	45.1	0.77	47.9
	30 + 10 Pruned	1.11	42.9	0.98	50.7*
	60 + 10 Pruned	0.93	63.8*	0.92	42.3
	Not Thinned	0.90	51.2	1.14*	43.9
	Thinned	1.14*	55.5	0.76	49.1*

* = main effect difference @ 5% level of significance.

= main effect difference @ 5% level of significance and defoliation x cluster thinning interaction (Fig. 20).

Table 4. Productivity and vine size of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1971. Values are main effect means on a per vine basis.

Site	Variable	Yield (Kg)	Fruit (Kg/node)	Soluble Solids	Sugar (Kg)	Cluster Size (g)	Berry Size (g)	No. Clusters
HIGH	Not Defoliated	7.88	0.13	17.1*	1.34#	96.0	3.17*	86.6
	Defoliated	7.75	0.13	13.3	1.03	102.2	2.99	78.5
	30 + 10 Pruned	7.09	0.14*	15.3	1.07	100.6	3.09	74.4
	60 + 10 Pruned	8.54*	0.12	15.1	1.31*	97.6	3.07	90.8*
	Not Thinned	9.56*	0.16*	15.0	1.45#	92.8	3.03	106.0*
	Thinned	6.07	0.10	15.4	0.93	105.3*	3.13*	59.1
LOW	Not Defoliated	8.93*	0.14*	17.1*	1.52*	96.6*	3.09*	96.4
	Defoliated	7.52	0.11	13.3	1.00	84.1	2.94	95.7
	30 + 10 Pruned	7.38	0.14*	15.3	1.13	96.1*	3.05*	80.4
	60 + 10 Pruned	9.07*	0.11	15.1	1.38*	84.6	2.98	111.7*
	Not Thinned	10.29*	0.16*	14.9	1.55*	80.9	2.93	129.8*
	Thinned	6.16	0.09	15.4*	0.97	99.8*	3.10*	62.3

* = main effect difference @ 5% level of significance.

= main effect difference @ 5% level of significance and defoliation x cluster thinning interaction (Fig. 13).

Table 5. Productivity and vine size of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1972. Values are main effect means on a per vine basis.

Site	Variable	Yield (Kg)	Fruit (Kg/node)	Soluble Solids	Sugar (Kg)	Cluster Size (g)	Berry Size (g)	No. Clusters
HIGH	Not Defoliated	10.74@	0.18*	16.9*	1.71@	120.1	3.24@	91.5@
	Defoliated	5.77	0.11	12.6	0.73	110.5	2.88	55.1
	30 + 10 Pruned	7.57	0.16*	14.5*	1.12	125.1*	3.11@	61.0
	60 + 10 Pruned	8.94	0.12	14.2	1.31@	105.4	3.00	85.6@
	Not Thinned	9.21	0.16*	14.2	1.35*	109.2	3.07	85.8*
	Thinned	7.30	0.12	14.4	1.09	121.4	3.05	60.8
LOW	Not Defoliated	12.40#	0.20#	15.3*	1.91*	119.9	3.23*	106.3#
	Defoliated	5.60	0.11	12.6	0.80	119.7	2.79	49.1
	30 + 10 Pruned	8.44	0.17*	14.0	1.32	120.7	3.02	70.7
	60 + 10 Pruned	9.56*	0.14	13.8	1.39	118.9	3.01	84.6*
	Not Thinned	10.03#	0.17#	13.8	1.55*	115.9	3.03	90.2#
	Thinned	7.97	9.14	14.1*	1.16	123.9	2.99	65.2

* = main effect differences @ 5% level of significance.

= main effect differences @ 5% level of significance and defoliation x cluster thinning (Figs. 2, 6, and 9).

@ = main effect differences @ 5% level of significance and defoliation x pruning severity interaction (Figs 1, 8, 16, and 17).

Table 6. Productivity and vine size of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1973. Values are main effect means on a per vine basis.

Site	Variable	Yield (Kg)	Fruit (Kg/node)	Soluble Solids	Sugar (Kg)	Cluster Size (g)	Berry Size (g)	No. Clusters
HIGH	Not Defoliated	10.64#	0.17#	16.5@	1.75#	113.4#	3.05#	97.3#
	Defoliated	5.34	0.12	12.2	0.65	95.7	2.82	60.0
	30 + 10 Pruned	7.67	0.16*	14.4	1.15	113.6*	2.95	68.6
	60 + 10 Pruned	8.31	0.13	14.2	1.24	95.5	2.92	88.6*
	Not Thinned	9.31#	0.17#	14.2	1.39#	92.0	2.87	99.5#
	Thinned	6.67	0.12	14.5	1.00	117.1#	3.01#	57.8
LOW	Not Defoliated	7.75#	0.14*	16.7*	1.29#	125.1	2.77	64.4*
	Defoliated	4.19	0.10	12.3	0.53	133.7	2.78	32.4
	30 + 10 Pruned	5.65	0.14*	14.6	0.87	140.6*	2.77	40.6
	60 + 10 Pruned	6.29	0.10	14.4	0.95	118.3	2.78	56.2*
	Not Thinned	6.75#	0.14*	14.4	1.02#	120.3	2.74	57.9*
	Thinned	5.19	0.10	14.6	0.79	138.5*	2.82#	38.9

* = main effect difference @ 5% level of significance.

= main effect difference @ 5% level of significance and defoliation x cluster thinning interaction (Figs. 4, 5, 7, 10, 11, 12, 14, 15, 18, and 19).

@ = main effect difference @ 5% level of significance and defoliation x pruning severity interaction (Fig. 21).

Fig. 1. The effect of defoliation and pruning severity on the yield (Kg) from high site Concord grape vines in 1972.

Fig. 2. The effect of defoliation and cluster thinning on the yield (Kg) from low site Concord grape vines in 1972.

Fig. 3. The effect of defoliation and cluster thinning on the No. clusters per node from low site Concord grape vines in 1972.

Fig. 4. The effect of defoliation and cluster thinning on the yield (Kg) from high site Concord grape vines in 1973.

Fig. 5. The effect of defoliation and cluster thinning on the yield (Kg) from low site Concord grape vines in 1973.

Fig. 6. The effect of defoliation and cluster thinning on the fruitfulness (Kg per node) of low site Concord grape vines in 1972.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Fig. 7. The effect of defoliation and cluster thinning on the fruitfulness (Kg/node) of high site Concord grape vines in 1973.

Fig. 8. The effect of defoliation and cluster thinning on the No. of clusters per vine from high site Concord grape vines in 1972.

Fig. 9. The effect of defoliation and cluster thinning on the No. of clusters per vine from low site Concord grape vines in 1972.

Fig. 10. The effect of defoliation and cluster thinning on the No. of clusters per vine from low site Concord grape vines in 1973.

Fig. 11. The effect of defoliation and pruning severity on the No. of clusters per vine from high site Concord grape vines in 1973.

Fig. 12. The effect of defoliation and cluster thinning on the cluster size (g/cluster) from high site Concord grape vines in 1973.

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Fig. 13. The effect of defoliation and cluster thinning on the total vine sugar (Kg) of high site Concord grape vines in 1971.

Fig. 14. The effect of defoliation and cluster thinning on the total vine sugar (Kg) of high site Concord grape vines in 1973.

Fig. 15. The effect of defoliation and cluster thinning on the total vine sugar (Kg) of low site Concord grape vines in 1973.

Fig. 16. The effect of defoliation and pruning severity on the total vine sugar (Kg) of high site Concord grape vines in 1972.

Fig. 17. The effect of defoliation and pruning severity on the berry size (g) from high site Concord grape vines in 1972.

Fig. 18. The effect of defoliation and cluster thinning on the berry size (g) from high site Concord grape vines in 1973.

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

Fig. 19. The effect of pruning severity and cluster thinning on the berry size (g) from low site Concord grape vines in 1973.

Fig. 20. The effect of defoliation and cluster thinning on the No. of berries per cluster from high site Concord grape vines in 1973.

Fig. 21. The effect of defoliation and pruning severity on the soluble solids of the fruit of high site Concord grape vines in 1973.

Figure 19

Figure 20

Figure 21

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SECTION FIVE

In Situ DESTRUCTION OF DORMANT CONCORD GRAPE PRIMARY BUDS WITHOUT SECONDARY BUD KILL

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In Situ Destruction of Dormant 'Concord' Grape Primary Buds Without Secondary Bud Kill[1]

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Abstract. **Field death of dormant primary uds of *Vitis labrusca* L. cv. Concord may be fectively simulated by *in situ* puncture with 1 aluminum needle super-cooled by liquid 2. This allows the subsequent development f the secondary buds for studies of their owth and productivity.**

A 'Concord' grape node contains a ompound bud, comprised of individual imary, secondary, and tertiary buds ig. 1). The primary bud is more oductive and less hardy than the secondary bud during periods of acclimation and deacclimation (1, 2, 4) and is thus more susceptible to low temperature injury in the field (1, 6).[2] When the primary bud is killed, the secondary bud will grow, producing a shoot which will be 50-70% as productive as a typical primary shoot (6).[3]

This hardiness-production differential between primary and secondary buds is important for economic reasons to producers (6), but it also indicates an endogenous mechanism for control of bud hardiness which can differentiate as much as 10°C between the primary and secondary.[2] The greater susceptibility of primary buds to field kill coupled with their much greater productivity leads to investigations to answer the following questions: Why is the primary bud less hardy? How does the primary bud influence hardiness and production of the secondary? These long term studies are presently underway. To proceed with these studies, it was necessary to develop a technique to simulate freezing destruction of the primary bud *in situ* without injury to the secondary bud. Such a technique would desirably be inexpensive, easily carried in the field, and selectively cause death by low temperature stress. This report describes such a device.

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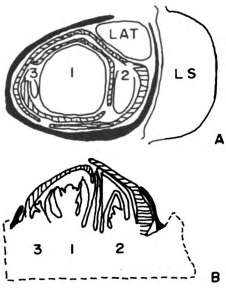

Fig. 1. A. Diagram of the leaf axil of 'Concord' grape showing relative positions of leaf scar, lateral shoot and 3 dormant buds.
B. Longisection in the plane of the axis through a node of 'Concord' grape showing 3 dormant buds. LAT = lateral shoot, LS = leaf scar, 1 = primary bud, 2 = secondary bud, 3 = tertiary bud [from Pratt, 1959].

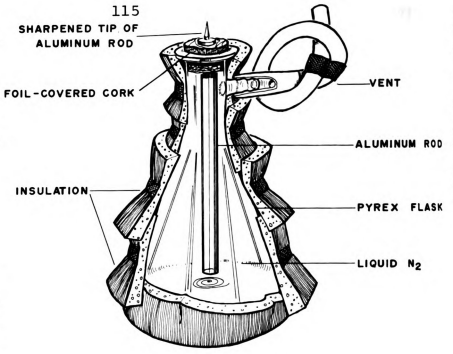

Fig. 2. Portable apparatus for *in situ* destruction of 'Concord' grape primary buds, consisting of an aluminum rod with a sharpened tip super-cooled with liquid N_2.

The equipment needed was a 1000 ml Buchner flask, an aluminum rod, liquid N_2, and insulating material. The tip of the aluminum rod was machined to a point, and the apparatus assembled as in Fig. 2. The flask was slowly filled with liquid N_2 allowing the rod to cool, also cooling the sharp point (below -73°C). We then carried the apparatus into the experimental vineyard on March 15, 1973 and punctured a series of nodes *in situ* at the site of the primary bud for 1, 3, 5, 10, and 15 sec timed by a wristwatch sweep hand. We excised canes containing these nodes and brought them into the laboratory to test for bud viability with the browning test (Table 1) and the growth test (Table 2) according to the procedures of Stergios and Howell (5). A primary bud was judged alive when it was all green, injured when its center portion browned, and dead when entirely brown. The field mortality (control) was 10% for the primary buds and 0% for the secondary buds (n = 10). In the control material, primary buds grew normally, i.e., expanding in an oblique angle away from the leaf scar and oriented in the center of the node, while secondary bud growth was suppressed. Although secondary bud growth in the control was suppressed, all the buds were still alive based on the visual observation of cut controls (Table 2). When we quickly punctured the primary buds with the liquid N_2-cooled needle apparatus, 60-90% injury in the primary buds occurred. However, the percentage of these completely killed was small (Table 1 and 2). When the primary bud was subjected to the treatment for 3 sec, 80 to 90% death was achieved coupled with 80% survival and growth of the secondary bud. Secondary infection in the node following primary bud puncture was not observed, and secondary bud mortality attributable to it was not apparent. At the present hardiness level and developmental stage of the buds, a 3-sec exposure to the liquid N_2-cooled needle produced the best results. Treatment at earlier or later dates in the fall or spring would require re-establishment of an appropriate exposure time. Puncture and needle

Table 1. Primary and secondary 'Concord' grape bud viability by the "browning test" in response to puncture by an aluminum, liquid N_2-cooled needle for 5 time periods (n =10 observations).

Treatment time (sec)	% uninjured		% injured		% dead	
	Primary	Secondary	Primary	Secondary	Primary	Secondary
Control	90	100	0	0	10	0
Fractional	20	80	60	0	20	20
3	0	90	20	10	80	0
5	0	50	0	30	100	20
10	0	20	0	20	100	60
15	0	0	0	0	100	100

Table 2. Primary and secondary 'Concord' grape bud viability by the "growth test" in response to puncture by an aluminum, liquid N_2-cooled needle for 5 time periods (n = 10 observations).

Treatment time (sec)	% growing		% uninjured but no growth		% injured (no growth)		% dead	
	Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary
Control	80	0	10	100	0	0	10	0
Fractional	0	50	0	30	90	10	10	10
3	0	80	0	0	10	10	90	10
5	0	30	0	30	0	20	100	20
10	0	0	0	10	0	10	100	80
15	0	0	0	0	0	0	100	100

exposure for 5 sec caused higher injury in secondary buds than did 3 sec, and their growth was poor (Table 1 and 2). Treatment for 10 sec produced almost complete death for both primary and secondary buds (Table 1 and 2), and after 2 weeks, no growth occurred. When primary buds were punctured at ambient temperatures, we noted that tissue injury occurred only in the immediate area of the needle thrust, and in most cases was almost indistinguishable from healthy tissue.

We feel that the liquid N_2-cooled aluminum needle apparatus will be a satisfactory tool for *in situ* destruction of primary buds while still in the dormant stage, and at the same time, allowing growth of the secondary bud to proceed unimpaired for subsequent study in the field. Thus the technique can be used to answer fundamental questions of hardiness and productivity of secondary buds by varying the time that the primary is frozen in the field.

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EPILOGUE

EPILOGUE

Although Concord grapes have been important to Michigan agriculture for many years, relatively little has been done to promote an understanding of field viticulture in Michigan since N. L. Partridge developed the concept of balance pruning in 1925, and Larsen et al. developed nutritional tools. Consequently, the Michigan grape industry lags behind other viticultural states, notably New York and California, in grape culture development for the soils and climate of Michigan. Research activities in viticulture at Michigan State University since 1970 have revealed that this situation is both unjustified and unnecessary. Indisputably, the climate in Michigan is not as favorable to vineyard establishment as it may be in other grape growing states. This assessment merely accentuates the need for a strong Michigan research program in this discipline, and constitutes a challenge rather than an obstacle. The field oriented studies presented in this dissertation were designed to pioneer that challenge for Michigan in a basic and forthright manner, and to establish a reasonable framework around which continued viticultural development in Michigan can be guided.

There are several approaches to the undertaking of applied field research. One approach involves establishing small and isolated field experiments with severely restricted purposes and objectives. I feel that this approach is unsatisfactory because just as the experiments are restrictive, so are the bits and pieces of information, which oftentimes are isolated and unrelated. The other approach, which is exemplified by the research undertaken for this dissertation, involves examining a spectrum of questions which evolve from a problem of wide interest and importance, such as the relationship between cold hardiness and productivity. The attempted resolution of such questions may produce not only pointed information, but also information which can be effectively integrated toward a broad and basic understanding of the problem. My dissertation problem was undertaken in an attempt to contribute to the basic understanding of cold hardiness and productivity patterns in Concord grape vines in Michigan, and to elucidate the basic nature of their relationship to each other.

The type of relationship involving cultural stresses on Concord grape vine hardiness and productivity which I propose is summarized briefly in Figures 1 and 2. When Concord grape vines are culturally stressed, both vine hardiness and productivity are restricted (Fig. 1). Once both are restricted, hardiness and productivity

restrict each other. When vines suffer freeze injury, bud loss reduces fruitfulness and vine productivity. Reduced productivity, then, further reduces vine hardiness because vines with no fruit channel their energy reserves into vegetative growth, resulting in over-vigorous and insufficiently matured over-wintering canes.

When good vineyard management (minimal cultural stress) is practiced, both vine hardiness and productivity improve (Fig. 2). In this situation, good hardiness and productivity complement each other, resulting in well-balanced vines (vegetative growth vs. fruit production) with optimal cropping conditions and fruit quality.

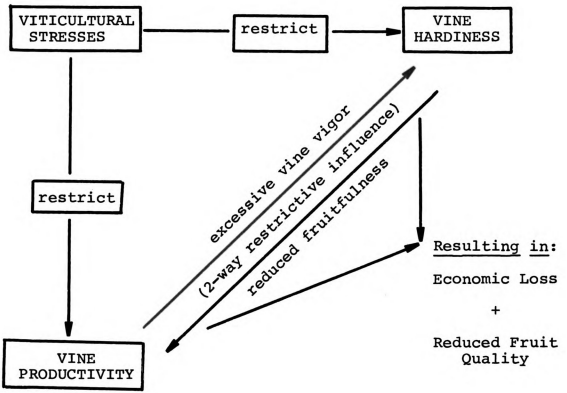

Fig. 1. Schematic representation of the relationship between viticultural stress and the vine hardiness - vine productivity complex in Concord grape.

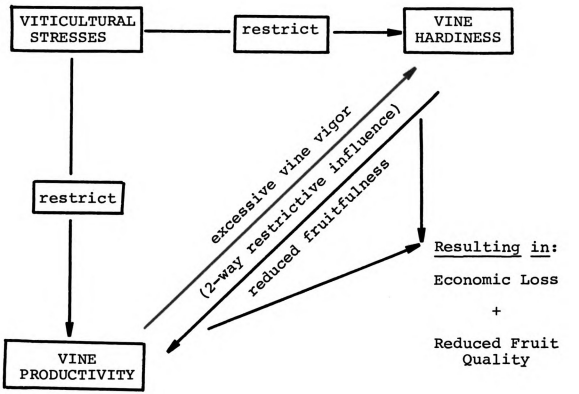

Fig. 1. Schematic representation of the relationship between viticultural stress and the vine hardiness - vine productivity complex in Concord grape.

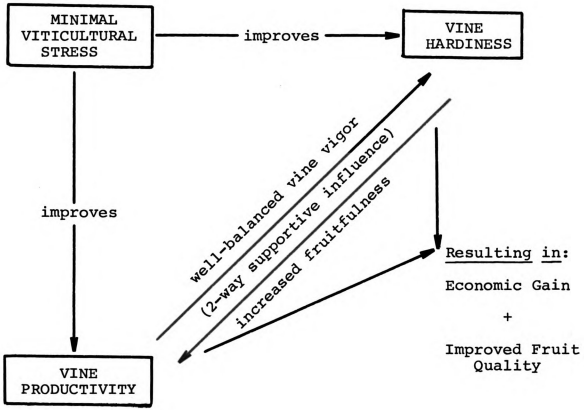

Fig. 2. Schematic representation of the relationship between minimal viticultural stress and the vine hardiness - vine productivity complex in Concord grape.

APPENDICES

APPENDIX A

TREATMENT EFFECTS OF DEFOLIATION, PRUNING SEVERITY, AND CLUSTER THINNING ON THE PRODUCTIVITY OF *Vitis labrusca* L. var. CONCORD VINES FROM A HIGH (ELEV. 277 m) AND A LOW (ELEV. 256 m) SITE IN SOUTHWESTERN MICHIGAN IN 1971, 1972, and 1973

Means are compared by the Tukey statistic at the 5% level of significance.

Table 1 = 1971

Table 2 = 1971

Table 3 = 1972

Table 4 = 1972

Table 5 = 1973

Table 6 = 1973

Table A-1. Productivity of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1971. The mean values (n = 36) given are on a per vine basis.

Site	Treatment	Yield (Kg)	Fruit (Kg/node)	Soluble Solids	Sugar (Kg)	Cluster Size (g)	Berry Size (g)
HIGH	Not defoliated, 30 + 10, not thinned	8.9	0.17	17.0	1.52	45.3	3.10
	Not defoliated, 30 + 10, thinned	5.4	0.11	17.2	0.92	103.8	3.18
	Not defoliated, 60 + 10, not thinned	10.7	0.15	16.9	1.80	87.1	3.16
	Not defoliated, 60 + 10, thinned	6.5	0.09	17.2	1.13	97.8	3.24
	Defoliated, 30 + 10, not thinned	8.6	0.17	13.1	1.13	94.3	2.99
	Defoliated, 30 + 10, thinned	5.4	0.11	13.9	0.75	109.0	3.09
	Defoliated, 60 + 10, not thinned	10.0	0.14	13.1	1.31	94.7	2.88
	Defoliated, 60 + 10, thinned	6.9	0.09	13.2	0.92	110.6	3.01
	Tukey's w @ 5% level	2.3	0.03	1.1	0.35	N.S.	0.24
LOW	Not defoliated, 30 + 10, not thinned	9.8	0.19	17.0	1.65	95.6	3.02
	Not defoliated, 30 + 10, thinned	6.1	0.11	17.6	1.08	110.6	3.20
	Not defoliated, 60 + 10, not thinned	12.6	0.15	16.3	2.06	84.4	2.96
	Not defoliated, 60 + 10, thinned	7.2	0.09	17.5	1.28	96.0	3.17
	Defoliated, 30 + 10, not thinned	8.9	0.15	13.1	1.17	75.8	2.91
	Defoliated, 30 + 10, thinned	4.7	0.09	13.5	0.64	102.5	3.09
	Defoliated, 60 + 10, not thinned	9.8	0.13	13.4	1.31	67.9	2.84
	Defoliated, 60 + 10, thinned	6.6	0.08	13.1	0.88	90.2	2.94
	Tukey's w @ 5% level	3.8	0.056	1.1	0.57	24.2	0.35

Table A-2. Productivity of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1971. The mean values (n = 36) given are on a per vine basis.

Site	Treatment	No. Cluster	Vine Size (Kg)	No. Nodes Retained	No. Cluster /node	No. Berries /cluster
HIGH	Not defoliated, 30 + 10, not thinned	101.0	1.42	51.6	1.96	30.7
	Not defoliated, 30 + 10, thinned	53.7	1.41	50.4	1.06	32.8
	Not defoliated, 60 + 10, not thinned	124.0	1.30	70.3	1.77	27.5
	Not defoliated, 60 + 10, thinned	67.8	1.51	78.0	0.87	30.2
	Defoliated, 30 + 10, not thinned	91.0	1.37	49.6	1.84	31.5
	Defoliated, 30 + 10, thinned	51.8	1.33	48.2	1.10	35.2
	Defoliated, 60 + 10, not thinned	108.2	1.35	74.2	1.47	32.7
	Defoliated, 60 + 10, thinned	63.2	1.52	78.7	0.81	36.9
	Tukey's w @ 5% level	34.0	0.49	15.0	0.62	N.S.
LOW	Not defoliated, 30 + 10, not thinned	103.0	1.48	52.1	2.03	31.6
	Not defoliated, 30 + 10, thinned	54.3	1.56	54.8	0.98	34.5
	Not defoliated, 60 + 10, not thinned	153.3	1.49	81.0	1.87	28.7
	Not defoliated, 60 + 10, thinned	74.8	1.42	79.3	0.94	30.4
	Defoliated, 30 + 10, not thinned	117.5	1.77	58.7	2.01	26.1
	Defoliated, 30 + 10, thinned	46.7	1.63	55.8	0.84	33.4
	Defoliated, 60 + 10, not thinned	145.3	1.23	76.0	1.92	24.0
	Defoliated, 60 + 10, thinned	73.2	1.49	81.2	0.90	30.7
	Tukey's w @ 5% level	37.5	0.53	12.5	0.52	8.4

Table A-2. Productivity of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1971. The mean values (n = 36) given are on a per vine basis.

Site	Treatment	No. Cluster	Vine Size (Kg)	No. Nodes Retained	No. Cluster /node	No. Berries /cluster
HIGH	Not defoliated, 30 + 10, not thinned	101.0	1.42	51.6	1.96	30.7
	Not defoliated, 30 + 10, thinned	53.7	1.41	50.4	1.06	32.8
	Not defoliated, 60 + 10, not thinned	124.0	1.30	70.3	1.77	27.5
	Not defoliated, 60 + 10, thinned	67.8	1.51	78.0	0.87	30.2
	Defoliated, 30 + 10, not thinned	91.0	1.37	49.6	1.84	31.5
	Defoliated, 30 + 10, thinned	51.8	1.33	48.2	1.10	35.2
	Defoliated, 60 + 10, not thinned	108.2	1.35	74.2	1.47	32.7
	Defoliated, 60 + 10, thinned	63.2	1.52	78.7	0.81	36.9
	Tukey's w @ 5% level	34.0	0.49	15.0	0.62	N.S.
LOW	Not defoliated, 30 + 10, not thinned	103.0	1.48	52.1	2.03	31.6
	Not defoliated, 30 + 10, thinned	54.3	1.56	54.8	0.98	34.5
	Not defoliated, 60 + 10, not thinned	153.3	1.49	81.0	1.87	28.7
	Not defoliated, 60 + 10, thinned	74.8	1.42	79.3	0.94	30.4
	Defoliated, 30 + 10, not thinned	117.5	1.77	58.7	2.01	26.1
	Defoliated, 30 + 10, thinned	46.7	1.63	55.8	0.84	33.4
	Defoliated, 60 + 10, not thinned	145.3	1.23	76.0	1.92	24.0
	Defoliated, 60 + 10, thinned	73.2	1.49	81.2	0.90	30.7
	Tukey's w @ 5% level	37.5	0.53	12.5	0.52	8.4

Table A-3. Productivity of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1972. The mean values (n = 36) given are on a per vine basis.

Site	Treatment	Yield (Kg)	Fruit (Kg/node)	Soluble Solids	Sugar (Kg)	Cluster Size (g)	Berry Size (g)
HIGH	Not defoliated, 30 + 10, not thinned	10.3	0.22	16.1	1.65	112.7	3.28
	Not defoliated, 30 + 10, thinned	8.6	0.16	16.2	1.40	143.0	3.18
	Not defoliated, 60 + 10, not thinned	13.2	0.18	15.7	2.08	104.6	3.28
	Not defoliated, 60 + 10, thinned	10.8	0.14	15.9	1.71	120.00	3.23
	Defoliated, 30 + 10, not thinned	6.4	0.15	12.6	0.81	122.9	3.05
	Defoliated, 30 + 10, thinned	4.9	0.11	12.9	0.64	121.8	2.95
	Defoliated, 60 + 10, not thinned	6.9	0.10	12.3	0.85	96.5	2.67
	Defoliated, 60 + 10, thinned	4.9	0.08	12.6	0.62	100.6	2.83
	Tukey's w @ 5% level	3.9	0.07	0.7	0.55	45.1	0.32
LOW	Not defoliated, 30 + 10, not thinned	13.3	0.24	15.4	2.03	118.6	3.19
	Not defoliated, 30 + 10, thinned	9.5	0.20	15.5	1.50	128.6	3.16
	Not defoliated, 60 + 10, not thinned	16.0	0.22	15.0	2.38	107.5	3.49
	Not defoliated, 60 + 10, thinned	10.8	0.14	15.2	1.65	125.8	3.09
	Defoliated, 30 + 10, not thinned	5.4	0.13	12.5	0.68	110.0	2.84
	Defoliated, 30 + 10, thinned	5.5	0.12	12.7	0.70	125.7	2.87
	Defoliated, 60 + 10, not thinned	5.5	0.09	12.3	0.67	127.6	2.60
	Defoliated, 60 + 10, thinned	6.0	0.08	12.9	0.77	115.3	2.85
	Tukey's w @ 5% level	3.4	0.05	0.9	0.39	N.S.	0.82

Table A-4. Productivity of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1972. The mean values (n = 36) given are on a per vine basis.

Site	Treatment	No. Cluster	Vine Size (Kg)	No. Nodes Retained	No. Cluster /node	No. Berries /cluster
HIGH	Not defoliated, 30 + 10, not thinned	88.2	1.38	50.5	1.77	35.0
	Not defoliated, 30 + 10, thinned	60.4	1.60	55.9	1.10	45.1
	Not defoliated, 60 + 10, not thinned	127.4	1.27	76.6	1.69	31.9
	Not defoliated, 60 + 10, thinned	90.2	1.31	77.9	1.17	37.1
	Defoliated, 30 + 10, not thinned	55.1	1.00	42.1	1.31	40.9
	Defoliated, 30 + 10, thinned	40.2	1.38	46.7	0.86	41.3
	Defoliated, 60 + 10, not thinned	72.6	0.90	69.6	1.05	36.2
	Defoliated, 60 + 10, thinned	52.4	1.24	74.7	0.70	35.7
	Tukey's w @ 5% level	30.1	0.67	13.5	0.57	N.S.
LOW	Not defoliated, 30 + 10, not thinned	113.4	1.21	46.6	2.44	37.4
	Not defoliated, 30 + 10, thinned	74.7	1.23	47.0	1.59	40.7
	Not defoliated, 60 + 10, not thinned	149.0	1.21	71.7	2.09	33.2
	Not defoliated, 60 + 10, thinned	88.0	1.23	76.1	1.16	40.6
	Defoliated, 30 + 10, not thinned	50.0	0.99	43.6	1.16	38.9
	Defoliated, 30 + 10, thinned	44.8	1.15	45.6	0.99	44.0
	Defoliated, 60 + 10, not thinned	48.2	0.70	61.4	0.78	48.8
	Defoliated, 60 + 10, thinned	53.4	1.11	71.8	0.73	40.5
	Tukey's w @ 5% level	33.4	0.57	12.9	0.57	N.S.

Table A-5. Productivity of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1973. Values are treatment effect means (n = 36) on a per vine basis. N.S. = No significant differences.

Site	Treatment	Yield (Kg)	Fruit (Kg/node)	Soluble Solids	Sugar (Kg)	Cluster Size (g)	Berry Size (g)
HIGH	Not defoliated, 30 + 10, not thinned	12.8	0.23	16.0	2.06	116.0	3.08
	Not defoliated, 30 + 10, thinned	7.8	0.15	16.8	1.32	130.0	3.03
	Not defoliated, 60 + 10, not thinned	12.7	0.18	16.4	2.09	95.7	3.00
	Not defoliated, 60 + 10, thinned	9.2	0.12	16.7	1.53	111.9	3.10
	Defoliated, 30 + 10, not thinned	5.7	0.15	12.5	0.70	86.	2.79
	Defoliated, 30 + 10, thinned	4.3	0.12	12.4	0.54	121.5	2.93
	Defoliated, 60 + 10, not thinned	6.0	0.11	11.8	0.71	69.4	2.61
	Defoliated, 60 + 10, thinned	5.3	0.12	11.9	0.63	105.0	2.98
	Tukey's w @ 5% level	2.68	0.06	N.S.	0.46	21.9	0.22
LOW	Not defoliated, 30 + 10, not thinned	8.47	0.18	16.9	1.42	136.0	2.77
	Not defoliated, 30 + 10, thinned	6.17	0.14	16.5	1.03	137.3	2.76
	Not defoliated, 60 + 10, not thinned	9.50	0.15	16.4	1.55	103.7	2.77
	Not defoliated, 60 + 10, thinned	6.85	0.09	16.9	1.16	123.5	2.80
	Defoliated, 30 + 10, not thinned	4.42	0.13	12.3	0.56	138.8	2.73
	Defoliated, 30 + 10, thinned	3.53	0.10	12.6	0.45	150.1	2.84
	Defoliated, 60 + 10, not thinned	4.59	0.08	11.9	0.55	102.9	2.68
	Defoliated, 60 + 10, thinned	4.22	0.09	12.6	0.54	143.0	2.88
	Tukey's w @ 5% level	3.48	N.S.	N.S.	N.S.	N.S.	N.S.

Table A-6. Productivity of Concord grape vines from a high (elev. 277 m) and a low (elev. 256 m) site in southwestern Michigan in 1973. Values are treatment effect means (n = 36) on a per vine basis. N.S. = No significant differences.

Site	Treatment	No. Cluster	Vine Size (Kg)	No. Nodes Retained	No. Cluster /node	No. Berries /cluster
HIGH	Not defoliated, 30 + 10, not thinned	112.7	1.66	56.1	2.01	37.7
	Not defoliated, 30 + 10, thinned	60.3	1.77	56.4	1.12	43.0
	Not defoliated, 60 + 10, not thinned	132.6	1.42	71.4	1.90	31.8
	Not defoliated, 60 + 10, thinned	83.9	1.71	78.4	1.10	36.1
	Defoliated, 30 + 10, not thinned	65.9	1.08	38.1	1.75	31.1
	Defoliated, 30 + 10, thinned	35.8	0.87	38.5	0.97	41.5
	Defoliated, 60 + 10, not thinned	86.7	0.56	51.8	1.71	26.7
	Defoliated, 60 + 10, thinned	51.5	0.83	64.5	0.80	35.3
	Tukey's w @ 5% level	26.4	N.S.	N.S.	0.48	6.4
LOW	Not defoliated, 30 + 10, not thinned	61.8	1.43	50.2	1.26	48.8
	Not defoliated, 30 + 10, thinned	45.2	1.63	52.5	1.03	50.0
	Not defoliated, 60 + 10, not thinned	94.3	1.07	64.8	1.51	37.4
	Not defoliated, 60 + 10, thinned	56.4	1.43	78.8	0.71	44.1
	Defoliated, 30 + 10, not thinned	31.9	0.63	33.4	0.96	50.9
	Defoliated, 30 + 10, thinned	23.7	0.74	35.4	0.67	52.9
	Defoliated, 60 + 10, not thinned	43.8	0.47	56.5	0.81	38.4
	Defoliated, 60 + 10, thinned	30.3	0.77	55.3	0.64	49.5
	Tukey's w @ 5% level	26.1	N.S.	N.S.	0.73	14.5

APPENDIX B

PILOT STUDIES ON THE HARDINESS AND PRODUCTIVITY OF PRIMARY AND SECONDARY BUDS OF CONCORD GRAPEVINES CONDUCTED IN SOUTHWESTERN MICHIGAN IN 1972 AND 1973

APPENDIX B

STUDIES ON THE HARDINESS AND PRODUCTIVITY OF PRIMARY AND SECONDARY BUDS OF CONCORD GRAPEVINES

(Basil G. Stergios, Gordon S. Howell, and S. S. Stackhouse)

In studies conducted in 1971 and 1972 of site effects on dehardening of Concord vines we discovered that during the late stages of dehardening that hardiness differences as large as 10°C existed between primary and secondary buds.

Of equal importance is the fact that the secondary is less productive than the primary. We became interested in examining this hardiness-production differential since it has considerable implications on both the economics of Concord production and the control of bud hardiness in grapevines. In years such as 1973 it is of considerable interest to know how to improve the productivity of the secondary or, considering another route, how to improve the hardiness of the primary and reduce loss to low temperature stress.

In 1972 a pilot study was initiated to gain information on the influence of the primary bud and developing cane on the growth and productivity of the secondary bud. The vines were trained to 4-Arm Kniffen and three treatments were chosen:

1. Normal vines (control);

2. Primary bud removed at alternate nodes;

3. Primary bud removed at each node.

Primaries were removed at bud swell (May 14). The productivity data collected are presented in Table B-1 and growth measurements are presented in Figure B-1.

It was necessary to develop a technique to selectively kill primary buds at various times during the dormant season. Our method of accomplishing this and the criteria for evaluating injury is presented in Basil Stergios' Ph.D. dissertation.

In the spring of 1973 the liquid N_2 apparatus (demonstrated last year) was used on March 15 to kill dormant primary buds and another treatment, as in 1972, was primary bud removal at bud swell (April 30). These data are presented in Table B-2 and in Figures B-2,A and B-2,B.

In the fall of 1973 a full-scale experiment was undertaken at the Sodus Research Station to test the effect of primary bud loss at different times of the dormant season on the hardiness and productivity of secondary buds. Our first treatment was November 15, 1973. On February 12, we again applied a puncture-kill treatment and collected samples for evaluation of both field hardiness and ability to take cold stress in our

laboratory freezer apparatus. All the data are not in and it would be premature to comment yet, but we feel that we now have developed tools which are going to allow us to penetrate to the basic relationships of hardiness and productivity of the Concord grape bud.

The effect of primary bud growth on development of secondary bud is rather straightforward. Through some mechanism, likely apical dominance, the primary controls the development and growth of the secondary shoot. Does this mechanism operate in the dormant bud? This year's data from Sodus should provide the answer.

What effect does the primary exert on yield and fruit quality? Table B-1 provides some insights on that. The primary shoot is far more productive than any secondary shoot. That is not all of the answer, however. The primary also reduces berry size and number of clusters of secondary buds even when removed as late as May 14--long after most authorities have considered such factors already anatomically determined. This is exciting information which suggests that we may be able to alter the productivity of secondary buds much later than previously believed.

In 1973 the plots on GDC trained vines and nodes at which primaries grew produced no secondary shoots. That is why that treatment is not represented in the

vine growth data in Figure B-2 and the productivity data in Table B-2.

The interesting thing about the data in Figure B-2 is the difference time of primary loss made on secondary shoot growth. If the primary was killed on March 15 secondary shoots grew equally well. If the kill date was April 30 the presence of secondary shoots at alternate nodes repressed the development of all secondary shoots to a significant degree.

The productivity data from 1973 did not follow the same trend. The poorest treatment was secondary shoots which had a primary at alternate nodes on the early treatment date. Although the field variability was great and the clusters/node figure is not statistically different I strongly feel that it is as Nelson Shaulis would say "viticulturally significant." We are confident that we have an experiment presently underway that will effectively test the validity of our feelings.

Table B-1. Effect of primary bud removal on secondary shoot productivity of balanced pruned, 4-AK trained, Concord grapevines harvested in October, 1972. Means are significantly different when $p < .05$.

Treatment	Yield (Kg/node)	Berry size (g/berry)	Clusters/ node	Cluster Size (g)	Kg sugar/ node	Soluble Solids
Primary Shoot (Control)	0.49a	2.8b	2.6a	174.3b	0.76a	15.4ab
Secondary (Primary Removed at Bud Swell)	0.29b	3.0a	1.5b	199.0b	0.49b	16.9a
Secondary (Primary Present at Alternate Nodes at Bud Swell)	0.26b	3.0a	1.4b	193.1b	0.43c	16.4a
Secondary (Primary Present)	0.22b	2.5c	0.8c	308.8a	0.32c	19.5b

Table B-2. Effect of primary bud removal on secondary shoot productivity of balanced pruned, GDC trained, Concord grapevines harvested in September, 1973. Means are significantly different when $p < .05$.

Treatment	Yield (Kg/node)	Berry size (g/berry)	Clusters/ node	Cluster Size (g)	Kg sugar/ node	Soluble Solids
Primary Shoot (Control)	0.41a	3.33	5.9a	14.7a	0.66a	16.1a
Secondary (Primary Removed on March 15)	0.34b	3.37	1.2b	27.2b	0.53b	15.6b
Secondary (Primary Present at Alternate Nodes from March 15)	0.20b	3.45	0.7b	29.5b	0.30c	15.1b
Secondary (Primary Removed on April 30)	0.27b	3.31	1.9b	23.7b	0.43b	16.1a
Secondary (Primary Present at Alternate Nodes from April 30)	0.31b	3.48	1.1b	31.3b	0.50b	15.9a
		N.S.				

Fig. B-1. Effects of primary bud removal on secondary shoot growth from May 16 to June 16, 1972. Primary buds were removed May 14, 1972. Confidence intervals compare treatment means.

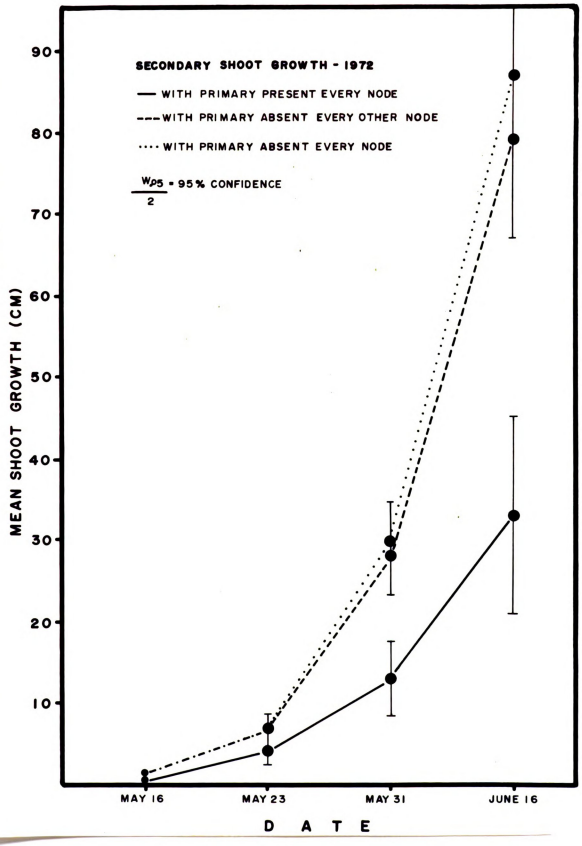
SECONDARY SHOOT GROWTH - 1972
— WITH PRIMARY PRESENT EVERY NODE
---WITH PRIMARY ABSENT EVERY OTHER NODE
····WITH PRIMARY ABSENT EVERY NODE
$\frac{W_{95}}{2}$ = 95% CONFIDENCE
MEAN SHOOT GROWTH (CM)
90
80
70
60
50
40
30
20
10
MAY 16
MAY 23
MAY 31
JUNE 16
D A T E

Figure B-1

Fig. B-2. Effects of primary bud removal on secondary shoot growth of Concord grape vines from May 13 to July 4, 1974.

A--primary buds killed March 15, 1973.

B--primary buds killed April 30, 1973.

Confidence intervals compare treatment means.

A B

Figure B-2

APPENDIX C

NUTRIENT LEVELS OF *Vitis labrusca* L. var. CONCORD VINES BASED ON QUANTITATIVE ANALYSIS OF LEAF PETIOLES SAMPLED IN AUGUST, 1971 FROM A HIGH (ELEV. 277 m) AND A LOW (ELEV. 256 m) SITE IN SOUTHWESTERN MICHIGAN

Table 1 shows main effect means, and Table 2 shows treatment effect means.

Table C-1. Nutrient levels in August, 1971 of Concord grape vines based on quantitative analysis of leaf petioles. Values are main effect means given as percent for N, K, P, Ca, Mg and parts per million for the rest.

Site	Variable	Percent and ppm of Element in Petiole									
		N	K	P	Na	Ca	Mg	Mn	Fe	Cu	B
	Not Defoliated	0.67	1.22	0.17	327.8	1.37*	0.64	653.4	19.8	10.3	27.8*
	Defoliated	0.65	1.12	0.19	323.8	1.27	0.56	644.2	23.6*	10.1	25.5
	30 + 10 Pruned	0.64	1.16	0.17	320.5	1.30	0.62	667.0	22.1	10.1	26.4
	60 + 10 Pruned	0.68*	1.18	0.19	331.0	1.34	0.58	644.2	21.3	10.3	26.9
	Thinned	0.65	1.24	0.19	304.0	1.27	0.54	646.6	20.8	9.6	26.5
	Not Thinned	0.67	1.11	0.17	347.5	1.37*	0.65*	674.6	22.7	10.8	26.9
	Not Defoliated	0.66	0.87	0.19	222.6	1.44*	0.76*	539.7	15.8	6.65	28.6
	Defoliated	0.69	0.91	0.26*	235.1	1.32	0.61	524.8	18.7*	7.17	27.4
	30 + 10 Pruned	0.67	0.94	0.23	242.1	1.38	0.68	512.8	17.6	7.94*	28.2
	60 + 10 Pruned	0.68	0.84	0.22	215.6	1.38	0.69	551.7	16.8	5.88	27.9
	Thinned	0.65	0.87	0.22	198.7	1.34	0.67	514.3	16.1	5.96	27.9
	Not Thinned	0.70*	0.92	0.23	259.0*	1.42*	0.70	550.2	18.3	7.85*	28.2

* = significance @ 5% level.

Table C-2. Nutrient levels in August, 1971 of Concord grape vines based on quantitative analysis of leaf petioles. The mean values (n = 6) given are percent in petiole for N, K, P, Ca, Mg and parts per million in petiole for the rest. N.S. = No significant differences.

Site	Treatment	Percent and ppm of Element in Petiole											
		N	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
HIGH	Not defoliated 30 + 10 not thinned	0.65	1.13	0.16	395	1.40	0.71	708	22.8	11.2	27.9	16.8	64.2
	Not defoliated 30 + 10 thinned	0.65	1.26	0.18	275	1.36	0.67	695	19.5	9.0	27.8	12.5	57.8
	Not defoliated 60 + 10 not thinned	0.72	1.24	0.15	316	1.43	0.67	610	18.5	10.7	27.5	15.5	61.0
	Not defoliated 60 + 10 thinned	0.67	1.26	0.18	325	1.30	0.51	601	18.5	10.4	27.9	15.8	57.8
	Defoliated 30 + 10 not thinned	0.65	1.13	0.17	322	1.31	0.64	677	24.2	11.0	26.9	15.3	72.7
	Defoliated 30 + 10 thinned	0.60	1.13	0.16	290	1.13	0.45	628	22.0	9.3	22.9	11.8	61.8

Table C-2. Continued

Site	Treatment	Percent and ppm of Element in Petiole											
		N	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
HIGH	Defoliated 60 + 10 not thinned	0.66	0.92	0.19	357	1.34	0.60	704	25.2	10.5	25.2	20.2	68.5
	Defoliated 60 + 10 thinned	0.67	1.30	0.23	326	1.28	0.54	662	23.2	9.8	27.2	12.0	61.0
	Tukey's w @ 5% level	0.11	N.S.	N.S.	129	0.31	0.35	N.S.	10.9	N.S.	7.3	N.S.	N.S.
LOW	Not defoliated 30 + 10 not thinned	0.65	1.00	0.19	278	1.44	0.73	540	15.5	6.23	28.1	25.3	63.2
	Not defoliated 30 + 10 thinned	0.64	0.85	0.19	211	1.41	0.77	465	16.5	8.48	29.3	29.2	67.3
	Not defoliated 60 + 10 not thinned	0.71	0.88	0.18	228	1.51	0.82	554	16.5	8.25	29.7	36.3	71.7
	Not defoliated 60 + 10 thinned	0.65	0.77	0.20	174	1.41	0.71	600	14.5	3.62	27.5	29.3	53.8

Table C-2. Continued

Site	Treatment	Percent and ppm of Element in Petiole											
		N	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
LOW	Defoliated 30 + 10 not thinned	0.74	1.01	0.31	293	1.41	0.61	581	21.8	10.12	27.7	41.3	71.5
	Defoliated 30 + 10 thinned	0.65	0.92	0.23	186	1.26	0.62	466	16.5	6.92	27.6	21.0	65.8
	Defoliated 60 + 10 not thinned	0.69	0.77	0.25	237	1.32	0.64	526	19.3	6.82	27.4	24.2	59.0
	Defoliated 60 + 10 thinned	0.67	0.93	0.27	224	1.28	0.57	527	17.0	4.83	27.0	18.8	57.0
	Tukey's w @ 5% level	0.12	N.S.	0.16	121	0.22	0.37	N.S.	7.9	5.06	N.S.	20.0	17.9

APPENDIX D

MEAN mg STARCH/g DRIED *Vitis labrusca* L. var. CONCORD BARK AND WOOD TISSUE FROM HIGH AND LOW SITE, HIGH AND LOW TRELLISED STEMS SAMPLED DURING ACCLIMATION AND DEACCLIMATION IN 1971, 1972, AND 1973 IN SOUTHWESTERN MICHIGAN

Table D-1. Mean mg starch/g dried Concord grape stem tissue collected on October 2, 1971 from a high, well air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	95.68	123.71	90.82	124.77
Not defoliated, 30 + 10, thinned	95.30	116.10	99.98	119.58
Not defoliated, 60 + 10, not thinned	136.34	156.88	126.01	112.43
Not defoliated, 60 + 10, thinned	98.19	152.16	147.33	168.11
Defoliated, 30 + 10, not thinned	57.94	100.67	73.85	104.01
Defoliated, 30 + 10, thinned	48.32	76.13	78.77	91.40
Defoliated, 60 + 10, not thinned	34.72	71.65	77.77	87.44
Defoliated, 60 + 10, thinned	56.78	89.94	71.57	93.88

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .02}{.0071}\right] [.92]$$

Table D-2. Mean mg starch/g dried Concord grape stem tissue collected on November 6, 1971 from a high, well air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	68.6	66.3	87.2	108.3
Not defoliated, 30 + 10, thinned	132.5	122.2	105.9	105.9
Not defoliated, 60 + 10, not thinned	136.1	122.6	81.4	85.9
Not defoliated, 60 + 10, thinned	73.0	137.6	72.5	92.5
Defoliated, 30 + 10, not thinned	85.8	100.1	123.5	88.7
Defoliated, 30 + 10, thinned	93.2	129.8	68.5	87.2
Defoliated, 60 + 10, not thinned	153.3	123.9	101.5	107.1
Defoliated, 60 + 10, thinned	70.4	91.5	68.8	55.3

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .017}{.0055}\right] [.92]$$

Table D-2. (cont.) Mean mg starch/g dried Concord grape stem tissue collected on November 6, 1971 from a low, poorly air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	120.5	118.3	91.4	93.2
Not defoliated, 30 + 10, thinned	-	-	-	-
Not defoliated, 60 + 10, not thinned	137.8	147.4	91.7	147.4
Not defoliated, 60 + 10, thinned	79.9	90.7	78.9	89.8
Defoliated, 30 + 10, not thinned	77.0	118.3	85.4	20.5
Defoliated, 30 + 10, thinned	134.5	118.8	102.3	100.6
Defoliated, 60 + 10, not thinned	74.5	78.5	75.4	40.6
Defoliated, 60 + 10, thinned	62.4	49.3	49.3	-

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} + .0667}{.0073}\right] [.92]$$

- = no data

Table D-3. Mean mg starch/g dried Concord grape stem tissue collected on December 11, 1971 from a high, well air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	33.00	79.24	57.76	69.87
Not defoliated, 30 + 10, thinned	64.18	146.35	125.24	72.97
Not defoliated, 60 + 10, not thinned	36.99	62.17	38.05	61.97
Not defoliated, 60 + 10, thinned	48.44	66.95	51.36	71.49
Defoliated, 30 + 10, not thinned	53.48	47.58	39.69	31.55
Defoliated, 30 + 10, thinned	38.52	60.45	44.70	42.92
Defoliated, 60 + 10, not thinned	39.14	25.65	72.26	45.53
Defoliated, 60 + 10, thinned	76.68	68.30	90.56	75.16

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .03}{.0062}\right] [.92]$$

Table D-3. (cont.) Mean mg starch/g dried Concord grape stem tissue collected on December 11, 1971 from a low, poorly air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	77.24	130.66	56.54	72.38
Not defoliated, 30 + 10, thinned	63.92	108.29	94.34	92.82
Not defoliated, 60 + 10, not thinned	53.90	45.83	78.30	66.43
Not defoliated, 60 + 10, thinned	33.02	101.44	68.34	93.34
Defoliated, 30 + 10, not thinned	79.47	38.52	48.47	30.45
Defoliated, 30 + 10, thinned	33.71	29.01	41.71	55.06
Defoliated, 60 + 10, not thinned	62.73	51.71	45.04	34.37
Defoliated, 60 + 10, thinned	56.87	55.83	70.00	39.58

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .06}{.0067}\right] [.92]$$

Table D-4. Mean mg starch/g dried Concord grape stem tissue collected on March 25, 1972 from a high, well air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	-	-	-	-
Not defoliated, 30 + 10, thinned	-	-	-	-
Not defoliated, 60 + 10, not thinned	41.3	88.2	64.2	105.6
Not defoliated, 60 + 10, thinned	52.2	79.9	-	-
Defoliated, 30 + 10, not thinned	-	-	-	-
Defoliated, 30 + 10, thinned	-	-	-	-
Defoliated, 60 + 10, not thinned	35.6	46.7	48.8	70.7
Defoliated, 60 + 10, thinned	44.7	17.7	51.5	81.9

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .0587}{.0057}\right] [.92]$$

Table D-4. (cont.) Mean mg starch/g dried Concord grape stem tissue collected on March 25, 1972 from a low, poorly air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	-	-	-	-
Not defoliated, 30 + 10, thinned	-	-	-	-
Not defoliated, 60 + 10, not thinned	76.0	105.4	102.9	-
Not defoliated, 60 + 10, thinned	67.0	121.3	75.1	111.6
Defoliated, 30 + 10, not thinned	-	-	-	-
Defoliated, 30 + 10, thinned	-	-	-	-
Defoliated, 60 + 10, not thinned	64.6	96.9	69.1	68.9
Defoliated, 60 + 10, thinned	56.8	-	76.2	118.9

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .0587}{.0057}\right] [.92]$$

- = no data

Table D-5. Mean mg starch/g dried Concord grape stem tissue collected on April 15, 1972 from a high, well air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	79.7	61.7	69.0	45.1
Not defoliated, 30 + 10, thinned	48.0	38.5	76.1	71.2
Not defoliated, 60 + 10, not thinned	63.7	104.5	43.1	86.4
Not defoliated, 60 + 10, thinned	121.6	86.4	128.7	85.7
Defoliated, 30 + 10, not thinned	43.0	85.3	43.6	61.5
Defoliated, 30 + 10, thinned	61.9	87.2	68.9	110.4
Defoliated, 60 + 10, not thinned	73.4	47.9	53.0	61.0
Defoliated, 60 + 10, thinned	25.4	56.2	36.4	35.2

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .0413}{.0057}\right] [.92]$$

Table D-5. (cont.) Mean mg starch/g dried Concord grape stem tissue collected on April 15, 1972 from a low, poorly air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	66.3	58.9	65.4	66.9
Not defoliated, 30 + 10, thinned	54.9	92.9	58.9	68.1
Not defoliated, 60 + 10, not thinned	52.6	94.4	58.3	85.4
Not defoliated, 60 + 10, thinned	57.2	120.3	70.2	87.8
Defoliated, 30 + 10, not thinned	48.6	89.3	42.6	65.9
Defoliated, 30 + 10, thinned	43.7	83.2	56.9	88.2
Defoliated, 60 + 10, not thinned	53.7	67.5	106.1	75.6
Defoliated, 60 + 10, thinned	60.8	67.1	33.6	26.0

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .0872}{.0058}\right] [.92]$$

Table D-6. Mean mg starch/g dried Concord grape stem tissue collected on December 15, 1972 from a high, well air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	19.1	13.5	7.1	6.5
Not defoliated, 30 + 10, thinned	2.9	1.4	6.3	3.0
Not defoliated, 60 + 10, not thinned	22.4	86.6	30.3	83.5
Not defoliated, 60 + 10, thinned	27.2	97.2	35.3	87.5
Defoliated, 30 + 10, not thinned	16.7	123.4	32.7	107.8
Defoliated, 30 + 10, thinned	16.5	56.8	21.2	94.2
Defoliated, 60 + 10, not thinned	ND	ND	ND	ND
Defoliated, 60 + 10, thinned	ND	ND	ND	ND

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .0948}{.0053}\right] [.92]$$

ND = not detected

Table D-6. (cont.) Mean mg starch/g dried Concord grape stem tissue collected on December 15, 1972 from a low, poorly air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	8.1	25.9	5.8	5.0
Not defoliated, 30 + 10, thinned	1.9	1.5	3.0	0.2
Not defoliated, 60 + 10, not thinned	25.4	103.6	21.4	89.8
Not defoliated, 60 + 10, thinned	29.6	92.7	35.3	85.9
Defoliated, 30 + 10, not thinned	12.5	60.5	12.3	65.2
Defoliated, 30 + 10, thinned	48.3	48.3	23.6	58.7
Defoliated, 60 + 10, not thinned	ND	ND	ND	ND
Defoliated, 60 + 10, thinned	ND	ND	ND	ND

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} + .0709}{.0053}\right] [.92]$$

Table D-7. Mean mg starch/g dried Concord grape stem tissue collected on April 15, 1973 from a high, well air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	51.1	10.3	22.6	-
Not defoliated, 30 + 10, thinned	22.6	30.5	28.7	24.6
Not defoliated, 60 + 10, not thinned	48.1	94.2	73.0	113.5
Not defoliated, 60 + 10, thinned	42.1	106.9	74.1	120.6
Defoliated, 30 + 10, not thinned	57.9	89.4	30.0	118.2
Defoliated, 30 + 10, thinned	43.1	99.7	61.4	124.2
Defoliated, 60 + 10, not thinned	26.4	16.1	37.7	30.1
Defoliated, 60 + 10, thinned	25.1	15.1	28.7	24.5

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .0207}{.0049}\right] [.92]$$

Table D-7. (cont.) Mean mg starch/g dried Concord grape stem tissue collected on April 15, 1973 from a low, poorly air-drained site. Wood = xylem and pith. Living Bark = cambium and phloem.

Treatment	Top Trellising		Bottom Trellising	
	Living Bark	Wood	Living Bark	Wood
Not defoliated, 30 + 10, not thinned	23.6	22.5	99.0	66.1
Not defoliated, 30 + 10, thinned	13.4	13.5	25.2	48.4
Not defoliated, 60 + 10, not thinned	59.8	155.7	43.4	117.0
Not defoliated, 60 + 10, thinned	60.4	145.0	37.9	133.5
Defoliated, 30 + 10, not thinned	32.1	114.7	69.5	84.4
Defoliated, 30 + 10, thinned	57.6	134.5	66.4	125.2
Defoliated, 60 + 10, not thinned	26.3	23.3	26.4	57.4
Defoliated, 60 + 10, thinned	33.9	39.8	25.5	25.9

$$\text{mg starch/g tissue} = \left[\frac{OD_{630} - .0207}{.0049}\right] [.92]$$

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