THE EFFECT OF DRIP IRRIGATION ON MICHIGAN VINEYARDS, AND THE GROWTH AND PHYSIOLOGICAL RESPONSES TO WATER DEFICITS ON CONCORD AND SEYVAL GRAPEVINES.

BY

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To my parents for their principles
and example through my life.

To my wife Angelica for all her
support and understanding.

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ABSTRACT

THE EFFECT OF DRIP IRRIGATION ON MICHIGAN VINEYARDS, AND GROWTH AND PHYSIOLOGICAL RESPONSES TO WATER DEFICITS ON CONCORD AND SEYVAL GRAPEVINES

BY

Hector Mauricio Escamilla

The effect of irrigation on yield and quality was tested on Concord and Seyval grapes. Greenhouse studies were conducted on phenological and physiological responses to drought. Irrigation had no effect on yield and quality of Seyval after the first year.

Shoot elongation and stomatal conductance were more sensitive to drought than shoot diameter and leaf area. Growth continued on lateral shoots after main shoots stopped growing. Preconditioning to drought yielded vines better able to withstand a second drought.

Clusters at pre-bloom, full bloom, and fruit set were sensitive to drought. Drought during pre-bloom induced fewer seeds/berry and reduced berry weight. Drought may contribute to delayed ripening of grapes. An acute drought during stage I caused cluster dessication , but did not affect yield and quality at stage II, veraison, and 1-week before harvest.

INTRODUCTION

Michigan ranks the fifth among grape producing states with approximately 6360 ha. Although in a temperate climate, Michigan may have periods of drought during the summer coupled with high temperatures. Most Michigan vineyards are located within 40 Km of Lake Michigan. The vineyard soils are predominantly sandy, well drained, and with low water holding capacity, increasing the importance of supplemental irrigation. The use of different irrigation systems has gradually increased and there are currently about 235 ha, where 55 % are by drip irrigation. Drip irrigation is one of the most efficient systems because of its low energy requirements for operation, its efficiency of water distribution, and its low volumes of application. However, very little research has been conducted in the viticulture of the Northeastern United States to help determine the effects of supplemental irrigation, appropriate amounts and rates of water application to meet grapevine's needs.

This research project was divided in 2 areas: (a) Field and (b) greenhouse studies with the following particular objectives:

1. Quantify the effect of supplemental irrigation on Concord and Seyval grapes at those critical periods where additional water would be beneficial to to vine size, yield, and quality of grapes.
2. To measure the sensitivity of different vine growth components and stomatal conductance to drought and to cyclic acute, short term drought on Concord and Seyval grapevines.
3. To determine the effect of drought stress at different stages of berry development.

LITERATURE REVIEW

WATER RELATIONS

Water is important for several physiological and morphological functions in vine growth and development. According to Kramer (40) water is important in plants as follows: 1) Constituent- it forms 80-90 % of the fresh weight of herbaceous plants; 2) Solvent- it is a solvent and a carrier for gases, minerals and other solutes for the whole plant; 3) Reactant- it is involved in reactions such as photosynthesis, hydrolytic processes such as the amylase-mediated hydrolisis of starch to sugar in germinating seeds; and 4) Maintenance of turgidity- it plays an essential role in the maintenance of turgor in order to maintain cell enlargement and growth. Turgor influences the opening of stomata and movement of leaves, flower and petals. Hence, lack of turgidity reduces plant's growth and development.

Water loss in plants is dependent on transpiration, which is influenced by environmental conditions. Continuous water uptake is necessary to replace transpirational losses. Plant water uptake is mainly done by its roots, but a small amount is absorbed through leaves and even through twigs (42).

The movement of water depends on the existence of gradients of decreasing water potential (61). The components of water potential (Ψw) are:

$$\Psi w = \Psi s + \Psi m + \Psi p$$

where Ψs is the osmotic potential, Ψm is the matric potential, and Ψp is the turgor potential. Ψm is usually low and negative. In fully turgid tissues Ψs is numerically greater than Ψp, so that Ψw is negative.

ARID ZONES AND HUMID AREAS

Areas receiving less than 200 mm of precipitation per year are arid, those receiving 200-500 mm are semiarid, from 500-750 are subhumid, and above 750 humid. This classification (21) is often misleading since distribution of the precipitation during the year can vary. It may occur that a humid location receives most of the rain in a very poor annual distribution, resulting in a season with two or three months of drought. Therefore, an area with a high precipitation level but poor distribution is sometimes considered a semiarid zone.

Michigan has the lowest summer rainfall of any state East of the Missisippi river. This lack of rainfall may generate a drought problem (47). Hence, irrigation may represent a desirable agricultural practice.

TECHNIQUES FOR RESEARCHING WATER RELATIONS.

Kramer (40) indicated that a satisfactory method of monitoring plant water status should have most of the following characteristics:

1. There should be a good correlation between rates of physiological processes and the degree of water stress measured by the method.

2. A given degree of water stress measured by the selected method should have similar, physiological significance in a wide range of plant materials.

3. The units employed to express water status should be applicable to plant material, soil, and solutions.

4. The method should be as simple, rapid, and as inexpensive as possible.

5. The method should require a very small amount of plant material

for a measurement.

Relative water content (RWC), is the expression of tissue water content as a percentage of the fully turgid water content:

$$RWC = \frac{\text{Field wt. - Oven dry wt X 100}}{\text{turgid wt - Oven dry wt}}$$

The use of RWC allows one to follow changes in water content with a minimum of apparatus. Leaves are obtained from plants under study and weighed, then floated on water for 4 hrs to allow them to obtain maximum turgidity and reweighed. Dry wt is obtained afterwards (21).

Unfortunately, a given RWC does not represent the same level of water potential in leaves of different species or ages, or from different environment s (40).

Leaf xylem water potential, can be obtained by using a pressure chamber (62). The chamber does not measure xylem potential directly. The method measures the pressure necessary to raise the potential of the xylem sap at atmostpheric pressure (7). The method consists of sealing the petiol of a leave in the chamber top so that the cut end of the petiol projects to the outside while the leaf blade is subjected to pressure on the inside. As pressure is applied to the blade, the water potential of the cell sap rises until it equals that of the sap in the xylem vessels at atmospheric pressure. At this point xylem sap emerges at the cut surface and the pressure required to cause this is recorded.

WATER RELATIONS IN GRAPEVINES

Water status influences the physiological and the biochemical processes and conditions which determine the vegetative growth and yield components of grapevines (43,69,34).

Under good cultural practices, nutrition, temperature and soil moisture, the seasonal growth cycle of bearing grapevines is described by Winkler, et al (79) as follows:

> A very rapid and succulent growth of the shoots in spring and early summer, a rapid slowing of shoot growth as the berries rapidly enlarge, and a gradual slowing of the shoots growth toward the ripening period with many shoots stopping growth by the time the grapes are ripe.

During the growing season the soil moisture in the root zone fluctuates between field capacity and permanent wilting point (PWP). When the soil moisture drops below the PWP there is no readily available moisture surrounding all of the roots and the grapevines begin to wilt in late afternoon or stop their growth (29,34). However, Furr and Magness (24) reported in their studies with apples that stomatal activity and fruit growth were affected, even when soil moisture in parts of the root zone was considerably above the PWP.

SYMPTOMS OF DROUGHT STRESS IN *VITIS*

Under conditions of drought stress the rate of growth in grape shoots dimishes or stops (73) while the growing tips gradually change from soft yellowish-green to the harder or grayish-green of the mature leaves (79). Young leaves and tendrils wilt (79,28). Young tendrils may also abscise (28). The shoot tips dry out, leaves curl, and the older leaves become dry, die and eventually drop (77,28). Mid-cane leaves, well exposed to the sun, develop unpatterned areas of necrosis (79). Leaves of drought stressed grapevines tend to hang vertically (73,68). Leaf angles greater than 60 between the junction of the petiole and lamina were associated with low transpiration rates and high stomatal resistance in "Perlette" grapevines (68). Drought stress during enlarging of berries will cause a reduction in berry size (73). Shriveling of the berries may occur at all the stages of development under conditions of drought stress (28).

PLANT RESPONSE TO DROUGHT STRESS

Drought stress and root development

Hofacker (31) observed an increased ratio of root to shoot weight in stressed "Aris" and "Muller-Thurgau" grapevines. With a relatively dry treatment "Shiraz" grapevines had a greater root production than with a wet treatment (22). These reports suggest that roots are less sensitive to drought stress than aerial parts. Richards and Cockroft (1974) (cited by 60) concluded that soil water potential lower than -50 Kilo-pascals (0.5 bars) had little effect on root elongation rates, but that few roots grew in soils drier than -1500 kilo-pascals (15 bars).

Drought stress and shoot growth in grapevines

Irrigated grapevines have a higher growth response (pruning weigth) than stressed vines (69,54,14). Grapevines adjust to drought stress by reduced shoot growth as a result of limitations imposed by water supply (34,79,16). Stomatal closure on stressed grapevines has been observed at a leaf water potential of -13 bars, and shoot growth rate is inhibited at lower tensions (68). Becker and Zimmerman (6) also found that restricted water supply reduced the vegetative growth, the transpiration coefficient, and consequently the amount of water necessary for the production of 1 Kg dry matter in the shoots.

Drought stress and trunk diameter fluctuations

Trunk diameter fluctuations have been shown to be a good reference for scheduling irrigation on fruit trees. The principle of this method is based on the fact that radial changes are influenced both by growth and by the degree of hydration of the tissues. Trunk growth rate and total seasonal growth in almonds was affected primarily by soil water. Of secondary importance were crop density conditions (72). Scheduling irrigation by trunk growth requires uniformity in age, vigor and crop load of the trees and uniformity in the soil. Smart (68) noted that trunks of stressed grapevines commence to shrink at Ψ_w of -7 bars or sooner in the early morning, subsequently declining, while irrigated vines had maximun rates of shrinkage about midday. Similar observations were made by Verner, et al (74) on apples, prunes and cherries.

Drought stress and leaf area.

An increase in leaf area directly increased the amount of the grape crop (78). Water deficiency in apples, peaches and prunes caused a reduction in shoot growth and leaf size (9). Irrigated "Cabernet Sauvignon" grapevines had an increased leaf area (14). An adequate water supply combined with shade increased the exent of leaf surface in "Riesling" and "Muller-Thurgau" grapevines (6). This is important considering that a reduction in the leaf area of vines also caused a reduction in the amount of assimilates produced and the quality of grapes (79).

LEAF WATER POTENTIAL, STOMATAL APERTURE AND PHOTOSYNTHESIS AFFECTED BY DROUGHT STRESS

The pressure technique described by Scholander, et al (62) has been extensively used in water relation studies. Water in the xylem of a transpiring plant was subjected to negative pressure and the pressure became more negative as drought stress increased (26). The use of leaf water potential as a guide to study stress in plants (7,35,8,49,22) and for irrigation timing has been reported (43,69,48,50,26).

Another method for measuring drought stress in plants is via stomatal aperture. Guard cells are very sensitive to water deficits and the premature closure of stomata is often the first indicator of developing drought stress (41). However, stomata do not always respond solely to water stress, so the correlation between stomatal aperture and water balance is not always pefect (5). Stomatal aperture has been also used at an irrigation criterion (3,66,67). Leaf conductance (cm/s) and resistance (s/cm) have been used to describe stomatal function. Stomatal conductance is the proportional parameter relating the flow of water vapor through the stomatal pore to the driving force (33). Conductance is affected by incident quantum flux density (radiation), leaf temperature, ambient humidity, carbon dioxide concentration and bulk leaf water potential (12). The term diffusive leaf conductence should be used more frequently, because transpiration, leaf water status and net photosynthesis are often directly related to conductance, whereas they are inversely related to resistance (27) . They also suggest that conductance should be expressed as a flow density per unit difference in relative partial pressure of water vapor between leaf and air with units

2 millimol/m^2s because the vapor pressure gradient is more appropiate as driving force than the absolute humidity gradient.

However, some authors still refer to stomatal resistance expressed in s/cm or conductance with units cm/s. Warrit, et al (75) showed in Malus that an increased leaf to air vapor pressure deficit reduced stomatal conductance and a linear relationship was established between stomatal conductance and leaf to air vapor pressure deficit.

Stomatal resistance of stressed "Shiraz" grapevines increased to 20 sec/cm as leaf water potential fell to -13 bars under field conditions (68). Liu, et al (45) observed similar results on potted "Concord" grapevines. Their data showed that when leaf water potential reached -16 bars, stomatal closure was essentially complete (15-25 sec/cm) and photosynthesis was minimal (1-5 mg carbon dioxide/dm^2 h). However, in field studies Liu (44) concluded that stomatal closure due to drought stress was never observed for mature, non senescent leaves, even when water potential was as low as -16 bars. Kriedemann and Smart (43) observed that photosynthesis declined at leaf water potential below -5 bars and fell to 0 at about -12 bars to -15 bars in potted "Sultana" grapevines. A prolonged leaf water potential at less than -16 yielded a large increase in abscisic acid and an incomplete recovery of photosynthesis despite opening of the stomata after rewatering (45). All these reports, and that of Freeman, et al (22) agreed that since stomatal conductance, carbon dioxide assimilation, and rate of photosynthesis were directly related, low stomatal conductance, carbon dioxide assimilation and rate of photosynthesis were being reduced.

Floral initiation and drought stress

Irrigation reduces floral initiation under those conditions where increased shoot length and leaf area result in a decline in light penetration to the renewal area (51,14). Primary bud development can be depressed by excessive water flow in the bud tissues (14). However, fruitfulness (expressed as the number and weight of bunch primordia per bud) was progressively depressed with increased of water stress (13). Therefore, irrigation during the period of bud formation has an important role influencing potential crop yield in arid zones.

Drought stress and berry development

In arid areas, soil moisture rather than temperature Allexander (1) or light intensity affect fruit set in grapevines (2). Alexander (1) added that water stress during or post-bloom would cause the bunch to shrivel.

If enough of the soil in the root zone reaches permanent wilting point when the berries are enlarging rapidly they will not reach full size (73,34,6). Even if water was applied after the period of rapid berry growth, the undersized fruits did not attain normal size (34). Drought stress prior to veraison reduced berry size was the yield component most sensitive to drought stress (68). Stress during veraison caused a decrease in color of grapes probably due to reduced carbohydrate availability (28).

Maturity drought stress and fruit maturation

Ripening processes are delayed by drought stress conditions (28). The delay is greater if stress is applied during the lag phase and is directly proportional to crop load remaining after stress (68). However, under conditions where irrigation caused strong vegetative growth and the fruit was shaded, maturity was delayed (30). Maturity was also delayed in situations where soils were deep and have a high water holding capacity (77). Finally, drought stress reduced total amount of sugar per berry (16,34,6).

METHODS OF IRRIGATION

Comparing drip, flood, and sprinkler irrigation on the response of St. Emilion (Ugni blanc) grapevines, Peacock et al (55) concluded that the principal benefit with drip irrigation was increased efficiency of water use. At the same time, yields and quality were mantained the same for the 3 methods. The only problem found with drip irrigation was that salts and sodium concentrated at the surface 100 cm from the row.

Location of vineyards is the most decisive factor in determining the possibilities and limits for a profitable drip-irrigation investment (71). Drip irrigation in vineyards has generally been a promising investment under conditions of moderate to steep slops which have limited top soil and low water holding capacity. Under these conditions irrigation has improved yields and quality of harvested grapes.

One of the problems of drip irrigation is the cost of the system. Reed, et al (59) ranked the cost of the 10 irrigation systems most commonly used as follows:

IRRIGATION SYSTEM	COST/ACRE/YEAR*
Drip	225.95
Permanent set sprinkler	219.60
Hose drag	204.20
Furrow	185.75
Hand move sprinkler	164.60
Wheel line sprinkler	140.60
Center pivot sprinkler	133.50
Center pivot corner system	125.90
Flood - Well water	121.00
Flood - district water	117.35

* Cost/acre/year: Includes expenses of water applied, investment, depreciation, interest, taxes and energy costs.

THE EFFECT OF DRIP IRRIGATION ON GROWTH AND YIELD COMPONENTS ON CONCORD AND SEYVAL GRAPEVINES IN MICHIGAN.

INTRODUCTION

Michigan has approximately 6360 ha. of producing vineyards. The use of supplemental irrigation has gradually increased, and is currently about 235 ha. (107 ha of sprinkler and 128 of drip irrigation, (Thomas, personal communication 1984). Very little information is available to help growers determine appropriate amounts and rates of water application to meet grapevine needs.

Although annual precipitation would be sufficient if appropriately distributed over time, high temperatures and evaporation frequently combined with the probability of low rainfall of June and July to induce periodic drought stress due to the limited amount of water in the soil. Depending on the time and duration of that stress, vine damage and economic loss may occur. When one adds these problems to the common condition of very sandy, well-drained soils with low water holding capacities characteristic of Michigan vineyards, irrigation becomes a potentially valuable potential practice for the state's viticulture.

The objective of this study is to quantify the effect of supplemental irrigation on Concord and Seyval grapes in those critical periods where additional water would be beneficial to vine size, yield and quality of grapes.

MATERIALS AND METHODS

Studies were conducted on two important grape cultivars at two locations (comercial vineyards) in Michigan. Seventeen-year-old Concord grapevines (Vitis labruscana Bailey) at Lawton, MI (latitude 42 13' N; longitude 85 51' W; and 241 m of elevation) trained to a Geneva double curtain (GDC) system (Figure 1.A) were selected for the first plot. Rows were orientated East to West, separated 3.05 m, and the vine separation within vines is 2.54 m. Eight-year-old grapevines of the hybrid direct producer (HDP) Seyval (Seyve-Villard 5-276) trained to a High head system (Figure 1.B) at Fennville (latitude 42 36' N; longitude 85 09' and 216 m of elevation) were selected as the second plot. At this location the rows are orientated North-South, the distance between rows was 3.05 m,and vine separation was 2.54 m. Soil characteristics are described in Table 1.

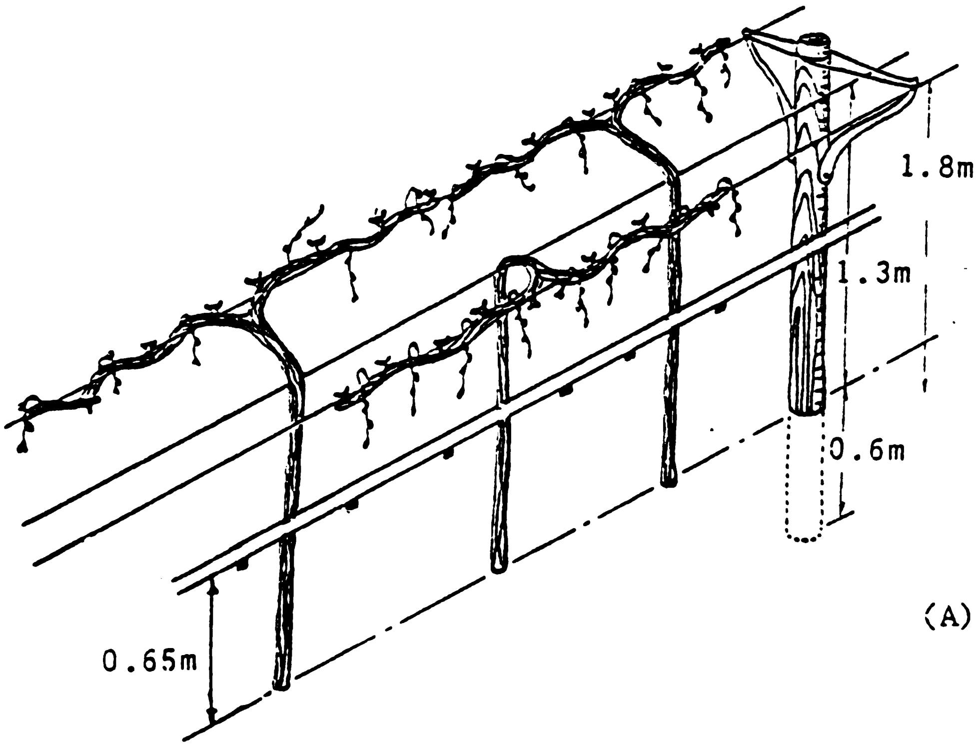
Table 1. Soil characteristics of Lawton and Fennville, Michigan.

LOCATION	TEXTURE	pH	F.C. (%)	P.W.P. (%)	A.W. (%)
LAWTON	Sandy-loam	4.7	9	3.2	5.8
FENNVILLE	Sandy-loam	5.8	15.5	5.2	10.3

F.C.= Field capacity P.W.P.= Permanent wilting percentage
A.W.= Available water

ANALYSIS OF DATA

Lawton: The experimental design was a split-plot, where main plots



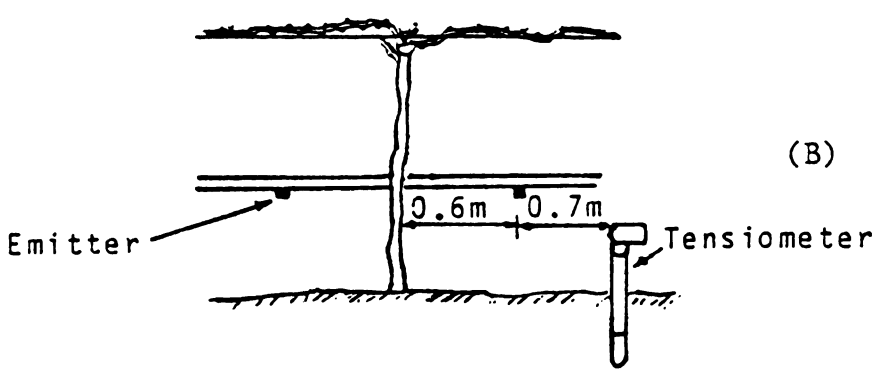


Figure I. Training system at Lawton (A - Geneva double curtain, after Shaulis, et al (65)) and at Fennville (B - High head), Michigan.

(irrigated and non-irrigated) were arranged in a randomized complete block design, and the sub-plots were vine size (0.79 Kg, 0.91-1.3 Kg, and 1.47 Kg), using a total of 24 vines per sub-plot, 44 per plot and and a total of 176 experimental vines. However, since the irrigation system did not operated during 1983, data was analyzed as a radomized block and further evaluated using regression analysis of the soil moisture coefficient and the different plant yield and quality variables.

Fennville: This plot was a randomized complete block design with 10 blocks, two treatments (irrigated and non- irrigated) and 5 vines with a total of 100 experimental vines.

PRUNING

Lawton: The average vine size at pruning for Concord grapevines was 1.15 Kg of cane prunings and vines were balanced pruned (64) to a 30+10 pruning severity (i.e., 30 buds retained for the first 0.45 Kg of cane prunings and 10 buds for each additional 0.45 kg). The fruiting nodes were retained on 5 node canes. In 1984 the grapevines were pruned in the same way.

Fennville: Seyval grapevines in Michigan must be pruned very severely because this cultivar produces very large clusters and thus tends to overcrop, flower cluster thinning is often a recommended practice. The base bud is counted in this cultivar when pruning because this bud, unlike the situation in Concord, generally is fruitful. Table 2 describes the pruning severities for 1983 and 1984.

In 1983 cane weight was not obtained because vines had been pruned prior to plot establishement; only bud number data was collected. For 1984 vines were grouped into 3 categories and bud number was set based on vine size and vineyard experience with the cultivar (Table 2).

Table 2. Pruning severities in 1983 and 1984 on Seyval grapevines at Fennville, Mi.

YEAR	Cane wt. (Kg)	Bud No./vine*	Percent of vines in this category
1983	-----	17	13
	-----	18-22	51
	-----	23	36
1984	0.34	16	59
	0.34-0.45	20	31
	0.45	24	10

* Base bud also counted

SOIL MOISTURE

Soil moisture changes were followed during the growing season at both locations. Samples of 90 cc of soil were taken (0-20 and 20-40 cm depth) in each experimental block of the study, wrapped in polyethylene bags weighed, later oven-dried for 24 hr at 105 °C, and then weighed again. Soil moisture was determined by substraction. Tensiometers were placed at 30, 60 and 90 cm depth within the rows at appropriate locations within the plot based on its topography (Figs 2 and 3). These tensiometers were used also to follow soil moisture tension changes at those levels in the soil (Figs. 2 and 3).

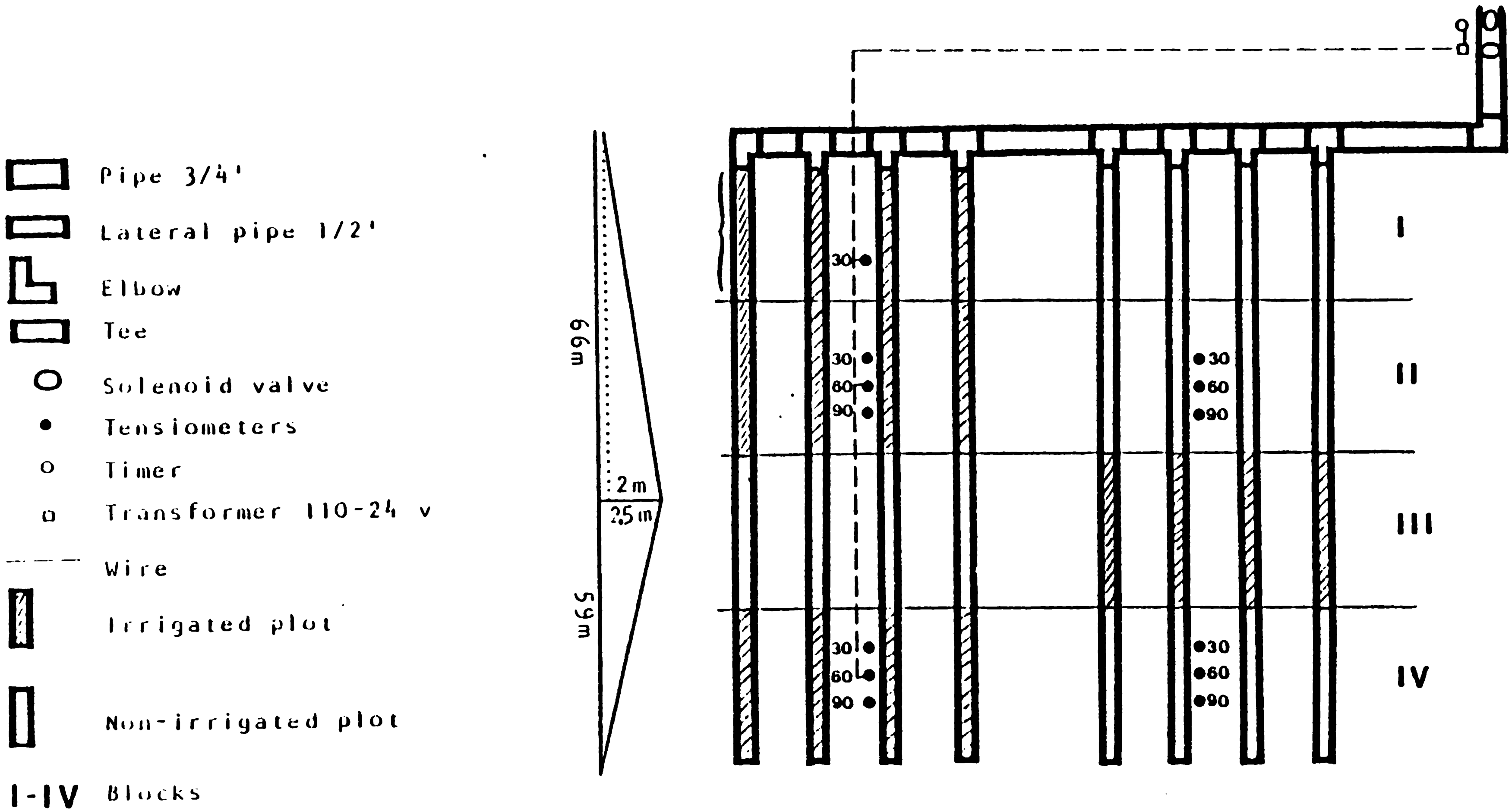


Figure 2. Schematic layout of the Concord drip irrigation research plot at Lawton, Mi. showing the topography of the plot and the position of tensiometers.

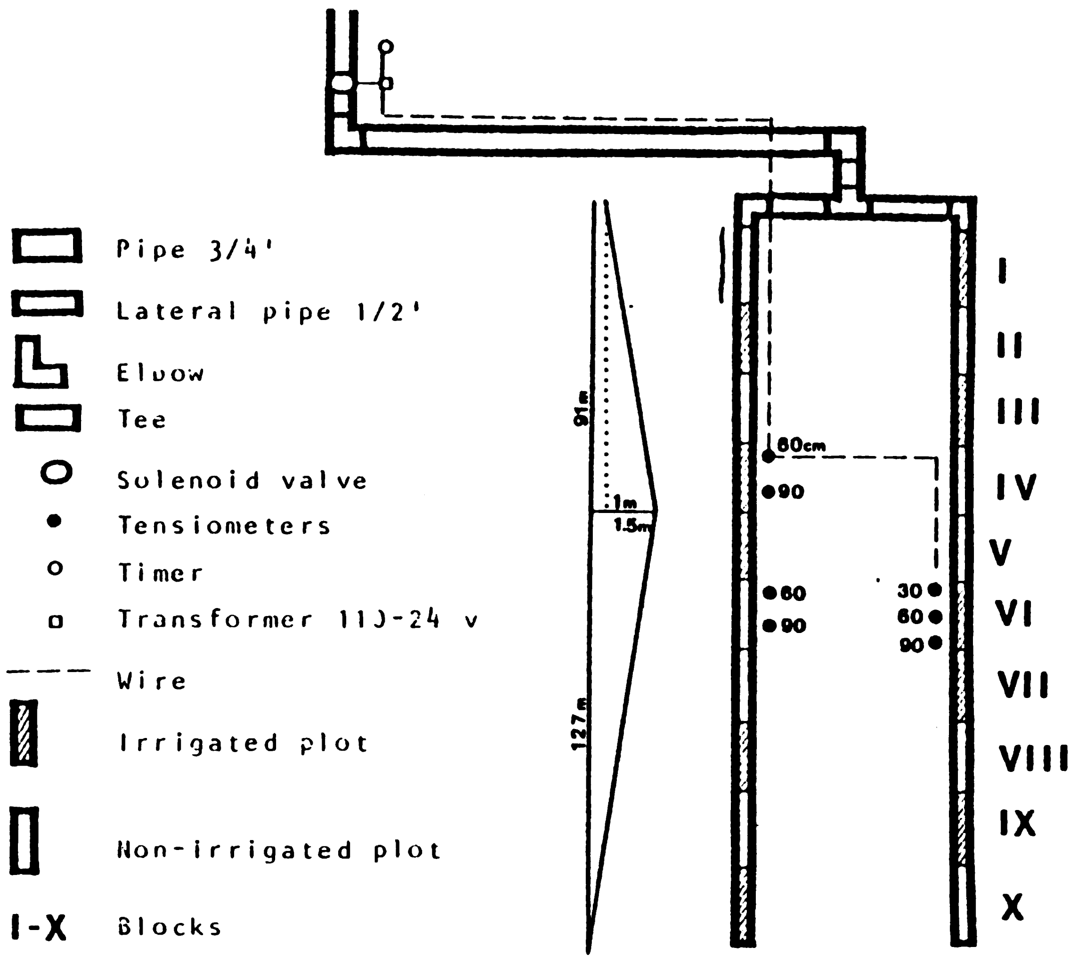


Figure 3. Schematic layout of the Seyval irrigation research plot at Fennville, MI. showing the topography of the plot and the location and depth of tensiometers.

IRRIGATION LAYOUT

Vines were either a non-irrigated control or irrigated during the growing season to mantain an adequate soil moisture tension. Tensiometers (Model "RA"-Irrometer, Co.) were used to produce automatic irrigation control.

Lawton: In 1983, three tensiometers (model "RA") were put at 60 cm and connected in series (wire No. 14 solid direct burial UF-UL listed) which controlled the 24 volt solenoid valve (3/4', 240-06-03) Figure 2. The tensiometer controls were set at -0.20 bars which would prevent the soil from getting below the soil moisture tension at field capacity for these kind of soils (-0.33 bar, 58). The system was set such that each of the 3 tensiometers needed to be -0.20 bars or more negative to initiate the operation of the system. This was unaceptable because the irrigation system at Lawton did not turn on during 1983. In both locations the electrical connections were in series and the depth of tensiometers set at 60 cm. In Fennville the irrigation system applied only 17.2 m3/ha. In 1984 the electrical layout and the depth of tensiometers was changed in 1984 to provide a better response to inadequate soil moisture in the root zone of the vines. Therefore, in 1984 tensiometers (model "RA") were set at 30 cm and the electrical layout connected in parallel so any given tensiometer could turn on the system when SMT was at -0.20 bars.

Two emitters (3.785 l/hr) were placed 60 cm from the trunk on each side of the vine (Fig 1 B). The time of irrigation was recorded by a the timer (Fig. 2) so that the amount of water applied could be calculated.

COLLECTION OF DATA

VINE DATA

Each year both vegetative and reproductive yield were estimated as weight of cane prunings and fruit weight and quality indices respectivelly. The weight of cane prunings was taken in the Spring prior to bud burst and the allocation of bud number per vine made at the same time.

At harvest, each vine was individually harvested and the fruit weight and the number of clusters per vine recorded. This allowed a calculation of cluster weight. Concord clusters were individually sampled for 50 berries (5 apical berries from 10 clusters selected ramdomly, (63)). This sample was weighed to determine average berry weight and thus allow for a calculation of average berry set per cluster. These same 50 berries were then mascerated and the soluble solids measured using an Abbe refractometer (Model-3L, Bausch and Lomb, Inc.). This berry sampling procedure varied for Seyval grapes. The 50 berry sample was collected from the 5 vines within each block and in addition to weight and soluble solids, the pH and the titratable acidity were measured.

SOIL DATA

At two week intervals gravimetric soil moisture determinations and soil tensiometer readings were made, and the amount of water applied via irrigation was calculated.

RESULTS AND DISCUSSION

WEATHER

The weather patterns of Michigan (Lawton, Fig. 4 and Fennville, Fig. 5) are characterized during the summer by high temperatures and evaporation, and low precipitation. This situation increases vine transpiration and evaporation from the soil water.

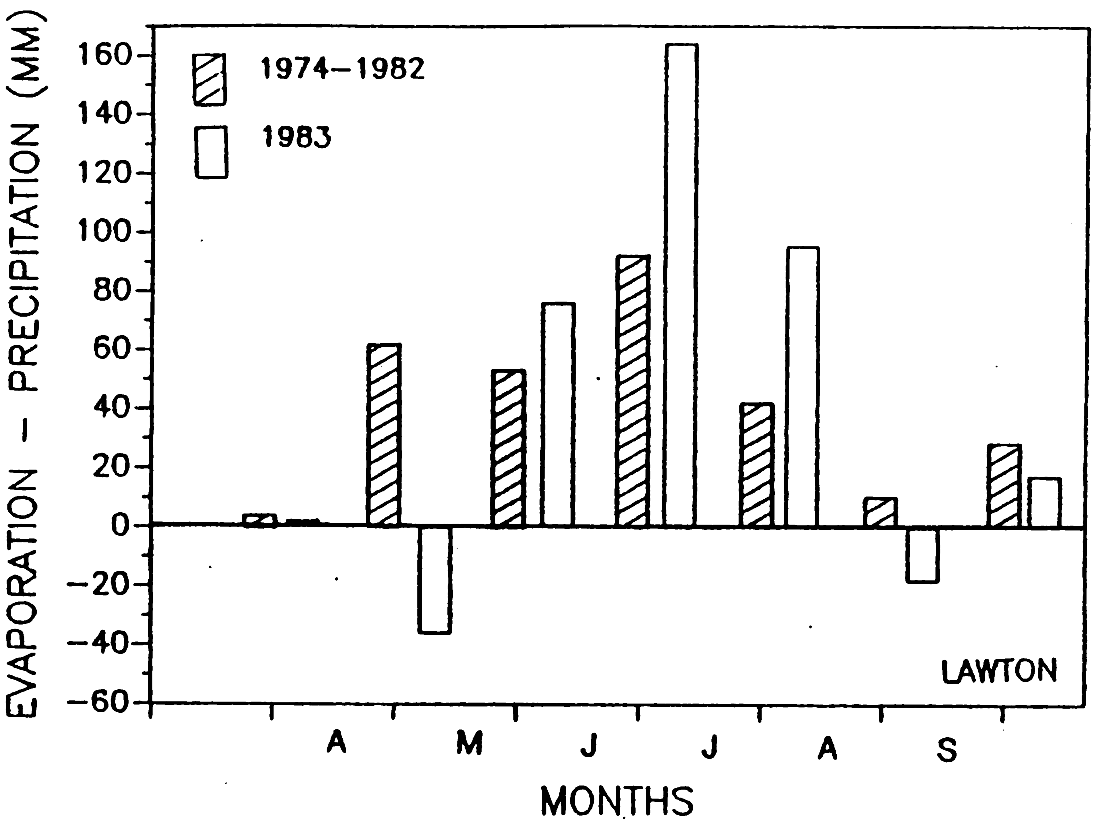
SOIL MOISTURE

Gravimetric sampling: The sandy-loam soils at both locations have a very low water holding capacity. The percentage of soil moisture in late June, early and mid-July were very low at both locations (Figures 6 and 7). There were areas where soil moisture varied among Blocks and this corresponded to changes in slope of the plot. In Lawton, Block I has the highest soil moisture level during the growing season while the Block IV has the lowest soil moisture level. At Fennville, Blocks VII, VIII, IX and X seemed to have a higher moisture content while the blocks I, II, III, IV, V and VI were lower.

Tensiometer readings: Tensiometers were a useful tool which helped to follow soil moisture tension (SMT) changes at 30, and 90 cm of depth. SMT was greater at 30 cm of depth while very minor changes occurred at the 90 cm depth.

The Fennville data (Figure 8) show those soil moisture changes at 30 and 90 cm of depth in an irrigated (I) and non-irrigated (NI) plot. SMT at 30 cm in the NI plot were more negative(up to -0.54 bars). At 90 cm in the non-irrigated plot SMT went up to -0.37 bars while in the

Figure 4. Monthly evaporation minus monthly precipitation and mean temperatures of the period 1974-1982, and during 1983 at Lawton, Michigan (Source: Agricultural Weather Service, Entomology Dept., Michigan State University, East Lansing, Mi.)


EVAPORATION – PRECIPITATION (MM)
160
140
120
100
80
60
40
20
0
−20
−40
−60
1974−1982
1983
LAWTON
A
M
J
J
A
S
MONTHS

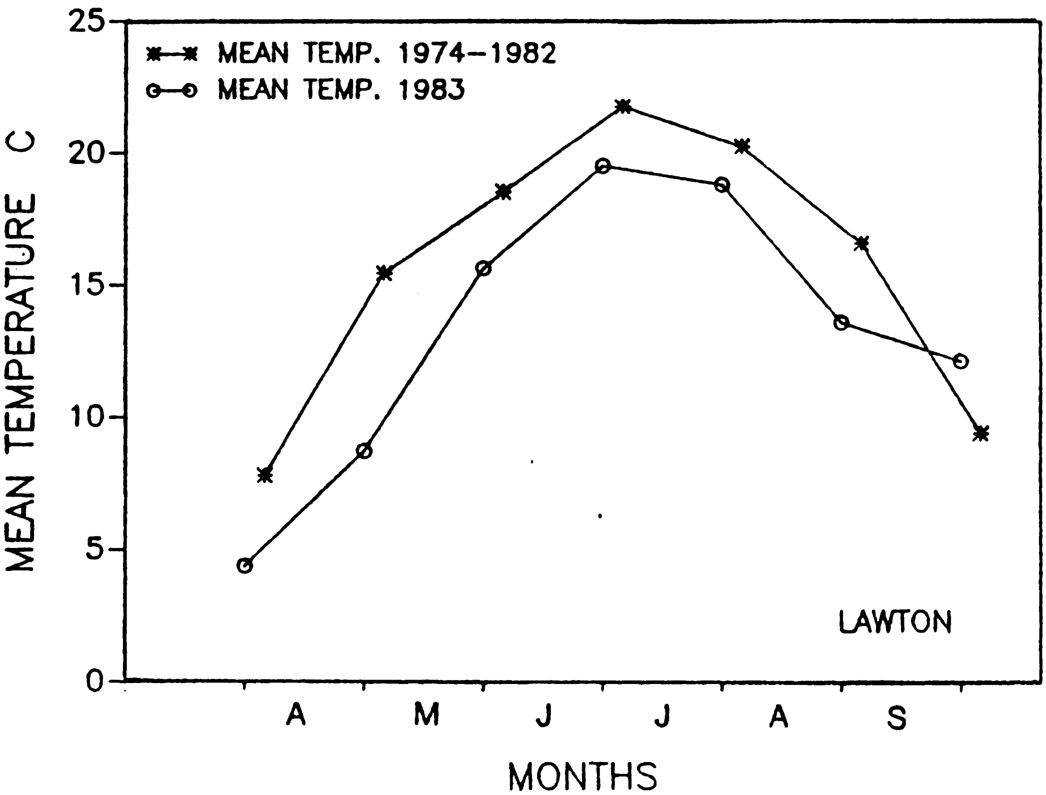
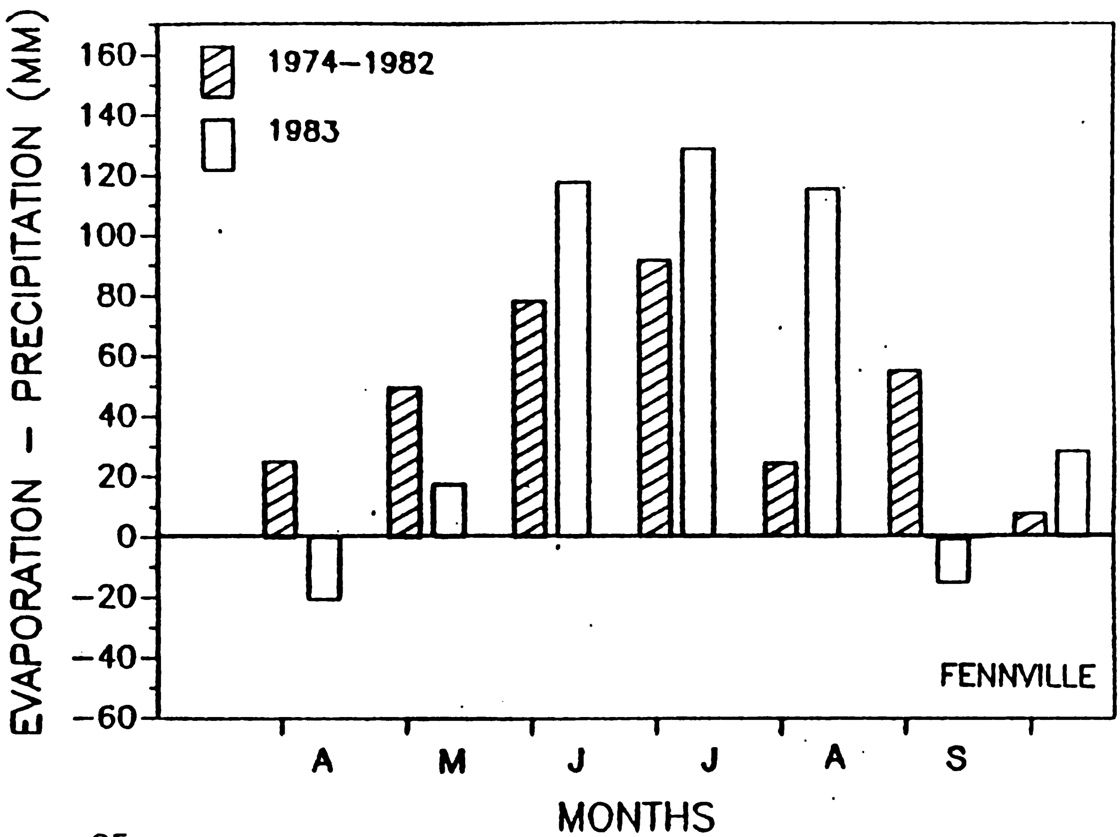

MEAN TEMPERATURE C
25
20
15
10
5
0
MEAN TEMP. 1974−1982
MEAN TEMP. 1983
LAWTON
A
M
J
J
A
S
MONTHS

Figure 5. Monthly evaporation minus monthly precipitation and mean temperature of the period 1974-1982, and during 1983 at Fennville, Michigan (Source: Agricultural Weather Service, Entomology Dept., Michigan State University, East Lansing, Mi.)


1974–1982
1983
EVAPORATION – PRECIPITATION (MM)
160
140
120
100
80
60
40
20
0
–20
–40
–60
FENNVILLE
A
M
J
J
A
S
MONTHS

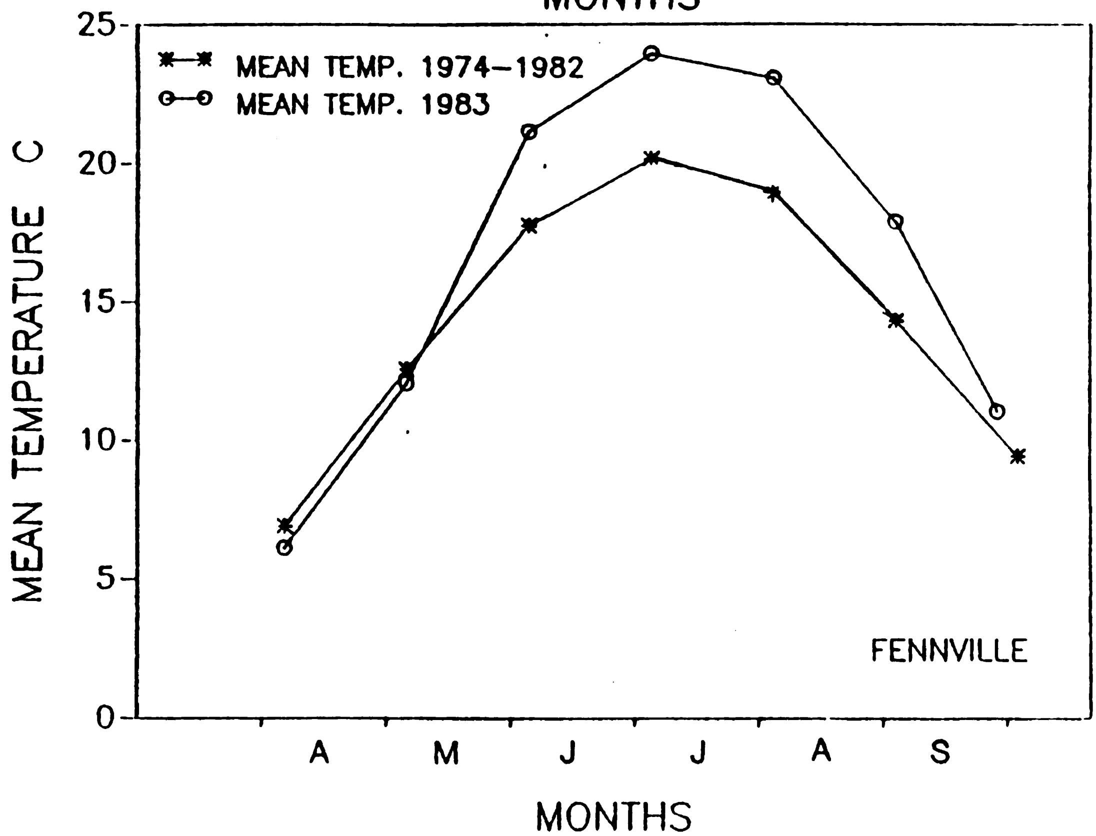
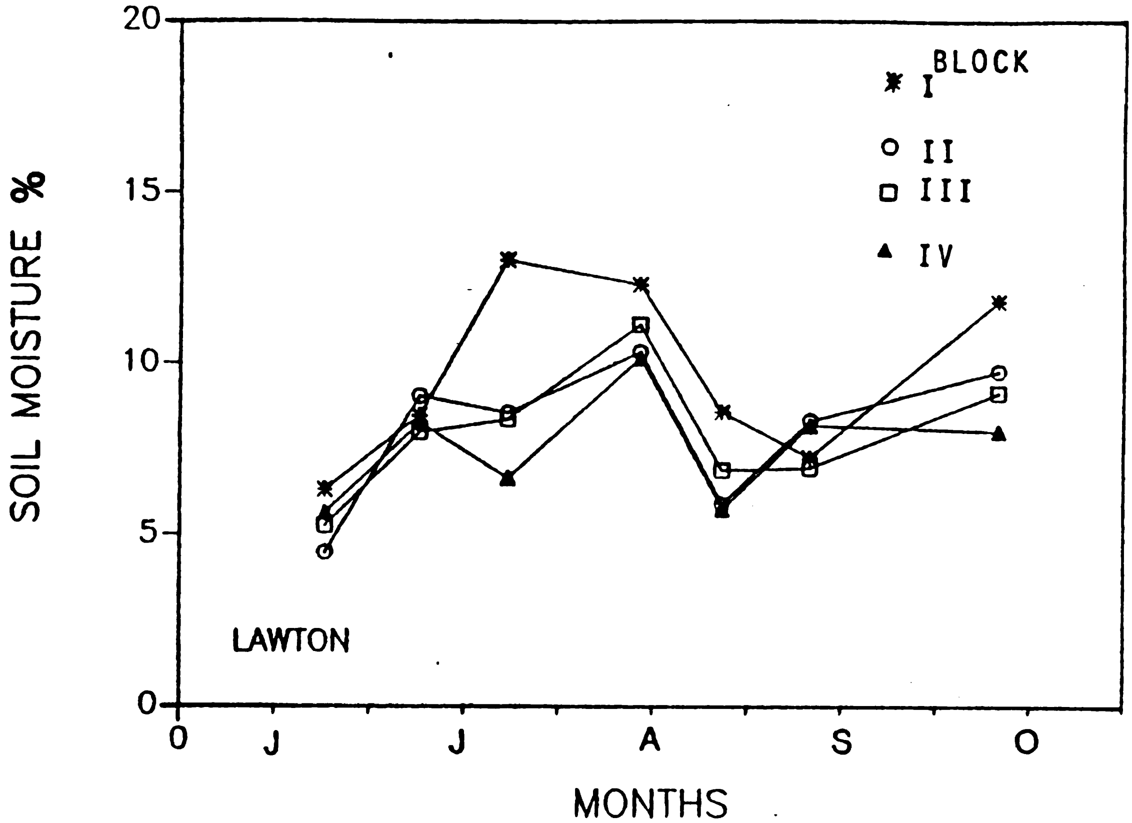
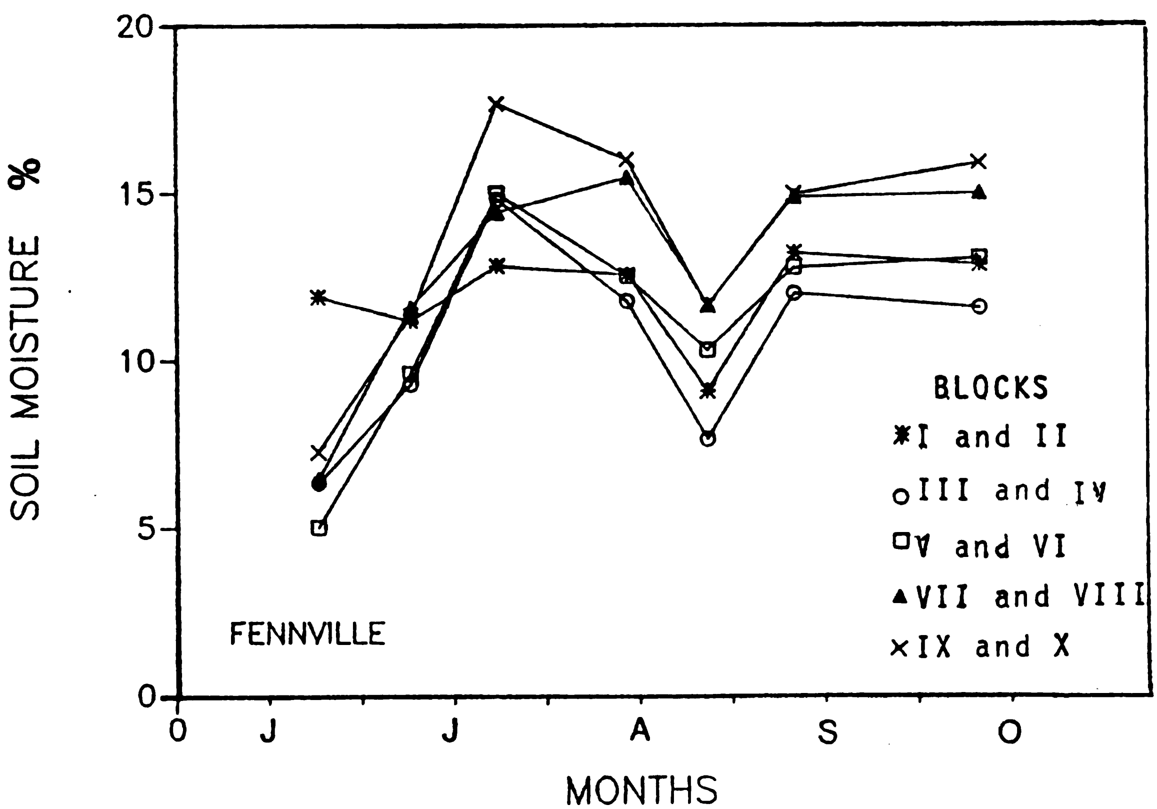

MEAN TEMP. 1974–1982
MEAN TEMP. 1983
MEAN TEMPERATURE C
25
20
15
10
5
0
FENNVILLE
A
M
J
J
A
S
MONTHS

Figure 6. Variation in soil moisture percentage within blocks during the 1983 season at Lawton, Mi. (For topography information of each block see figure 2).

Figure 7. Variation in soil moisture percentage within blocks during the 1983 season at Fennville, Mi. (For topography information of each block see figure 3). Soil moisture percentage for grouped blocks represent the averaged value.


BLOCK
I
II
III
IV
SOIL MOISTURE %
20
15
10
5
0
LAWTON
O
J
J
A
S
O
MONTHS


SOIL MOISTURE %
20
15
10
5
0
BLOCKS
I and II
III and IV
V and VI
VII and VIII
IX and X
FENNVILLE
O
J
J
A
S
O
MONTHS

irrigated plots SMT never were more negative than -0.32 bars at 30 cm and -0.18 bars at 90 cm deep that correspond approximately to the SMT at field capacity.

The statistical uniformity (10) due to the emitter flow rate for Lawton was 80.1 + 7.3 % and 91.0 + 1 % for Fennville . An emitter performance of 16.3 % for Lawton and 7.5 % for Fennville indicated that the emitter performance at Lawton was a little bit low and precautions must be taken to avoid any emitter plugging (Appendix A Table 16).

YIELD AND QUALITY COMPONENTS

Lawton: Because the experiment did not have irrigation during 1983, the initial experiment design (Randomized complete block - split plots) could not be applied. However, the soil moisture accumulated for samples taken (June 10 and 23, July 8 and 22, August 12 and 25, September 8 and October 8) provided an opportunity for regression analysis for the different variables shown in Table 3. No association of the soil moisture was related to cane weights or bud number either year, cluster number (1983), yield and Brix (1983).

Fennville: An irrigation treatment equivalent to 17 m3/ha of water did not have any effect on: cane weights (1984), berry weight, yield/vine, Brix, pH and titratable acidity of 1983.

Supplemental irrigation, like many other vineyard practices, may not have an immediate effect and will not have an effect until the following year (1984) when the effect of irrigation during 1983 may be observed due to the better conditions of soil moisture that existed

Figure 8. Soil moisture changes during 1983 at Fennville, Mi. in irrigated (I) and non-irrigated (NI) plots.

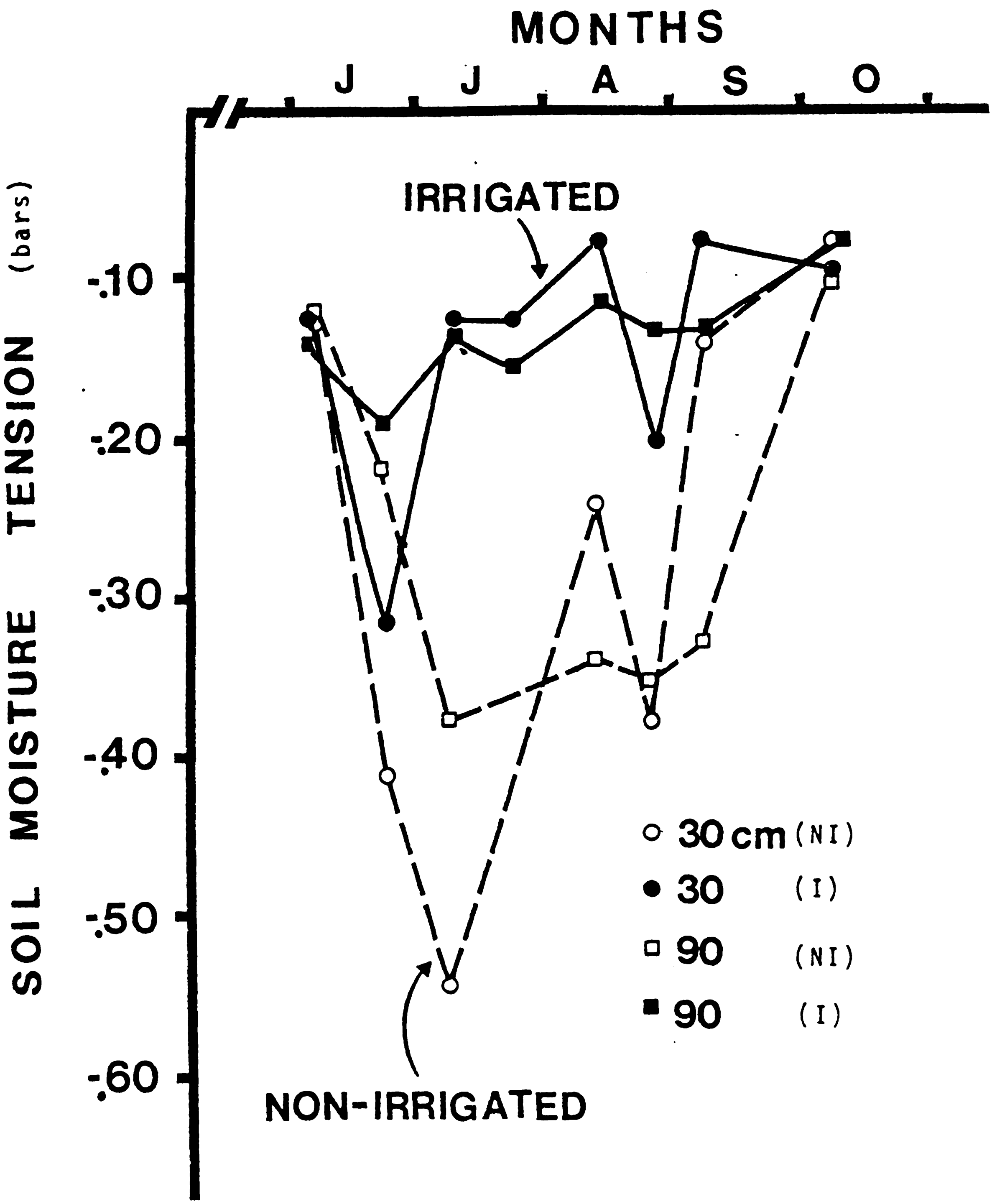


Table 3. Soil moisture, yield and quality components of Concord grapevines at Lawton, Michigan (1983-1984).

VINE SIZE Kg	BLOCK	SOIL MOISTURE 1983*	CANE WEIGHT Kg 1983	CANE WEIGHT Kg 1984	BUD NUMBER 1983	BUD NUMBER 1984	CLUSTER NUMBER	YIELD Kg/vine	BRIX	BERRY WEIGHT (50 Berries)
≤ 0.8	Ia	70.5	0.60	0.78	34	37	110	13.68	15.6	153
	b	64.7	0.47	0.68	32	35	125	14.80	16.0	150
	IIa	56.4	0.59	0.75	33	37	96	11.02	15.6	169
	b	56.1	0.59	1.12	34	45	120	14.16	15.6	160
	IIIa	57.7	0.60	1.01	34	42	106	12.94	15.8	163
	b	53.5	0.59	0.76	33	38	90	12.00	15.4	171
	IVa	55.8	0.60	0.78	34	37	101	11.92	15.6	157
	b	49.2	0.49	0.99	32	41	116	13.91	15.7	161
AVERAGE			0.57	0.86	33	39	108	13.05	15.7	161
0.9-1.4	Ia	70.5	1.15	0.96	45	41	127	16.50	15.0	156
	b	64.7	1.11	1.12	44	44	148	19.13	15.7	157
	IIa	56.4	1.11	1.12	44	45	118	15.21	15.3	166
	b	56.1	1.10	0.89	44	35	134	16.60	16.0	158
	IIIa	57.7	1.07	1.08	44	43	131	16.92	15.7	162
	b	53.5	1.20	1.02	46	43	122	16.11	15.2	162
	IVa	55.8	1.00	0.87	42	41	105	13.98	14.8	164
	b	49.2	1.13	1.01	45	43	148	17.84	15.6	155
AVERAGE			1.11	1.01	44	42	129	16.54	15.4	160
≥ 1.5	Ia	70.5	1.66	1.31	57	49	116	16.56	15.2	156
	b	64.7	1.80	1.22	59	47	158	19.92	15.5	159
	IIa	56.4	1.67	1.36	57	50	126	15.52	15.3	157
	b	56.1	1.83	1.38	58	50	130	17.05	15.8	159
	IIIa	57.7	1.67	1.49	57	52	156	20.93	15.9	159
	b	53.5	1.69	1.32	56	49	125	17.30	15.8	164
	IVa	55.8	1.86	1.51	61	53	131	17.46	15.4	157
	b	49.2	1.91	1.31	58	47	129	16.22	15.1	160
AVERAGE			1.76	1.36	58	50	134	17.62	15.5	159

* :Soil moisture expressed as the sum of soil moisture percentages found from bud burst to harvest by gravimetric sampling every 2-4 weeks.
a :Plot of irrigation
b :Plot of no-irrigation

... irrigation treatment on yield and quality components of irrigated (I) and non-irrigated (NI) Seyval grapes at Fennville, MI. 1984.

TREATMENT	BUDS RETAINED	CANE WEIGHT	CLUSTERS/	BERRIES/	YIELD	BRIX

TABLE 4. Effect of irrigation treatment on yield and quality components of irrigated (I) and non-irrigated (NI) Seyval grapes at Fennville,Mi. 1983.

TREATMENT	BUDS RETAINED	CANE WEIGHT gr/vine (1984)	CLUSTERS/ VINE	BERRIES/ CLUSTER	YIELD Kg/vine	BRIX	pH	TA gr/100ml
I	21	254 NS	42	98	7.16 NS	21.3 NS	3.49 NS	0.74 NS
NI	21	295 NS	41	98	7.03 NS	21.8 NS	3.43 NS	0.77 NS

NS: ANOVA-2 with no statistical differences.

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formation. Good soil moisture supply during the differentiation of flower primordia will improve the fruitfulness of vines (Buttrose, 1974; Alleweldt and Hofacker, 1975) under areas with limited water supply during this stage.

GENERAL COMMENTS AND EXPERIMENT SUGGESTIONS FOR FURTHER FIELD STUDIES

1. Most of the soil moisture fluctuations that may cause a low water availability occur in the top 30 cm of the soil profile. Fruit crops that have a shallow root system will be more often under stress due to the lack of water than those with a deeper root system (56). Therefore, it is necessary to consider the following studies:

(a) Root distribution studies: There is some information on Concord grapes (56) where its root system was characterized as having more than 35% on the top 0-15 cm depth. No information is currently available for Seyval grapevines.

(b) Selection of cultivars and rootstocks: Cultivars and rootstocks with a deeper root system could grow better in the sandy-loam soils of Michigan than those cultivars with a shallow root distribution. This is because a deeper root system has a better chance to obtain water from the soil at deeper levels.

2. Connecting the tensiometers (model RA) in series with the solenoid valve and located at a depth of 60 cm in the soil was unacceptable because the irrigation system at Lawton did not turn on during 1983. All of the tensiometers that controlled the solenoid valve needed to have a soil moisture tension higher than -0.2 bars to turn the

irrigation system on. This caused problems because during the growing season some areas in the vineyard where drier than other (e.g. a tensiometer had a higher SMT than -0.2 bars while another or the other tensiometers indicated a lower SMT) and the irrigation system did not turn on. Considering this and the fact that the greater SMT fluctuations occurred in the top 30 cm of the soil profile, connection of the tensiometers was changed during 1984 to parallel to the solenoid valve and positioned at a depth of 30 cm. With the tensiometers connected in parallel, irrigation occurs whenever any of them reaches a SMT higher than -0.2 bars.

4. Drip irrigation in sandy or sandy-loam soils combined with the weather patterns of Michigan can have a greater impact in the establishment of new vineyards and/or young vineyards where the root system of grapevines is small.

5. In Michigan vineyards (sandy, sandy-loam soils) the practice of mulching with organic matter, or the use of a cover crop and its incorporation into the soil, would improve soil water holding capacity Some Michigan growers are using cover crops such as rye; the crops are incorporated into the ground in August to improve the soils. However, cover crops may increase competition for water and nutrients.

SENSITIVITY OF GROWTH AND STOMATAL CONDUCTANCE OF CONCORD AND SEYVAL GRAPEVINES TO DROUGHT.

INTRODUCTION

Drought limits grapevine growth and berry development (68,28) development. Irrigation will ameliorate the effect of drought, but there is a need to identify appropriate timing and amount of water to be applied (28). Vine growth components have been used as an indicator of drought stress. So, one likely can be used as a physiological indicator of time to irrigate. Smart (68) observed that stomatal closure occurred at a leaf water potential of -13 bars, but shoot growth rate and trunk shrinkage started at a lower soil moisture tension (SMT). It is also important to identify the critical soil moisture that causes the growth components and stomatal conductance to decline. This will tie vine physiology with a critical SMT which associated with the appropriate plant drought indicator should provide a workable basis for assesing grapevine water needs.

The objective of Experiment I was to measure the sensitivity of different growth components to water stress. These growth components measured were: shoot elongation (rate of growth of main and lateral shoots), cumulative shoot diameter and its daily fluctuation, leaf area rate of growth and stomatal conductance.

The objective of Experiment II was to measure the response of the same vine criteria to a cyclic, short-term, drought stress on Concord vines.

MATERIALS AND METHODS

The following two experiments were done to quantify the sensitivity of growth and stomatal conductance of Concord and Seyval grapevines:

EXPERIMENT I. Drought sensitivity of different growth components of Concord and Seyval grapevines.

EXPERIMENT II: The effect of a cyclic, short-term drought on Concord grapevines.

VINES

Two-year-old Concord (*Vitis labruscana* Bailey) and Seyval (Seyve-Villard 5-276, Galet, 1979) (Experiment I) and three-year-old Concord vines (Experiment II) were transplanted into pots with a volume of 19 liters and placed in a greenhouse with an average mean temperature of 24°C, a mean maximum of 27°C, and a mean minimum of 21°C with a range of ± 4°C during the experiments. The vines were irrigated every other day and after one month experiments were initiated.

Vines were pruned back to 1 bud and one shoot per vine was allowed to grow (Experiment I). In Experiment II, and to two buds per vine were retained so that two shoots were produced.

SOIL

In Experiment I, a mixture of 1:perlite:1 sandy loam soil was employed, while a and 2 sand:1 perlite:1 loamy soil mixture v:v:v was used to produce a coarse texture and allow rapid water depletion conditions in Experiment II. The bottom of each pot had a 2.5 cm layer of gravel (0.4-0.8 cm) to allow better conditions for aeration and drainage. Vines were fertilized at the begining of the study with 1 liter of soluble fertilizer (Peters 20-20-20) to yield 400 mg/l N.

The water holding capacity of the soil in the pots (70) of Experiment II was 18.3 % , and the PWP was 3.1 % (see determination method in Appendix).

PLANT INDICATORS QUANTIFIED

The response of different physiological plant indicators of drought stress was measured during the study to find the critical soil moisture that modified the natural growth and development of the vines.

GROWTH COMPONENTS

Shoot elongation: In Experiment I, the length of main and lateral shoots (in 12 and 4 vines respectively) was measured with a measuring tape daily at 07:00-7:45 hrs. In Experiment II, measurements were taken every other day prior to drought treatment and then daily at 07:00-07:45 hrs on 5 vines per treatment. Rate and cumulative shoot elongation of main and lateral shoots were then calculated by dividing the daily increase in growth by the unit time (day).

Shoot diameter: In Experiment I, shoot diameter was measured each day at 06:30-07:00 hrs and 15:00-15:30 hrs. A tag was attached to the first internode to insure precise point of measurement, and measurements were made with a digital micrometer (accuracy of .01 mm, Mitutoyo, Co) at the same position.

Trunk growth: In Experiment II, the increase in trunk diameter of vines was measured with linear transducers (TransTek Inc, CONN) which were attached to 3 control and 3 treatment vines. The transducers measured with an accuracy of 0.01 mm. Measurements at 06:00 hrs of every day were considered for cumulative increase of trunk diameter.

Leaf area: Leaf area of the 4 uppermost leaves of 4 vines per treatment (Experiment I) were measured every day at 07:00-07:45 hrs. as shown in Fig. 9 and leaf area rate of growth (LARG) was calculated. Measurements in Experiment II were taken every other day at 07:00-7:15 hrs.

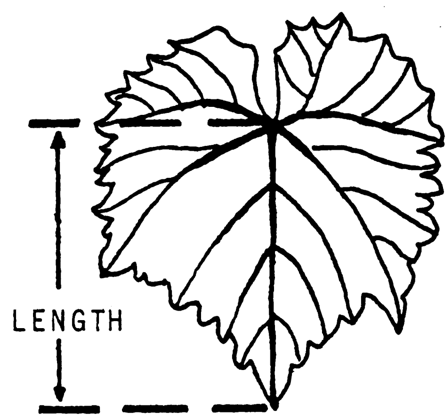


FIG. 9. Seyval leaf showing procedure for determination of leaf area.

Calculation of leaf area was done by measuring the length of the leaf blade, squaring its value and then substituting this value as "x" in the equation Y=0.842 X + 4.121, this gave a correct assessment (r=.96) of the leaf area (Y) on Concord grapes given by a Leaf area meter (LICOR 3000). A similar procedure was followed to obtain leaf area by substituting the squared leaf area value as "x" in the equation Y=0.912 + 8.815 (r=0.91) at the initiation and at the end of the study and its percentage of increment calculated in Seyval grapes.

Total leaf area for each experimental vine was determined with the same method at the end of the study (Experiment I) or by using the leaf area meter (Experiment II).

Dry matter: At the end of Experiment I vines were partitioned and oven-dry at temperature of 60 °C during 3 weeks, and dry weight of vegetative components obtained.

STOMATAL APERTURE

In Experiment I, stomatal resistance (sec/cm) which is an estimate of the stomatal aperture was taken about every other day at 15:30-16:00 hrs with a porometer (Model Licor-60, Li-Cor Inc., Lincoln, NE.) and expressed as stomatal conductance (g_s in cm/sec) which is the inverse of resistance. This measurement was done on the youngest fully expanded and well exposed leaf of each vine and on the abaxial side of the leaf. Calibration of the porometer LI-60 was done every week during the experiment according to the company's recommendation.

In Experiment II, stomatal resistance (sec/cm) measurements were taken and stomatal conductance (cm/sec) was measured on the abaxial surface of the exposed youngest fully expanded leaves of each shoot of the vine being examined so the two readings per vine were averaged. A steady state porometer (LICOR INC., MODEL 1600) was used for taking measurements during the period prior to stress (11:30 am and 15:30 pm) from April 11-17 and then 3 or 4 times each day from May 5-10.

Environmental conditions in the greenhouse during Experiment II at the time of measurements are shown in Tables 5 and 6.

EXPERIMENTAL DESIGN

The experimental design used in Experiment I was a randomized complete block with two irrigation treatments and two cultivars. Irrigated (I) and non-irrigated (NI) Concord and Seyval grapevines with 4 replications per treatment combination were involved and 1 vine per replication. A completely randomized design was used in Experiment II.

DROUGHT STRESS TREATMENTS

In Experiment I, water was withheld to induce drought stress in the non-irrigated treatment, while the irrigated treatment vines were watered every other day maintaining the SMT less than -0.2 bars in the pots .

In Experiment II, drought stress was applied by withholding watering at different stages (Figure 11). Rye grass was planted into the pots to induce a faster depletion of soil moisture.

Recovery of drought stressed vines was considered when their rate of shoot elongation and stomatal conductance became same as the irrigated vines.

Figure 10. Watering practices on Concord grapevines, (I) irrigation and (S) no irrigation period.

IRRIGATION TREATMENT		PERIOD IN DAYS I II III IV
CONTROL	(C)	IIIIIIIIIIIIIIIIIIIII *
IRRIGATED-STRESSED-IRRIGATED	(ISI)	IIIIIIIIIIIISSSSIIIII
STRESSED-IRRIGATED-STRESSED-IRRIGATED	(SISI)	SSSSIIIIIIIISSSSIIIII
STRESSED IRRIGATED	(SI)	SSSSIIIIIIIIIIIIIIIII

* Each I or S represent 1 day during the experiment, except in period II where each I is 2 days.
Period I Drought stress period for SISI and SI grapevines.
Period II Recovery period for vines stressed at stage I
Period III Previously stressed SISI vines were stressed a second time and compared with vines that experience first time stress.
Period IV Recovery for stressed vines.

Table 5. Environmental conditions at the time of stomatal conductance measurements. Air temperature (T °C), relative humidity (RH %) and photosynthetic photon flux density (PPFD µmol/m^{2}s.) April 11-17.

DATE	PARAMETER	TIME OF DAY (HRS) 11:30	15:30
April 11	T °C	29.3	28.3
	RH %	50.0	18.0
	PPFD µmol/m^{2}s	1467.0	112.7
April 12	T	27.2	27.2
	RH	25.6	17.0
	PPFD	1161.0	1170.0
April 13	T	30.2	26.3
	RH	30.6	29.1
	PPFD	958.0	368.0
April 15	T	24.3	27.3
	RH	38.1	24.4
	PPFD	831.0	426.0
April 16	T		27.1
	RH		24.2
	PPFD		305.0
April 17	T	27.2	26.3
	RH	23.8	24.5
	PPFD	333.0	332.0

Table 6. Environmental conditions when stomatal conductance measurements were taken. Air temperature (T °C), relative humidity (RH %), and photosynthetic photon flux density (PPFD μmol/m^2 s). May 5-10.

DATE	PARAMETER	7:30	9:30	11:30	13:30	15:30	17:30
		TIME OF DAY (HRS)					
MAY 5	T °C			29.0		27.8	
	RH %			35.0		36.0	
	PPFD μmol/m^2 s			778.0		875.0	
MAY 6	T			30.6	31.7	28.3	27.8
	RH			29.9	20.4	23.6	22.0
	PPFD			946.0	741.0	348.0	438.0
MAY 7	T	24.4	27.2			27.3	25.6
	RH	34.8	38.0			35.1	23.4
	PPFD	762.0	147.0			752.0	260.0
MAY 8	T			25.0	26.4	25.6	
	RH			31.1	24.7	20.8	
	PPFD			77.7	214.0	117.0	
MAY 9	T			26.4		26.1	
	RH			30.1		31.0	
	PPFD			186.0		327.0	
MAY 10	T			29.4			
	RH			27.7			
	PPFD			217.0			

RESULTS AND DISCUSSION - EXPERIMENT I

The linear regression equations of the different plant indicators were studied and their relationship with the change in time (Figs. 11 and 12) were taken as a basis for determining the sensitivity of each to drought. The order of sensitivity was given by the value of the slope and the percent variability associated with the change in time. The greater the slope and the percent variability of the plant indicators associated with the change in time indicated the greater sensitivity of the given plant indicator.

CONCORD

The rate of shoot elongation (RSE) appeared slightly more sensitive than stomatal conductance (g_s), but the slopes were generally identical. The RSE and g_s 70% (r=-0.84) and 45% (r=-0.67) of their change was associated with the change in time and hence SMT changes in the soil (Fig. 11). This agrees with Hsio (32) who reported that in general cell growth as more sensitive than stomatal conductance to drought stress and with Smart (68) who reported shoot elongation more sensitive than stomatal conductance in grapevines. Of lesser sensitivity were leaf area rate of growth (LARG) (r=-0.44) and shoot diameter fluctuation (r=-0.67) respectivelly. Neither of these two plant indicators showed a strong change associated with changes under drought stress (Fig. 11).

SEYVAL

Seyval RSE and g_s values were similar to Concord in their

Figure 11. Sensitivity of growth components and stomatal conductance to drought on Concord grapevines RSE: Rate of shoot elongation; LARG: Leaf area rate of growth; RDG: Rate of shoot diameter growth; g_s: Stomatal conducatance.

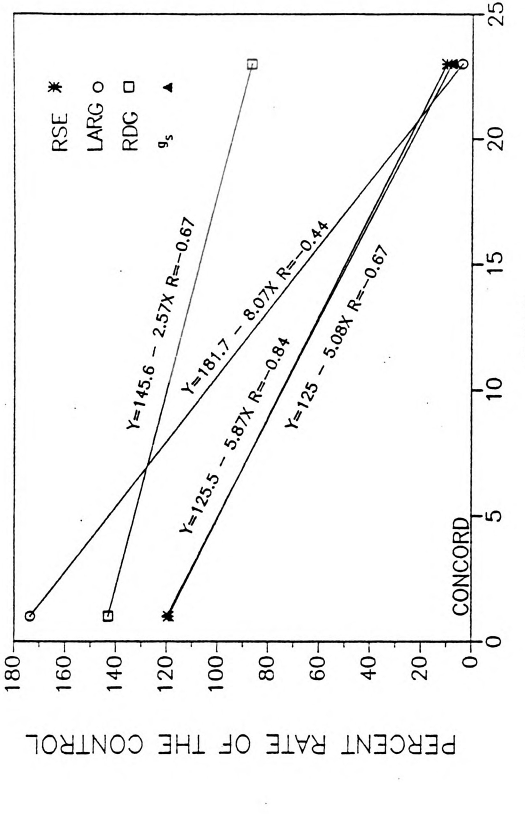
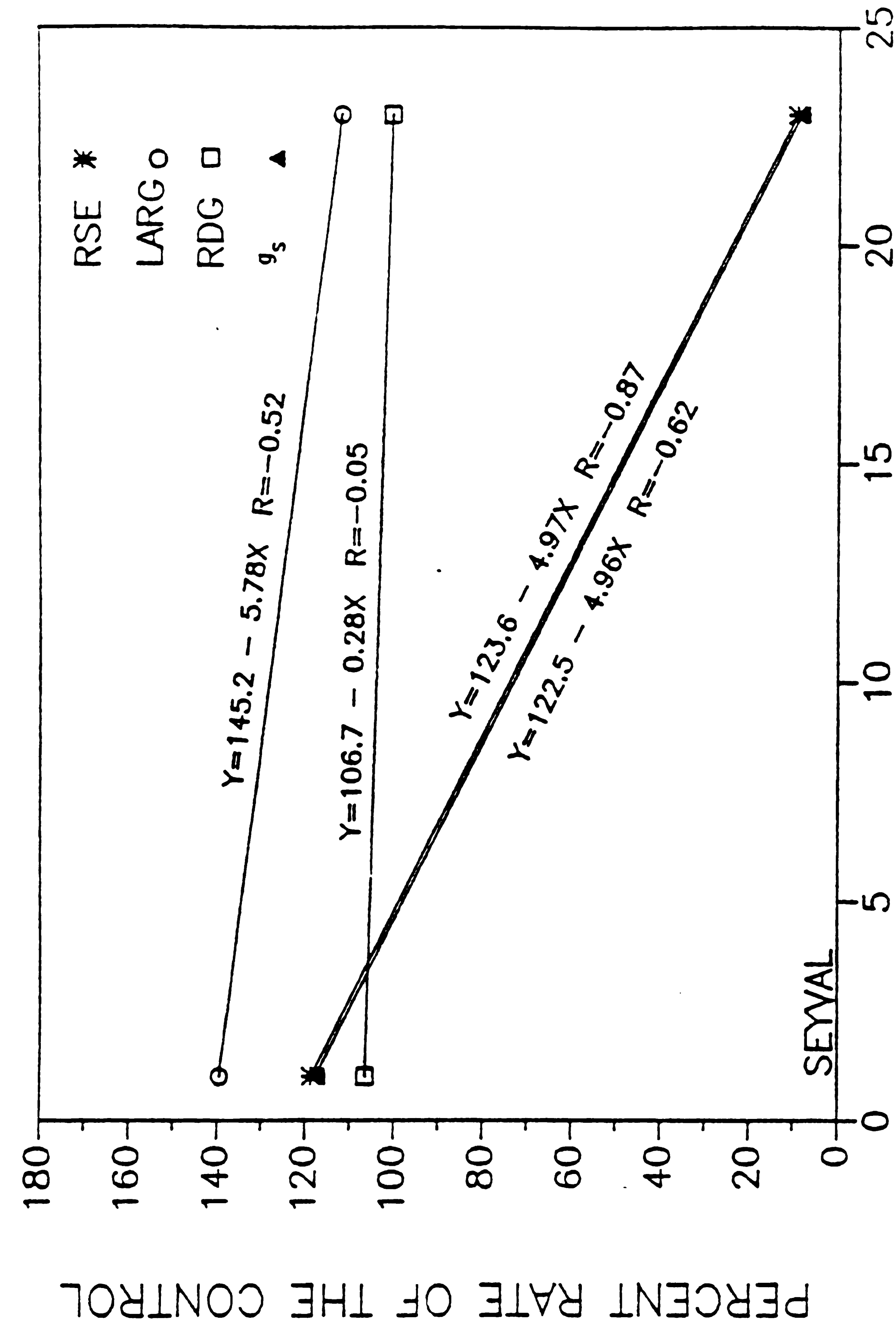

RSE
LARG
RDG
g_s
Y=145.6 – 2.57X R=–0.67
Y=181.7 – 8.07X R=–0.44
Y=125.5 – 5.87X R=–0.84
Y=125 – 5.08X R=–0.67
CONCORD
DAYS
PERCENT RATE OF THE CONTROL
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180

Figure 12. Sensitivity of growth components and stomatal conductance to drought on Seyval grapevines. RSE: Rate of shoot elongation; LARG: Leaf area rate of growth; RDG: Rate of shoot diameter growth; g_s: Stomatal conductance.


PERCENT RATE OF THE CONTROL
0
20
40
60
80
100
120
140
160
180
DAYS
0
5
10
15
20
25
RSE
LARG
RDG
g s
Y=145.2 – 5.78X R=–0.52
Y=106.7 – 0.28X R=–0.05
Y=123.6 – 4.97X R=–0.87
Y=122.5 – 4.96X R=–0.62
SEYVAL

sensitivity during the drought treatment as indicated by their slope's values. However, the percentage of the association with the time under stress was higher for RSE (75%; r=-0.87) than for g_s (43%; r=-0.62). This indicated a greater probability for RSE to be more sensitive to the time under drought than g_s. The LARG of the 4 uppermost leaves had a greater value in its slope than the RSE and g_s. However, the percent of association with the time under drought accounted only 27% (r=-0.52). The RSDG showed little sensitivity to the time under drought (r=-0.05) and its use as a indicator of drought in the grapevines seems questionable (Fig. 12).

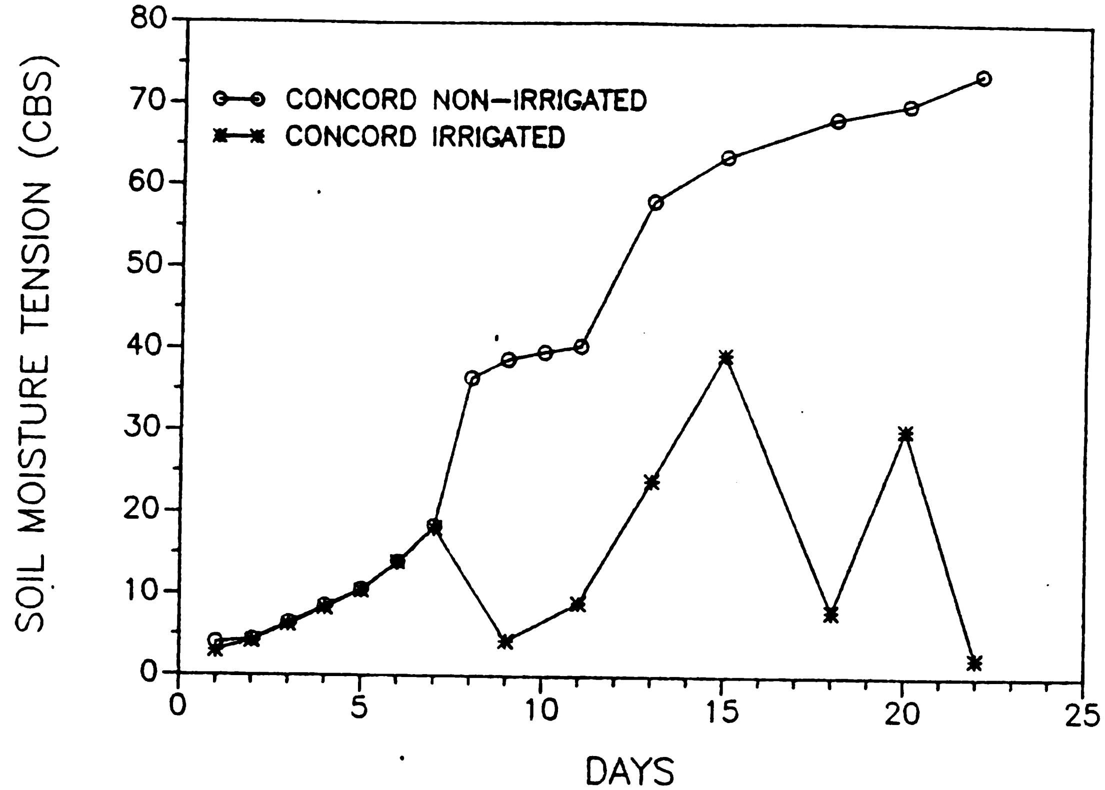
SOIL MOISTURE TENSION AND ITS RELATIONSHIP WITH PLANT INDICATORS

CONCORD

The rate of shoot elongation (RSE) appeared as one of the most sensitive and constant plant indicators of drought stress (Table 7). The RSE of irrigated and non-irrigated vines was statistically different at 8 % level on the 7th day after water was withheld (Table 7). However, the appearance of statistical differences may be related to a cause otherthan drought, or to measurement accuracy, or inadequate replication, because the soil moisture tension (SMT) of both control and non-irrigated vines was the same (Fig. 13. A). Therefore, statistical differences for RSE were considered to start on the 10th day of the study when the averaged SMT of the 4 vines reached -0.38 bars (Figs. 13.A and 13.B). Stomatal conductance was measured that day and no differences were found. Two days later, differences were observed on g_s but those differences did not continue on the 11 th day, while occurring

Figure 13.A. Changes in soil moisture tension (SMT) on irrigated and non-irrigated Concord grapevines.

Figure 13.B. Rate of shoot elongation affected by soil moisture tension changes on Concord grapevines.


SOIL MOISTURE TENSION (CBS)
CONCORD NON-IRRIGATED
CONCORD IRRIGATED
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
DAYS

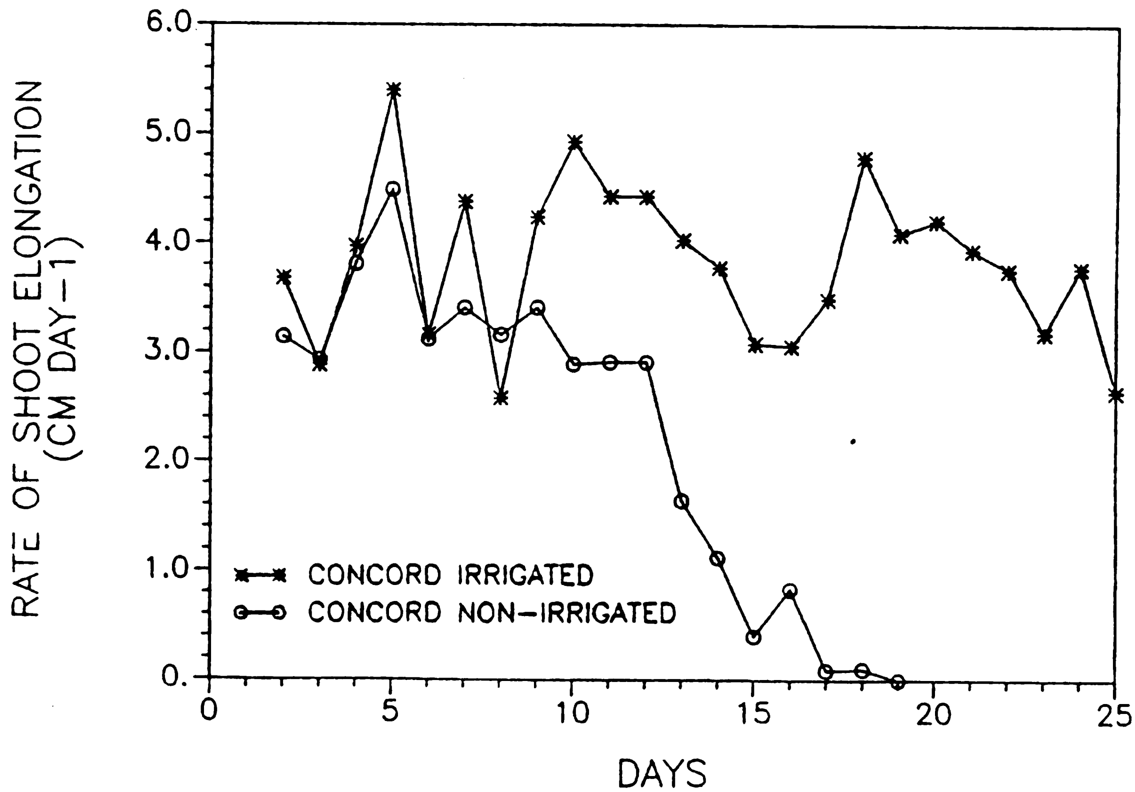
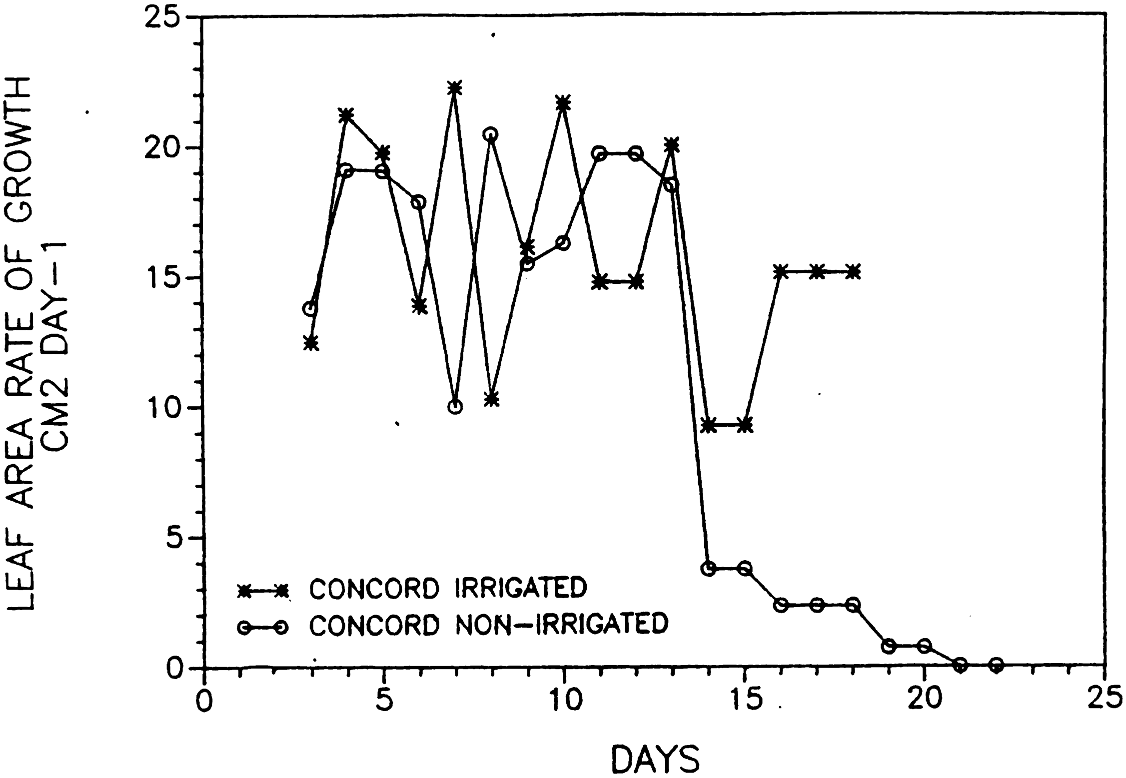

RATE OF SHOOT ELONGATION (CM DAY-1)
CONCORD IRRIGATED
CONCORD NON-IRRIGATED
0.
1.0
2.0
3.0
4.0
5.0
6.0
0
5
10
15
20
25
DAYS

Figure 14.A. Leaf area rate of growth affected by changes in soil moisture tension (SMT) on Concord grapevines.

Figure 14.B. Stomatal conductance affected by changes in soil moisture tension (SMT) on Concord grapevines.


LEAF AREA RATE OF GROWTH
CM2 DAY-1
DAYS
CONCORD IRRIGATED
CONCORD NON-IRRIGATED
0
5
10
15
20
25

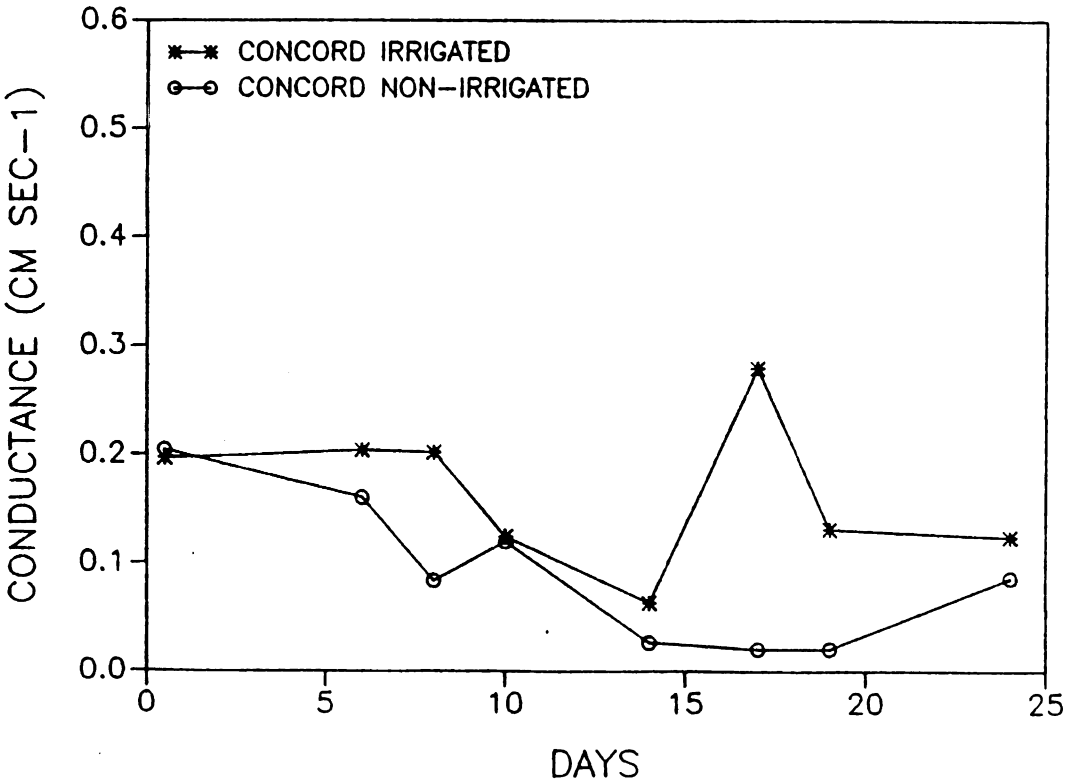
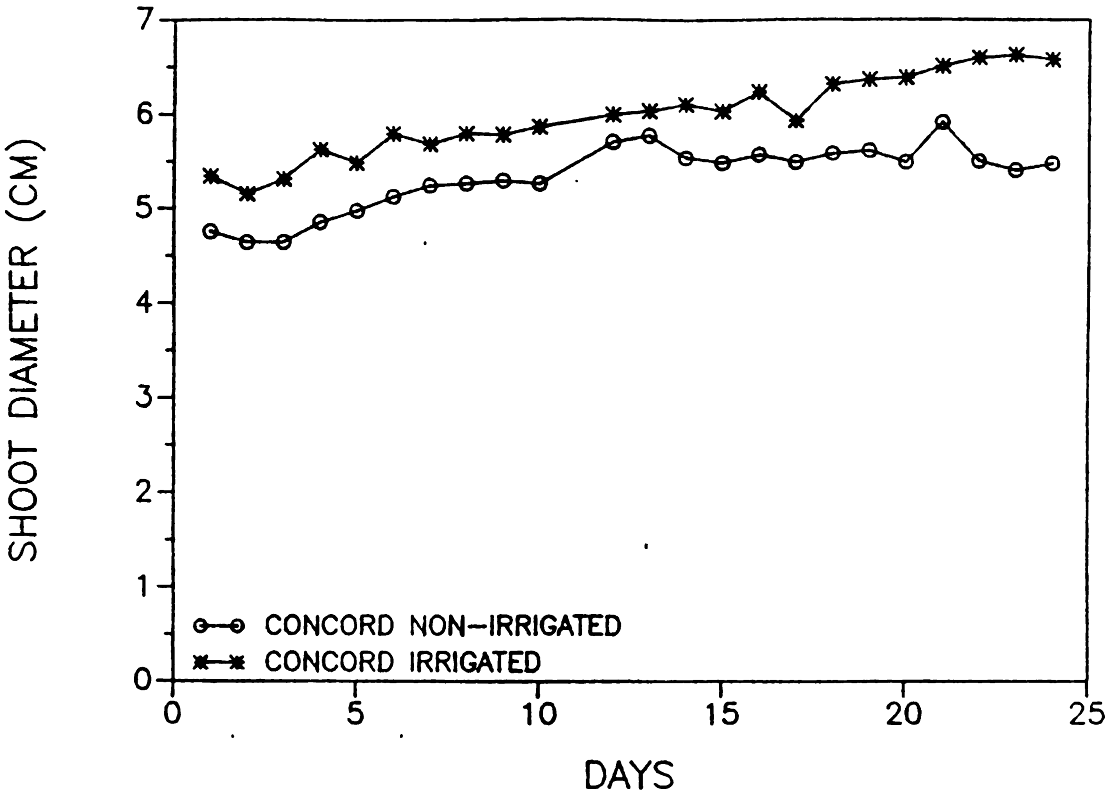
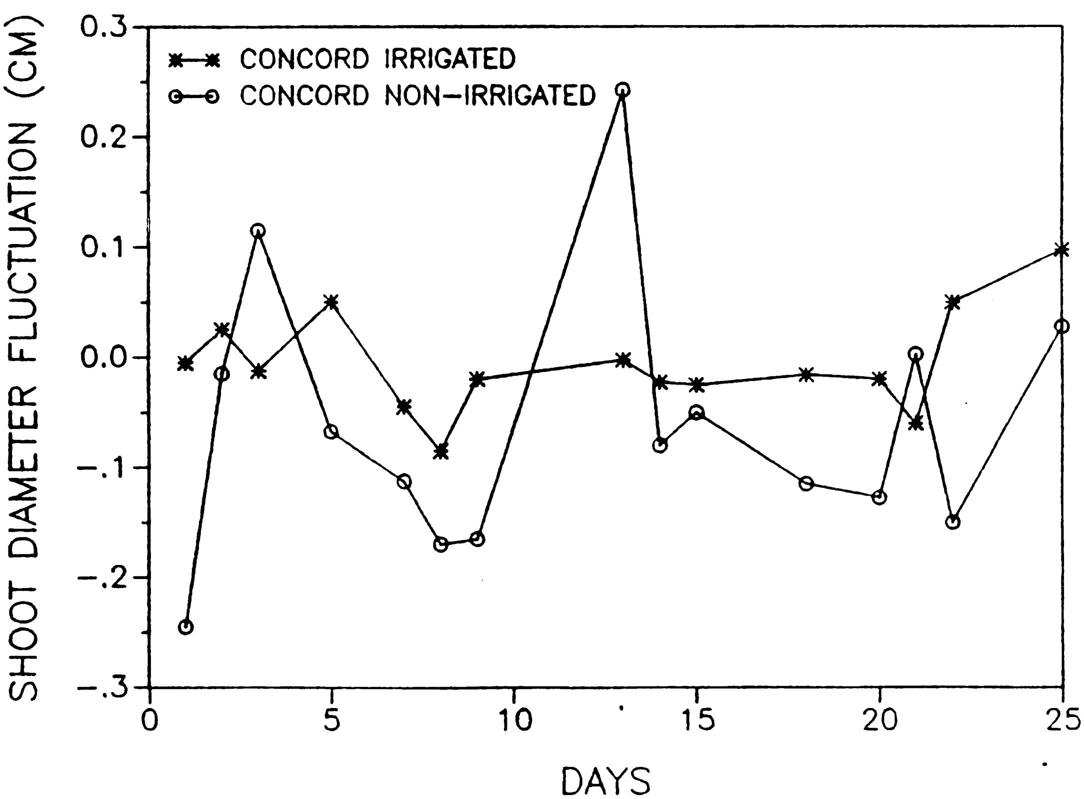

CONDUCTANCE (CM SEC-1)
DAYS
CONCORD IRRIGATED
CONCORD NON-IRRIGATED
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25

Figure 15.A. Cumulative shoot diameter affected by changes in soil moisture tension (SMT) on Concord grapevines.

Figure 15.B. Shoot diameter fluctuations affected by changes in soil moisture tension (SMT) on Concord grapevines.


SHOOT DIAMETER (CM)
DAYS
CONCORD NON-IRRIGATED
CONCORD IRRIGATED
0
1
2
3
4
5
6
7
0
5
10
15
20
25


SHOOT DIAMETER FLUCTUATION (CM)
DAYS
CONCORD IRRIGATED
CONCORD NON-IRRIGATED
0.3
0.2
0.1
0.0
-.1
-.2
-.3
0
5
10
15
20
25

again for RSE.

Soil moisture data (Fig. 13.A) indicated that the high SMT of the control treatment vines occurred on the 15th day could have masked the appearance of statistical differences for stomatal conductance that day. SMT in the control treatment vines reached -0.39 bars (Table 8) and stomatal conductance (Fig. 14.B) fell considerably close to that of the drought stress ones.

Shoot diameter measurements (Fig. 15.A) taken at 15:00 hrs. became significatively different on the 15th day (Table 7) at -0.64 bars (Table 8) while measurements at 07:00 hrs. started to show differences three days later. This suggests that the vines were recovering overnight as observed before (37,38) and the existance of a threshold moisture stress level where overnight recovery for shoot diameter could not occur (38).

Daily shoot diameter fluctuation did not appear statistically different during the study (Table 7). However, a marked trend was observed from the 7th to the 12th day of the study where shoots of drought stressed vines shrank more than unstressed vines (Fig.15.B).

Leaf area rate of growth (Fig. 14.A) of the four uppermost leaves of the shoots did not appear as sensitive to drought stress as the other parameters studied (Table 7).

SEYVAL

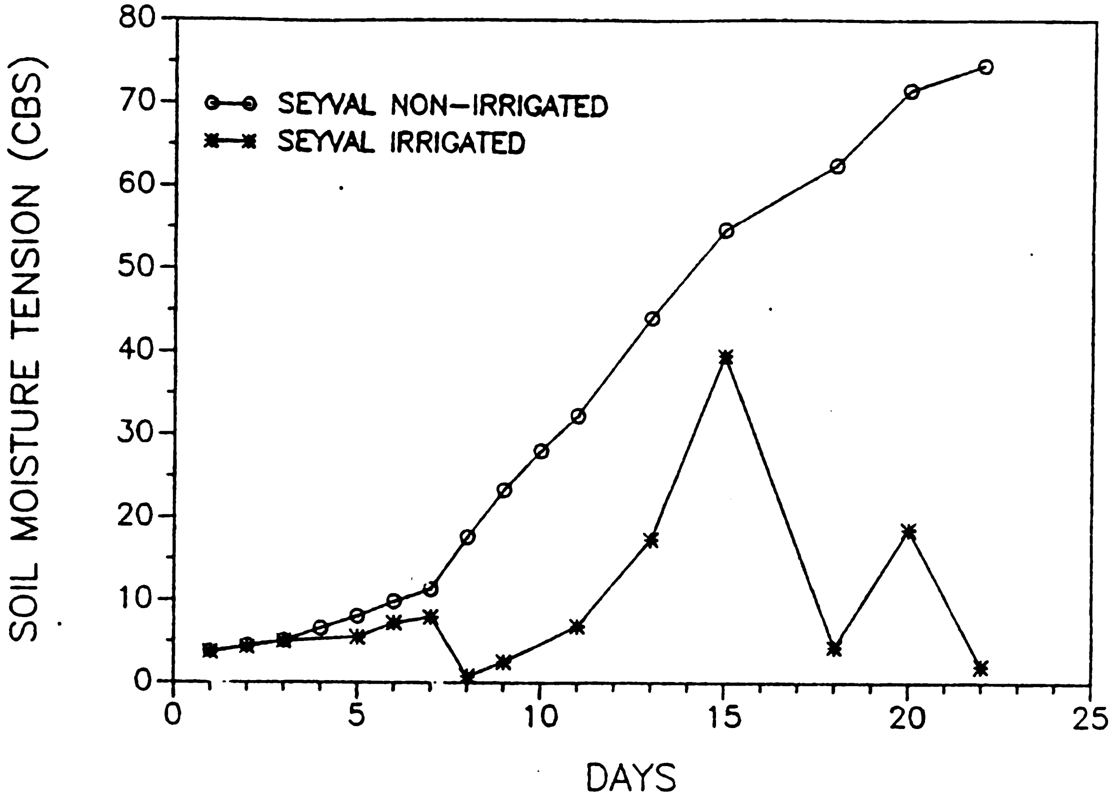
The RSE started to decrease earlier than g_s (Table 7). Even though g_s was not taken when differences in RSE occurred on the 10, 12, 13 and 14th day, data suggests that differences in the RSE did not appear on the 15th day (Table 7) due to the high SMT in the control treatment vines. RSE was more sensitive to water deficits than other plant indicators. The RSE of the control was reduced to the same magnitude as the stressed vines on the 15th day and for the stressed vines had started to decrease 2 days earlier indicating a greater sensitivity to drought. Then, statistical differences appeared on the RSE on the 15th day after water was withheld (Table 7). This can be supported by the findings of Smart (68), that shoot growth rate and trunk shrinkage were more sensitive to drought than g_s.

Shoot diameter fluctuation (DF) (Fig. 18.B) became significant on the 14th day (Table 7) at -0.48 bars (Table 8). This indicated the appearance of a significant shrinkage between the morning and the afternoon. Similar differences occurred on the 21st and 25th day of the study. Although shoot diameter fluctuation was a sensitive plant indicator, it occurred only on 3 isolated dates (Table 7). However, no consistancy in the appearance of statistical differences of this plant indicator occurred. Therefore, the usefulness of DF as an indicator of vine drought stress in grapevines is low because it could have easily been missed and no response observed.

Cumulative shoot diameter (Figure 18.A) on Seyval grapevines did not appear to be a sensitive plant indicator at 07:00 hrs. or at 15:00 hrs. (Table 7). One of the reasons that may have reduced its sensitivity was the initially greater diameter of the non-irrigated treatment vines. Even though statistical differences did not occur for the shoot diameter on the drought stressed vines, it started to decrease after the 21st day (Fig. 18.A). Contraction of trunks has been

Figure 16.A. Changes in soil moisture tension (SMT) on irrigated and non-irrigated Seyval grapevines.

Figure 16.B. Rate of shoot elongation affected by soil moisture tension changes on Seyval grapevines.


SOIL MOISTURE TENSION (CBS)
SEYVAL NON-IRRIGATED
SEYVAL IRRIGATED
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
DAYS

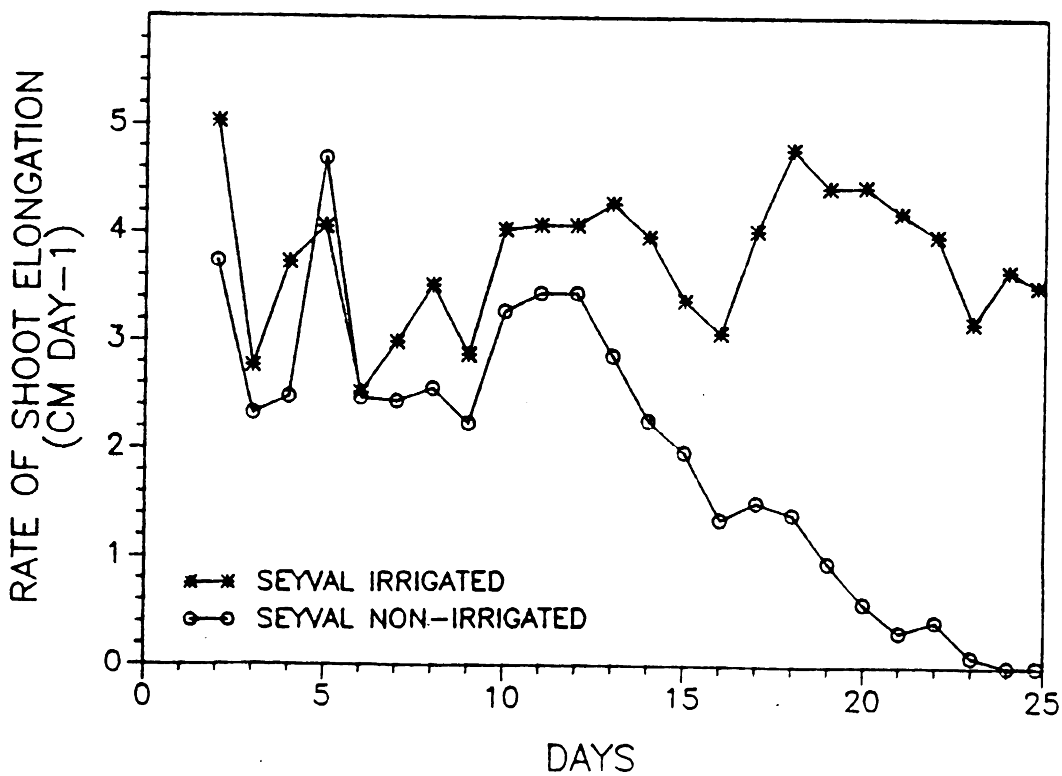
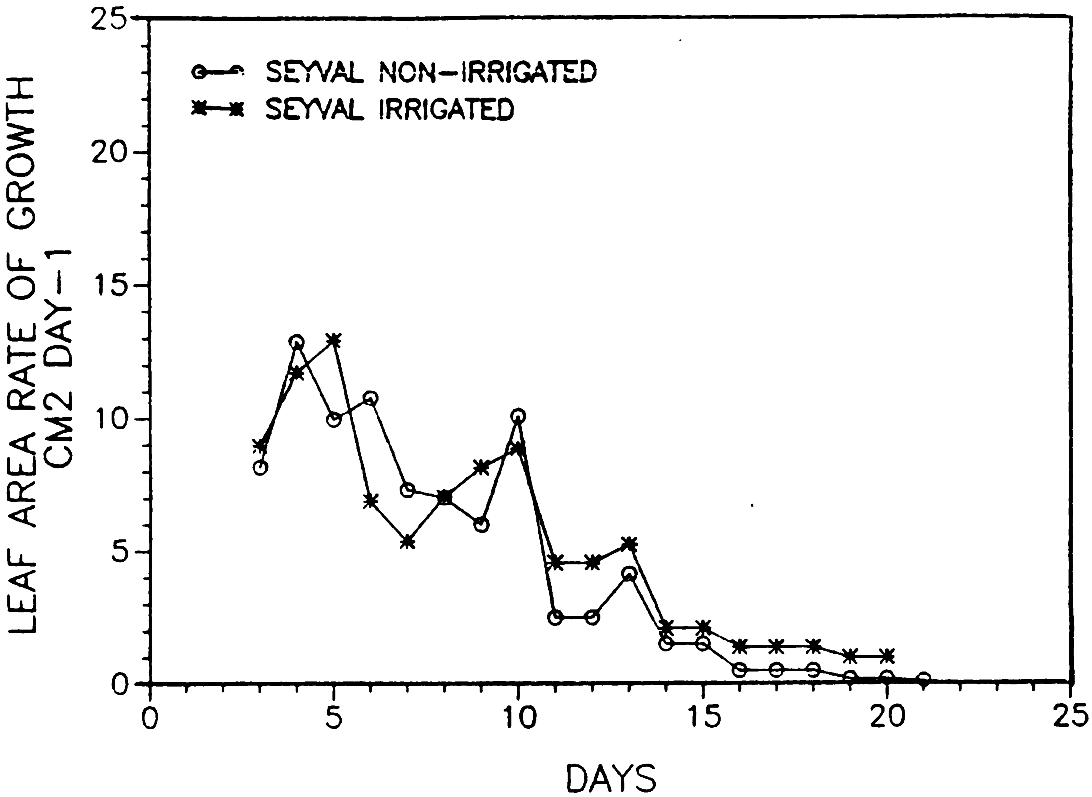

RATE OF SHOOT ELONGATION (CM DAY−1)
SEYVAL IRRIGATED
SEYVAL NON-IRRIGATED
0
1
2
3
4
5
0
5
10
15
20
25
DAYS

Figure 17.A. Leaf area rate of growth affected by changes in soil moisture tension (SMT) on Seyval grapevines.

Figure 17.B. Stomatal conductance affected by changes in soil moisture tension (SMT) on Seyval grapevines.


SEYVAL NON-IRRIGATED
SEYVAL IRRIGATED
LEAF AREA RATE OF GROWTH
CM2 DAY-1
0
5
10
15
20
25
DAYS

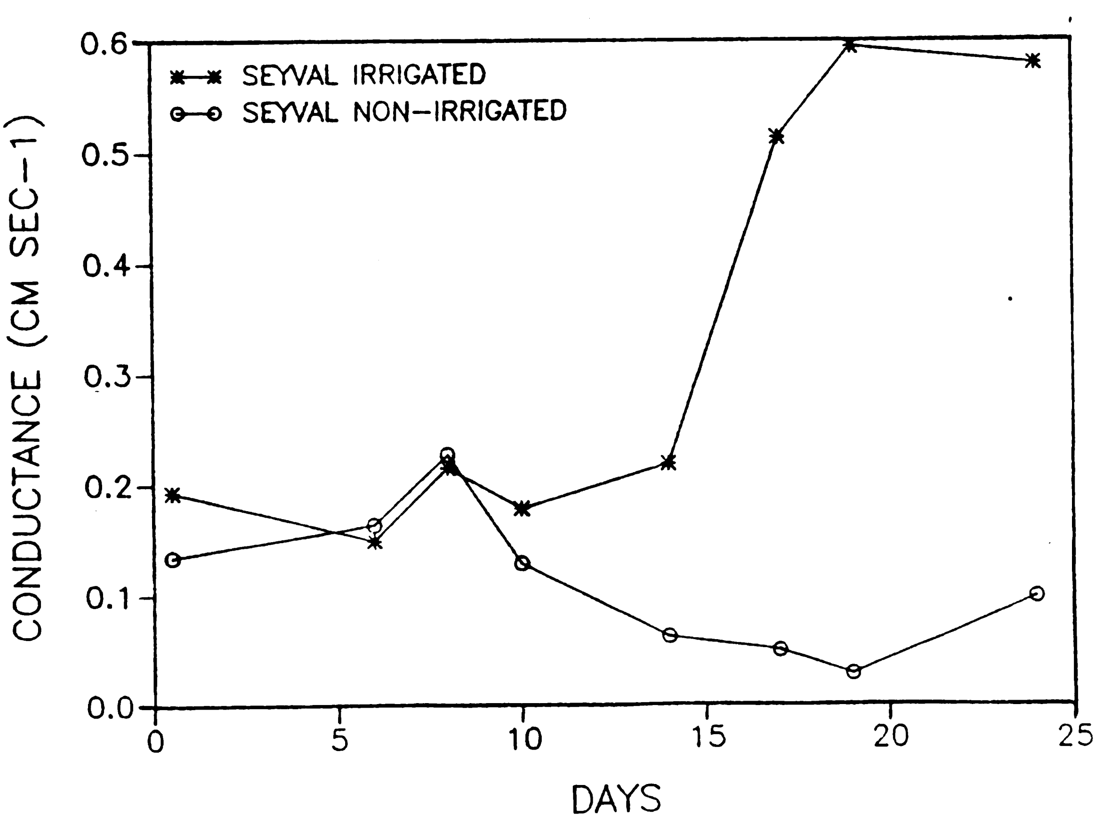
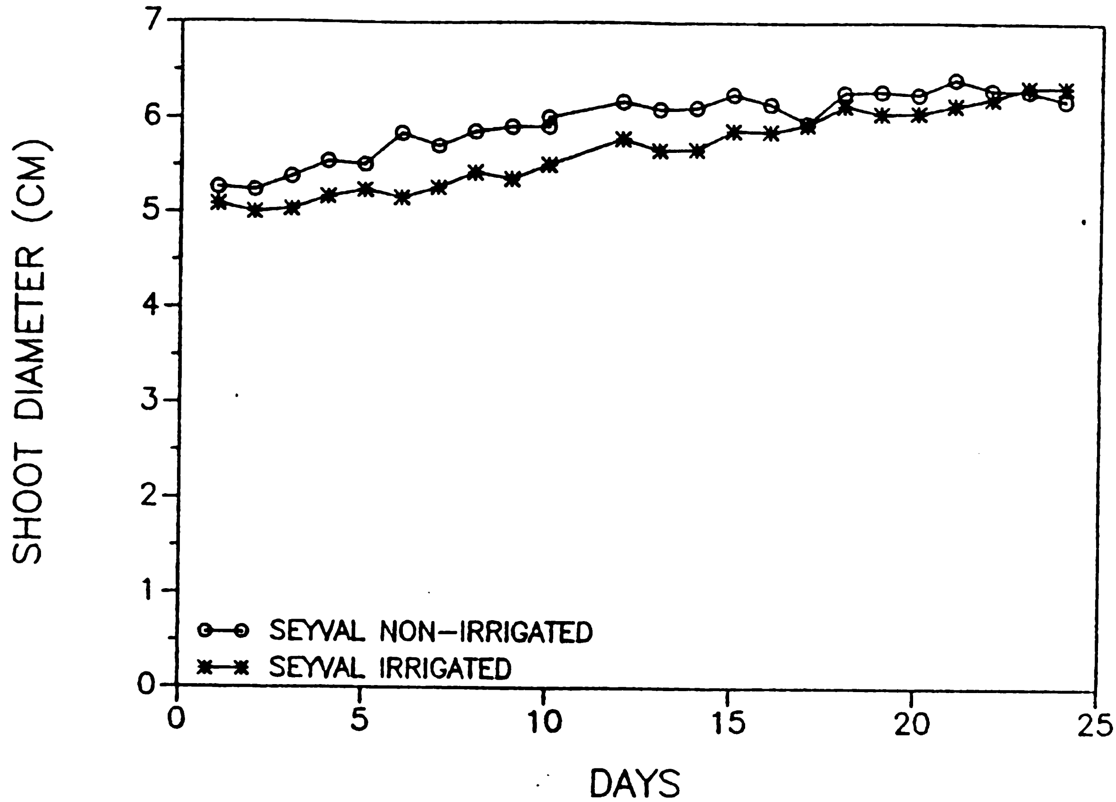

SEYVAL IRRIGATED
SEYVAL NON-IRRIGATED
CONDUCTANCE (CM SEC-1)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
DAYS

Figure 18.A. Cumulative shoot diameter affected by changes in soil moisture tension (SMT) on Seyval grapevines.

Figure 18.B. Shoot diameter fluctuation affected by changes in soil moisture tension (SMT) on Seyval grapevines. The values represent the difference of the shoot diameter at 07:00 hrs and 15:00 hrs.


SHOOT DIAMETER (CM)
SEYVAL NON-IRRIGATED
SEYVAL IRRIGATED
DAYS

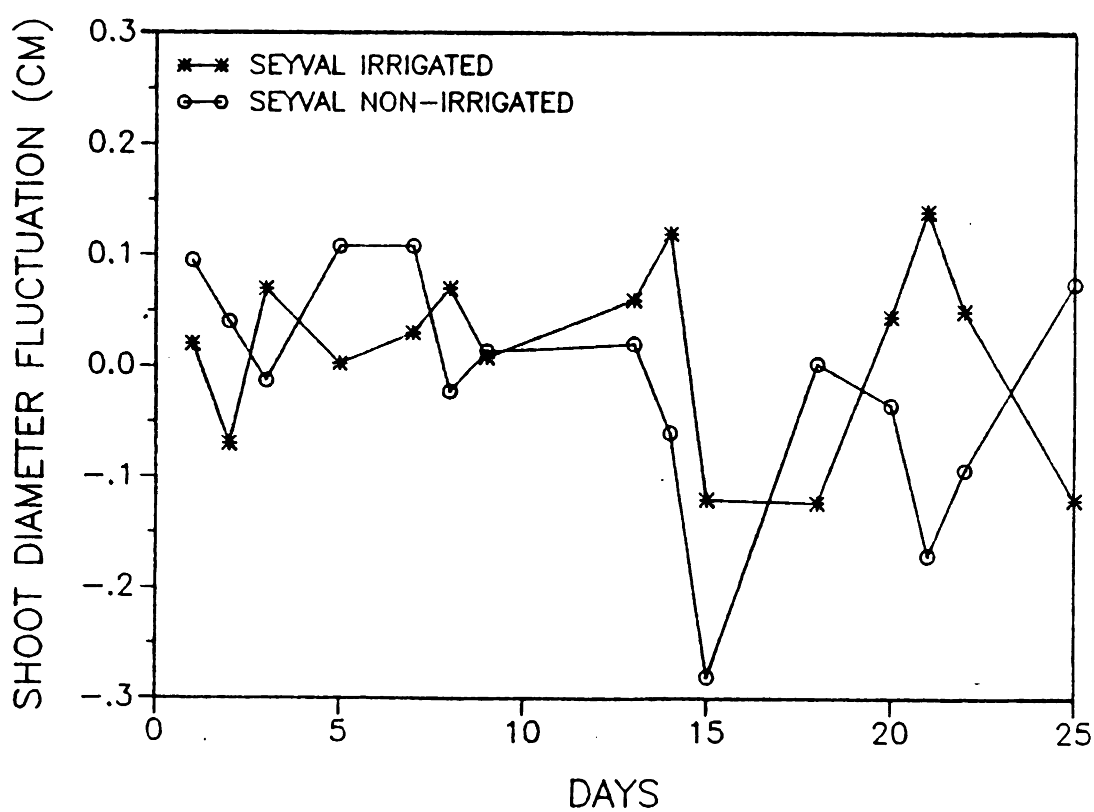

SHOOT DIAMETER FLUCTUATION (CM)
SEYVAL IRRIGATED
SEYVAL NON-IRRIGATED
DAYS

TABLE 7. Time when statistical differences began for plant indicators on Concord and Seyval grapevines under conditions of drought.

PLANT INDICATOR	DAYS 4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
g_s CONCORD				NS *		2		NS				NS			4		8					2
SEYVAL				NS		NS		NS				9			7		9					9
RSE																						
CONCORD				8			4	7	7	3	3	2	3	0.1	0.3	0.1	0.1	0.1	0.01	0.03	0.01	0.03
SEYVAL	6						4			7	6		1	3	0.4	0.2	1.1	0.05	0.2	0.02	0.1	0.03
LARG																						
CONCORD																						
SEYVAL		2 @											5	5	5							
SD (07:00 hrs.)																						
CONCORD															8	8	2	3	7	4	4	1
SEYVAL			7 @																			
(15:00 hrs.)																						
CONCORD												7			7		4	3	3			1
SEYVAL		6 @								3 @												
DF (07:00 - 15:00 hrs)																						
CONCORD																						
SEYVAL											5							5				6

g_s : Stomatal conductance
RSE: Rate of shoot elongation
LARG: Leaf area rate of growth
SD : Shoot diameter
SDF: Shoot diameter fluctuation
@ Value of NI treatment > I vines.
* Probability of the F value (2-way ANOVA).

TABLE 8. Soil moisture tension at which statistical differences started to appear on potted drought stressed Concord and Seyval grapevines.

PLANT INDICATOR	S M T CONCORD Cb	 SEYVAL Cb
Rate of shoot elongation (RSE)	- 38 *	- 44
Somatal conductance (g)	- 64, - 68	- 54
Leaf area rate of growth (LARG)	-	- 56
Shoot diameter		
07:00 hrs.	- 68	-
15:00 hrs.	- 64	-
Fluctuation	-	- 48

* Average of 4 vines.

Table 9. Cumulative growth for total lenght oflateral shoots per vine on Concord and Seyval grapevines.

CULTIVAR	15	18	D A Y 21 cm	28
CONCORD				
Irrigated	33.5 *	35.3	40.9	45.4
Non-irrigated	18.6	18.8	19.5	20.2
SEYVAL				
Irrigated	46.6	53.5	65.8	80.5
Non-irrigated	43.9	44.3	47.4	48.3

* Each value represents the average of 4 vines.

directly related to drought symptoms in woody plants (23,37,38,39).

Statistical differences observed in the morning and in the afternoon early in the experiment (on the 6th (am) and on the 5th and 11th (pm)) days (Table 7) indicated that care must be used in interpreting the data. Reasons for these differences may be due to causes other than drought stress. Differences appeared, but were caused by the initially bigger diameter of the vines selected for non-irrigated treatment (Fig. 18.A).

Leaf area rate of growth (LARG) (Fig. 17.A) was less sensitive than RSE to drought stress. Statistical differences in this variable began on the 16th day and continuously appeared after that (Table 7).

Lateral shoots were less sensitive to drought stress than main shoots in both cultivars. Main shoots of drought stressed Concord and Seyval vines stopped growing on the 18th and 21st day respectivelly. Their lateral shoots had not stopped growth after 9 days (Table 9).

Measuring g_s gave a good reference as to when stomata were closing (Fig. 17.B). RSE decreased later (Table 7). However, in later studies it was necessary to increase the number of experimental measurements (more days) and also within days, and to measure the photosynthetically active radiation at the time of g_s measurements to better understand stomatal responses to drought and light.

GROWTH COMPONENTS AT THE END OF THE DROUGHT PERIOD

Growth was considerably reduced by drought (Table 10). A reduction of 42%-52% occurred in the total dry weight, 40% reduction in the total shoot elongation, and a reduction in the total leaf area of 39-40% in drought stressed Concord and Seyval grapevines.

TABLE 10. Percent reduction in the growth components of Concord and Seyval grapevines compared to the control at the end of the drought treatment.

PLANT COMPONENT	CONCORD I	CONCORD NI	CONCORD (%)	SEYVAL I	SEYVAL NI	SEYVAL (%)
Shoot Length (cm)						
Main	180.6	116.4	36	149.6	96.5	36
Lateral	44.7	23.6	47	84.4	43.5	49
Total	225.3	140.0	38	234.0	140.0	40
Shoot Diameter(mm)	6.6	5.2	21	6.8	5.8	15
Node No.	21.8	16.9	22	25.3	19.4	23
Leaf No.	32.0	21.0	34	54.0	35.5	34
Total Leaf Area (dm^2)	42.7	23.6	45	27.4	16.7	39
Dry Weight (gr)						
Root	21.1	10.6	50	12.8	7.1	45
Shoot and leaves	35.2	22.1	37	38.7	17.8	54
Total	56.3	32.7	42	51.5	24.9	52

I - Irrigated vines
NI- Non-irrigated vines

RESULTS AND DISCUSSION - EXPERIMENT II

FIRST STRESS

Stomatal conductance (g_s) started decreasing on stressed vines on April 12th (Table 11). On April 13th, g_s of the stress-irrigated-stress-irrigated (SISI) and stress-irrigated (SI) treatment vines became statistically different from the unstressed vines. The decrease in g_s has been correlated with the increase of abscisic acid (46). Drought was ended on April 16th at 9:00 hr. On April 17th 17:30 hr, 16:00 hrs after rewatering. Then, symptoms of recovery based on g_s and RSE became the same as the unstressed plants (Table 11).

Statistical differences started at the same time for g_s and for the rate of shoot elongation (RSE) (Table 11). That is, the sensitivity of the RSE and g_s to fast developing drought stress were the same. This differs from the information provided by Smart (68) were he states that g_s was more sensitive than shoot elongation. The differences between this study and Smart's (68) may be due to the time in which the stress was developed. That is, under conditions of fast developing stress (68) internal changes such as osmoregulation may not occur and therefore the plant indicators may react differently to water deficits. Changes of soil moisture in this study occurred so fast that those internal changes ocurred earlier did not appear.

SECOND PERIOD OF STRESS

Stressed vines were allowed to recover after drought by watering the vines every other day. Recovery was considered to be when g_s and RSE became the same as the unstressed vines. However, all vines started

TABLE 11 Time when statistical differences began for plant indicators under short-term drought conditions on Concord grapevines(April 12th-17th)

PLANT INDICATOR	APRIL (HOUR) 12 10:30	12 15:30	13 10:30	13 15:30	15 10:30	15 15:30	16 15:30	17 10:30	17 15:30
CONDUCTANCE									
Probability of * the F value (%)			0	.04	0	.3	.03	.13	1.4
C	0.32	0.14	0.47a	0.28a	0.44a	0.38a	0.23a	0.54a	0.35
ISI	0.32	0.10	0.45a	0.28a	0.37a	0.46a	0.23a	0.54a	0.47
SISI	0.24	0.06	0.11b	0.07b	0.02b	0.02b	0.06b	0.27b	0.22
SI	0.30	0.09	0.09b	0.06b	0.02b	0.09b	0.05b	0.27b	0.31
RSE									
Probability of the F value (%)			.4		0		0		1.5
C			a		a		a		a
ISI			a		a		a		a
SISI			a		b		b		a
SI			b		b		b		b
LATERAL SHOOTS									
Probability of the F value (%)			NS -----						
LARG									
Probability			3.02						
I			a						
NI			b						

* Probability of the F value after an analysis of variance.
** Separation of means was done by Tukey's multiple range at 1 %.

showing a decreasing RSE. The reason for this is unexplained. The rye could have released some kind of allelopatic compound, and thus inhibited the growth of the vines. Barnes and Putnam (4) showed the inhibitory properties of rye root leachates reducing dry weight on tomatoes. This is an speculative answer, however, and further research is needed because rye is commonly used as a cover crop in orchards and vineyards on Michigan. Therefore, since the RSE did not change for either the control or for the stressed treatment and g_s was recovered for both treatments, the vines were watered for 17 days. Afterwards, watering was withheld for the 2nd period of stress.

On May 5th SISI vines showed the lowest g_s in the afternoon (Table 12). Stomatal conductance of drought stressed SISI vines became statistically different at 0.01% from g_s of vines that experienced drought for first time ISI (irrigated-stressed-irrigated) at 11:30 hr. Even though g_s of SISI and ISI vines were statistically the same, g_s was higherin those vines that had experienced their 2nd stress(SISI). This suggests that the first stress may have preconditioned the vines and resulted in changes which made them more tolerant to a 2nd period of stress. Even when statistical differences were not appreciable on May 7th g_s was higher at 7:30, 15:30 and 17:30 hr. On May 8th SISI treatment vines were statistically the same as the unstressed (Control and SI) vines, on that day g_s was also higher in SISI than ISI vines. This preconditioning effect of cycles of drought where g_s of preconditioned plants is higher than non-preconditioned was reported also in greenhouse studies on apple (19). Therefore, Concord grapevines seemed to have improved their capacity to tolerate subsequent periods of drought. Symptoms of recovery were observed 24 hr after watering the

Table 12. Time when statistical differences began for plant indicators under short-term drought conditions on Concord grapevines (May 5th-10th)

PLANT INDICATOR	MAY (HOUR) 1	5 10:30	5 15:30	6 11:30	6 13:30	6 17:30	6 19:30	7 07:30	7 09:30	7 15:00	7 18:00
CONDUCTANCE											
Probability of the F value (%)	*		3	.03	.01	.01	.04	0	.01	.01	.01
C		0.23	0.29	0.37a	0.27a	0.19a	0.07a	0.15a	0.11ab	0.22a	0.19a
ISI		0.23	0.19	0.05b	0.05b	0.04b	0.03b	0.01c	0.02b	0.02b	0.04b
SISI		0.25	0.32	0.11b	0.09b	0.06b	0.03b	0.04b	0.03bc	0.03b	0.06b
SI		0.31	0.39	0.25ab	0.36a	0.17a	0.04b	0.12ab	0.18a	0.26a	0.19a
RSE											
Probability of the F value (%)	6		NS ----------								
C	ab										
ISI	b										
SISI	a										
SI	ab										
LATERAL SHOOTS											
Probability of the F value (%)	NS ----------										
LARG											
Probability of the F value	NS ----------										
I											
NI											

* Probability of the F value after an analysis of variance.
** Separation of means was done by Tukey's multiple eange at 1%

stressed vines. On May 9th no differences appeared in g_s for all treatments indicating that recovery from drought had taken place. On May 10 at 10:30 hrs all values of g_s were the same showing that full recovery had ocurred.

The trunk diameter growth changes measured by linear transducers indicated that contraction of the trunk diameter occurred under conditions of drought stress (Fig. 18). Even though no statistical differences appeared between the irrigated and stressed vines on the 6th and on the 7th data indicated that this plant indicator is also quite sensitive to drought. On May 6th g_s for the stressed vines was lower than the control and the same day the trunk of the drought stressed vines shrank considerably. Upon rewatering on May 7th trunks responded faster than g_s and expansion of the stressed trunks was observed. This suggested that under conditions of drought trunks were a good indicator of stress. If devices such as linear transducers are designed for field operation and at lower price, irrigation scheduling based on this may become a feasible practice.

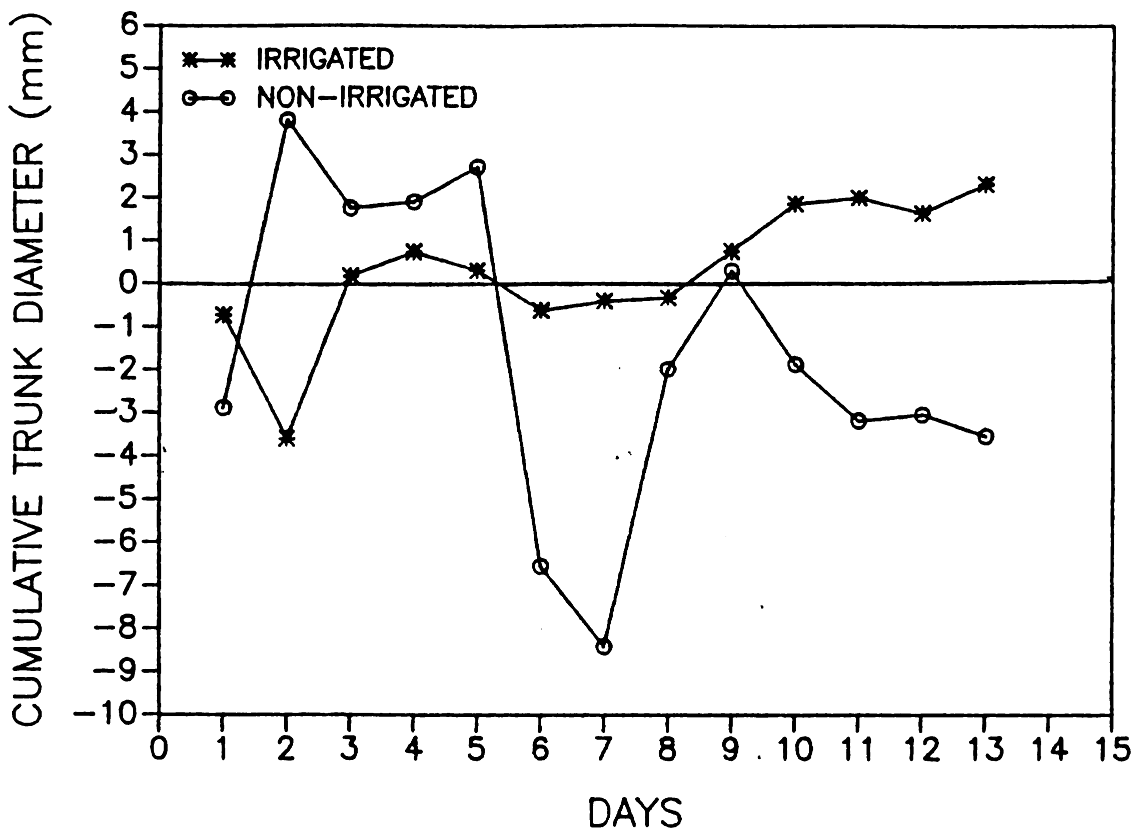


Figure 19. Influence of drought on trunk diameter of Concord grapevines.

CONCLUSIONS - EXPERIMENT I

The RSE appeared to be of equal or greater sensitivity than g_s in both Concord and Seyval grapevines. However, the percent of change of these plant indicators associated with the time under drought stress was higher in both cultivars for RSE under conditions of relatively fast developing drought (Figs. 11 and 12). The critical soil moisture where differences started was -0.38 bars and -0.44 bars for Concord and Seyval grapevines respectively.

Even though main shoots of drought stressed Concord and Seyval grapevines stopped their growth, some growth continued in the lateral shoots.

Shoot diameter fluctuations appeared as a physiological sensitive parameter to drought stressed Seyval, but not in Concord grapevines. In practice with the methodology used its use as an indicator of drought in the field seems difficult because it is time consuming and expensive.

Shoot diameter shrinkage preceeded the time when the cumulative shoot diameter started decreasing. A marked trend occurred for both cultivars as to greater shrinkage during the afternoon up to the point where no night recovery was observed.

Stomatal conductance appeared as sensitive as shoot diameter fluctuations for Seyval grapes, and appeared less sensitive to drought than RSE in both cultivars.

The leaf area rate of growth was less sensitive to drought than the other plant indicators measured.

CONCLUSIONS - EXPERIMENT II

Under conditions of an acute drought stress no difference in the sensitivity of RSE and g_s took place in potted greenhouse grown Concord grapevines.

Higher g_s of preconditioned vines than those with first drought experience indicates an acquired gain in tolerance to a second period of drought.

EFFECT OF DROUGHT STRESS AT DIFFERENT STAGES OF DEVELOPMENT ON CONCORD AND SEYVAL GRAPEVINES

INTRODUCTION

Cell number, volume and density are described as the components of fruit weight (5). These components combined with environmental conditions and management techniques, determine fruit size and weight of the fruits at harvest. The accumulative berry growth (berry diameter, length, volume, or weight) results in a general sigmoidal growth curve (57,76) that consists of: (I) a period of rapid growth, (II) a period of slow growth (Lag phase), and (III) a final increase in growth.

The high temperatures and evaporation, combined with the low precipitation that characterize Michigan's summer, increases vine's water deficit, and both yield and quality can be affected. Grapes during the early stages of fruit development are very susceptible to water deficits (28). Water stress during or inmediately after bloom may cause the bunch to shrivel (1). If the stress occurs during the rapidly enlarging phase, berries will remain undersized even if water is applied afterwards (34). The total amount of sugar is also reduced with drought (16).

The objective of Experiment I was to determine the effect of drought stress at pre-bloom, full bloom and fruit set stages on Concord and Seyval grapevines.

The objective of Experiment II was to determine the effect of drought stress during Stage I, II (lag phase), Stage III (veraison) and 1 week before harvest on yield and quality components of Seyval grapevines.

MATERIALS AND METHODS

This study was done in two experiments due to space limitation as follows:

EXPERIMENT I. EFFECT OF DROUGHT STRESS DURING PREBLOOM, FULL BLOOM AND FRUIT SET ON CONCORD AND SEYVAL GRAPEVINES.

EXPERIMENT II. EFFECT OF DROUGHT STRESS AT DIFFERENT STAGES OF BERRY DEVELOPMENT ON SEYVAL GRAPEVINES.

GRAPEVINES

In Experiment I, potted one-year-old Concord and Seyval grapevines were grown outdoors during 1982 in 19 liter pots with proper nutrition and water supply. In 1983 both cultivars were pruned back to 2 buds per vine to obtain a total of 4 clusters in each. Vines were grown from early February until late June. Two vines of each cultivar were grown a week earlier to be use as reference to assign drought treatments. Grapevines were positioned in a greenhouse with an average mean temperature of 25 °C, a mean maximum of 28 °C, and a mean minimum of 21 °C, with a range of ± 4 °C during the study.

In Experiment II, one-year-old Seyval grapevines were managed as in Experiment I. Fertilization was made early in the study (Stage I) and in the middle (end of lag phase) of the study with 1 liter of soluble fertilizer (Peters 20-20-20) to yield 400 mg/l of nitrogen.

SOIL

A soil mixture 2 sand:1 perlite:1 peat (v:v:v) was used in Experiment I. In Experiment II, the soil mixture was composed of 2 sand:1 perlite:1 loamy soil (v:v:v). These light soil mixtures were used to produce have a fast developing drought. Fertilization consisted of 2 1-liter applications of water soluble (20-20-20) fertilizer (300 ppm of N) early in the study (burst) and during stage II of berry development.

In Experiment I, the container media water holding capacity (70) was 19.9 %, and the PWP 4.2 %. In Experiment II was 18.13 %, and the PWP 3.1 % . In both experiments the bottom (2.5 cm) of each pot was filled with a layer of gravel (0.4 - 0.8 cm) to facilitate drainage and aereation.

Soil moisture changes were followed with the lysimeter technique weighing the whole pots and with the use of tensiometers (Appendix). Tensiometers were place in the middle of the pot and soil moisture tension (SMT) changes followed during the study.

EXPERIMENTAL DESIGN AND DROUGHT STRESS TREATMENTS

In Experiment I, there were 4 treatments including a control which was irrigated every other day to mantain 80 - 100 % available moisture in the soil. Drought stress treatments were applied at pre-bloom, 50 % bloom and at fruit set by withholding irrigation for 4-6 days before vines reached the phenological stage where treatments were desired.

The experimental design of Experiment I was a Completely Randomized Design with 7 single-vine observations per treatment.

In Experiment II, five treatments arranged in a Randomized Complete Block Design with 4 single-vine replicates per treatment and were tested as follows:

(A) Control vines were irrigated every other day to mantain 80-

100 % available moisture during the study (Fig. 20).

(B) Stage I - (Cell division and cell elongation phase) Drought was applied 10 days after fruit set.

(C) End of Stage II - (Lag phase) When a reduction in the rate of growth of the berry becomes evident.

(D)Stage III - (Veraison) When softening and change in color take place.

(E) One week before harvest.

Treatments were applied based upon a berry growth curve (Fig. 20). During the study a berry growth curve was obtained by measuring the diameter of 3 berries per cluster (basal, middle and apical) every other day (07:30 hrs). in one cluster per vine with a digital micrometer (Mitutoyo, Co.).

VARIABLES MEASURED

Yield components:

i) In Experiment I, percent of fruit set was obtained by counting the total number of flower primordia in each cluster and by counting the number of berries at harvest. In Experiment II, percent of fruit set was calculated based upon the number of berries before and after the drought period for each treatment.

ii) Berry weight was obtained by weighing the clusters and dividing their weight by the number of berries in each cluster.

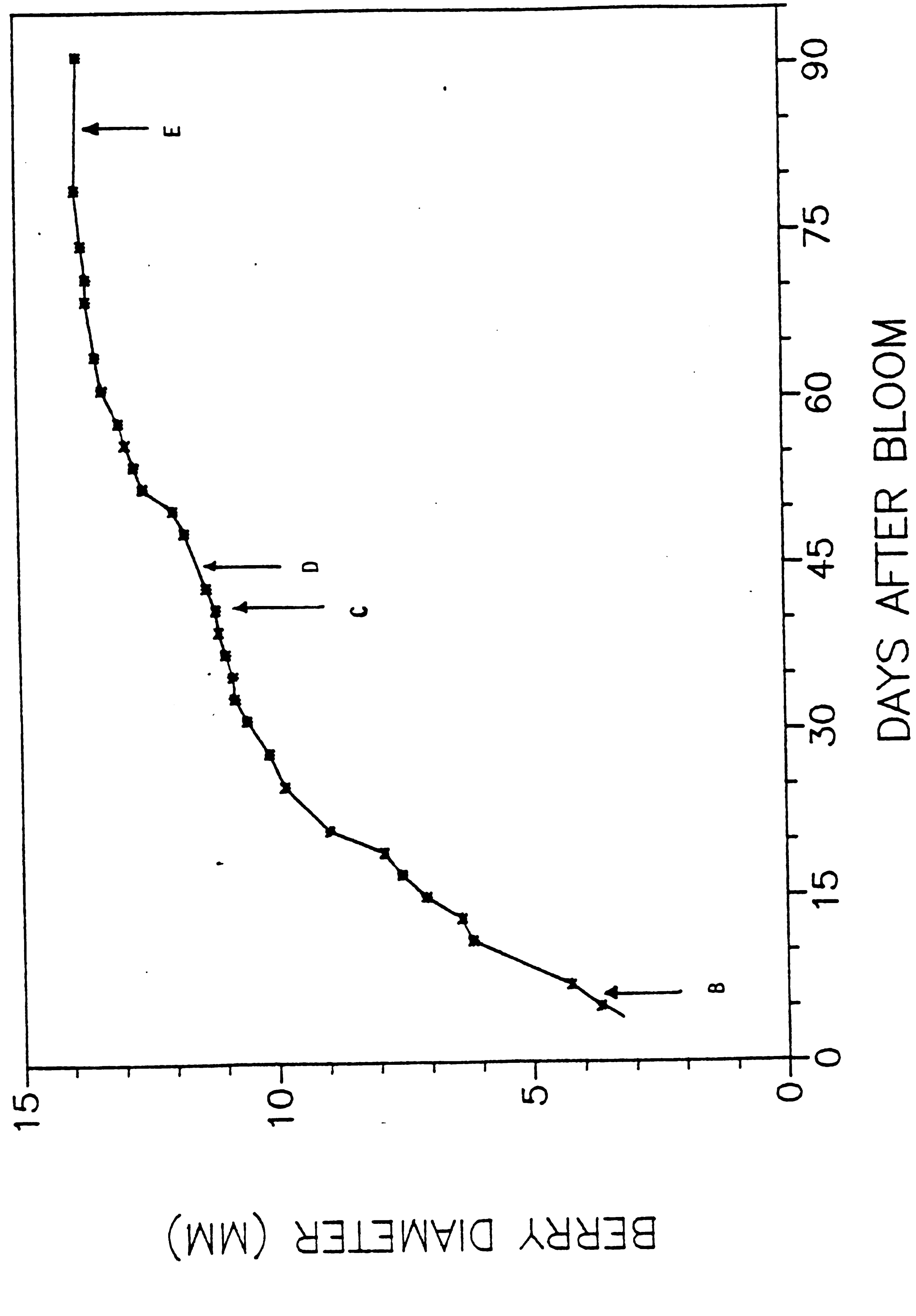
iii)Berry volume in both experiments was obtained by displacement of water by the cluster and dividing the volume displaced by the number of berries in the cluster.

Quality components:

i) For Concord grapes in Experiment I, juice soluble solids expressed as Brix was determined with a Abbe refractometer(Bausch & Lomb, Inc).

ii) For Seyval grapes in experiments I and II, juice soluble solids expressed as Brix, pH, and titratable acidity (TA) expressed as grams of tartaric acid/100 cc of juice were measured on a pH meter and via titration with 0.1 N NaOH respectivelly.

Figure 20. Berry growth and the time of drought on Seyval grapevines. A: Control; B: Stress at stage I; C: Stress at stage II; D: Stress at veraison; E: Stress one week before harvest.



BERRY DIAMETER (MM)
DAYS AFTER BLOOM
0
5
10
15
0
15
30
45
60
75
90
B
C
D
E

RESULTS AND DISCUSSION - EXPERIMENT I

Creating stress treatments at the precise phenological stage was problematic. In justa fewobservationsin each treatment, drought occurred at the exact desired time. The small numbers preclude statistical analysis, therefore observations are give for drought treatments of drought during bloom and fruit set in Seyval and pre-bloom and fruit set on Concord grapes.

SEYVAL

Drought during pre-bloom stage of 41 % of the water holding capacity of the pot (WHCP) developed during 16 days did not produce a significant reduction in the percentage of fruit set.

Weight and volume per berry were reduced when drought occurred at pre-bloom. This effect could be due to the greater number of fully developed seeds per berry. Fruit size and shape are often related to seed number. Hormones produced by the seed may be responsible for these effects (20). A relationship between increased berry size and the seed number has been shown to occur in grapes (57,79). Seed number per berry was directly related to accumulation of 14C-photosynthates, fresh weight, and dry weight (15). The lower number of seeds could be caused by an induced lower viability of pollen developed during prebloom stage. Similar observations were made by Modlibowska (52) where the number of seeds/fruit decreased proportional to a decrease of soil moisture during the prebloom stage.

Even though no differences were observed for soluble solids and pH, a higher percentage of soluble solids and an higher pH was found in the control than was found in the pre-bloom drought stress treatment. The lower acidity for the control suggests the possibility of a maturity delay for the prebloom stressed vines (Table 13).

As mentioned, problems occurred in this experiment in inducing drought at the proper stage. This was also the case for the bloom and fruit set treatments. Only one of the six observations of the stress at full bloom experienced drought when 40 % of the flowers in the cluster were open. Soil moisture in that pot was 52 % of WHCP and was developed during an 18 days period (Table 13). Upon rewatering, berries at this stage continued to desiccate and eventually the whole cluster dried. One of the six vines stressed at fruit set experienced a 49 % of WHCP and a similar desiccation.

CONCORD

Three of the six control and full bloom treatment vines produced inflorescences. There were 5 vines in the prebloom stage and 4 vines in the fruit set stage. Drought treatments in the latter group resulted in cluster desiccation in all but 1 vine, when the soil moisture in the pots decreased to 40% and 44 % of WHCP. Vines stressed during full bloom were exposed to 46% of WHCP and 3 vines retained their clusters after that exposure.

Considering the amount of treatment variation concerning vine numbers the number of vines with clusters before and after the drought stress, and that statistical comparisons were limited to the control and drought stress at full bloom, a few comments can be made: Fruit set was

Table 13. Effect of drought stress on different stages of berry development (pre-bloom, full bloom and fruit set) of Concord and Seyval grapes.

	Range of soil moisture %	Fruit Set %	Berry wt gr	Berry volume cc	Seeds/berry	Brix	pH	T.A.
SEYVAL								
Control	16.3-17.7	7.57a	1.35a	1.25a	2.0a	26.0a	3.23a	0.68b
Pre-bloom	5.7- 8.1	10.23a	1.17b	1.05b	1.5b	24.9a	3.20a	0.77a
Full Bloom	8.1-11.0	0.00b	-	-	-	-	-	-
Fruit Set	6.6-10.4	0.00b	-	-	-	-	-	-
CONCORD								
Control	15.8-17.4	7.12	1.84	1.58	1.3	22.6a	-	-
Pre-bloom @	7.3- 9.1	1.87	1.91	1.62	0.9	20.3	-	-
Full bloom	9.7-13.9	9.14	1.65	1.59	1.1	21.8b	-	-
Fruit set @	6.6-10.9	3.25	1.24	1.21	1.0	21.1	-	-

Duncan 5 %
@: Only one observation in the treatment

not affected when the soil moisture dropped below 38 % of WHCP during full bloom. Soil moisture levels of 26 % and 32 % of WHCP caused dramatic reduction in fruit set of vines stressed at the pre-bloom and fruit set stages respectivelly. The stress was too great. Even though statistical comparisons did not show differences among the 4 treatments, percentage of fruit set in pre-bloom and fruit set was considerably reduced and only one of the 3 vines set fruit.

The average number of seeds per berry, and weight per berry for the control appeared slightly higher than the berries from vines stressed at full bloom. This supported the results derived from Seyval. However, no statistical differences appeared and nothing conclusive can be stated.

Soluble solids were statistically different between control vines and stressed vines during full boom (Table 13). This, and the soluble solids of the vines stressed at pre-bloom and at fruit set (1-observation) supported the Seyval , where drought during pre-bloom, full bloom and fruit set delayed maturation of the crop.

RESULTS AND DISCUSSION - EXPERIEMENT II

Berry diameter (36,80) was measured by taking 3 berries per cluster (1 basal, center, and apical position). Monitoring berry growth by berry volume changes by displacement of water (28) was not desirable. Submerging the cluster into water caused berries to fall from the cluster.

EFFECTS OF DROUGHT STRESS FOR A SHORT PERIOD OF TIME

In Stage I, drought stress, as measured by tensiometer -0.70 + 5 bars and developed in a period of 3 - 4 days, caused berries to desiccate and whole clusters to abscise. At this time berries had a diameter of 3.6 mm (2 weeks after bloom) and this indicated that berries were very sensitive to drought at Stage I. Complete desiccation of whole clusters and parts of clusters was reported during the three weeks following anthesis (1,28).

Shriveling was observed during berry development. A SMT at the end of Stage II of -0.83 + 5 bars, at veraison of -0.82 + 8 bars, and 1 week prior to harvest -0.83 + 7.5 bars did not have a significant effect on shriveling. Three to four days after the drought treatment occurred, some berries in Stage II and veraison abscised, but none abscised when drought stress (- 0.83 + 7 bars) was applied 1 week prior to harvest.

YIELD AND YIELD COMPONENTS

Only treatment B, acute drought stress at Stage I, caused a statistically significant reduction in yield per vine, and berry volume and weight. Treatments (A, C, D, E) did not show any statistical differences (Table 14).

Percent fruit set differences were observed as mentioned earlier (Table 14). No statistical differences among treatments A, C, D, or E appeared. This suggests that acute drought for a short period of time (3-4 days) does not have a significant effect on fruit set.

QUALITY COMPONENTS

No statistical differences were observed among A, C, D and E treatments for Brix, pH and titratable acidity (Table 14).

FACTOR AFFECTING BERRY SIZE

At the end of the study, total leaf area among treatments was compared and no statistical differences were found (Table 14). However, 35% and 31% of the variablity in berry volume and weight respectively was associated with leaf area (at 1 % and 2% significance level respectively). This indicates that berry size of berries can be affected by leaf area and therefore, when a study of this nature is performed it is preferable to select vines with a similar leaf area. Leaf area may also affects fruit set in grapevines (17).

Table 14. Effect of a short term drought stress (4 days exposure) on Seyval grapevines at different stages of berry development.

TREATMENT	Soil @@ moisture tension bars	Yield gr/vine	Berry volume cc	Berry weight gr	Fruit set @ %	Brix	pH	Tartaric acid %
A - CONTROL	$\leq$ -0.2	66.53a	1.28a	1.45a	38.8a	23.6a	3.31a	0.82a
B - STAGE I	-0.70 + .05	00.00b	-	-	00.0	-	-	-
C - END OF STAGE II	-0.83 + .05	69.48a	1.41a	1.61a	40.9a	22.7a	3.37a	0.89a
D - VERAISON	-0.82 + .08	87.29a	1.26a	1.46a	45.0a	21.1a	3.20a	0.85a
E - 1-WEEK PRIOR TO HARVEST	-0.83 + .08	79.42A	1.33a	1.51a	43.2a	20.0a	3.31a	0.81a

@ : Percent fruit set calculated by considering the number of before and after the drought stress treatment.
@@: Maximum soil moisture tension held for 2 days.

CONCLUSIONS - EXPERIMENT I

A pre-bloom drought treatment of 41% of WHCP did not induce a reduction in the percent of fruit set in greenhouse grown Seyval grapevines. The lower number of seeds per berry found in pre-bloom stressed Seyval grapes was related to the effect of the drought during this stage. Unstressed vines had more seeds and a higher berry volume and weight than stressed vines.

Clusters of Seyval and Concord grapes were very sensitive to prolonged water stress during, pre-bloom, full bloom, and fruit set. The ocurrence of drought during early stages of development may contribute to delayed ripening of Seyval and Concord grapes.

The lysimeter technique done by weighing of whole pots with a scale was a useful method for assessing soil moisture changes.

For future studies, a greater number of vines resulting from larger populations of vines are suggested. This should yield a more homogenous group and reduce the sources of uncontrolled variation in environmental and soil moisture conditions influential in this experiment.

CONCLUSIONS - EXPERIMENT II

Berry diameter was a satisfactory means of evaluating berry growth and the double sigmoid curve of the fruit in Seyval grapes was produced.

In the early stages of berry development (2 weeks after bloom) berries are very sensitive to a short term drought stress. A similar drought stress treatment applied at the end of Stage II, veraison and 1-

week prior to harvest did not have any effect on yield .he yield components, or quality components. Therefore, berries at the latter particular stages of development were more tolerant of an acute, short term drought stress.

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APPENDIX A

UNIFORMITY OF THE DRIP IRRIGATION SYSTEM

UNIFORMITY OF THE DRIP IRRIGATION SYSTEM

The uniformity of water applied in any kind of irrigation systems is very important to obtain a uniform water distribution. Knowing the emitter flow rate variation provides a basis for estimating variation of the total drip irrigation system. This results in better management of the irrigation system. In general the emitter flow rate is affected by hydraulic, manufacture and field conditions. The most important field conditions that affect the emitter flow rate are plugging, slope changes and temperature.

Bralts and Kesner (10) described a method of submain line uniformity estimation for field determinations based upon the statistical uniformity coefficient. This was used for the evaluation of the drip irrigation systems at Lawton and Fennville. The method consists of chosing 18 emitters at random along the system, and by measuring the time that each of the emitters took to fill a 100 cc graduated cylinder. The intersection point of Tmax and Tmin (T= sum of the three longest and/or shortest times measured) is plotted in Figure 21 and the uniformity of the emitter flow rate is obtained. This uniformity can be also calculated by the formula:

$$Us = 100\ (1 - Vq\ ) = 100\ (1 - \frac{Sq}{q}\ )$$

where:

Us = Statistical uniformity of the emitter flow rate
Vq = Sample coefficient of variation
Sq = Standard deviation of the times to fill 100 cc
q = Mean of the times needed to fill a 100 cc container.

Obtaining the Us envolves various factors such as lateral line friction, elevation differences, emitter plugging and emitter manufacturer's variation (11). Using the same formula but using the standard deviation of 18 emitters and their mean value, it is obtained the hydraulic pressure uniformity Ush. To obtain the emitter performance uniformity;

$$Use = (Us^2 + Ush^2)^{1/2}$$

where:

Use = Statistical uniformity of the emitter performance.

UNIFORMITY OF THE DRIP IRRIGATION SYSTEM

The data taken in field is shown in Table 15, where the pressure and the time of the emitters to fill a 100 cc container of 18 emitters is organized for its evaluation.

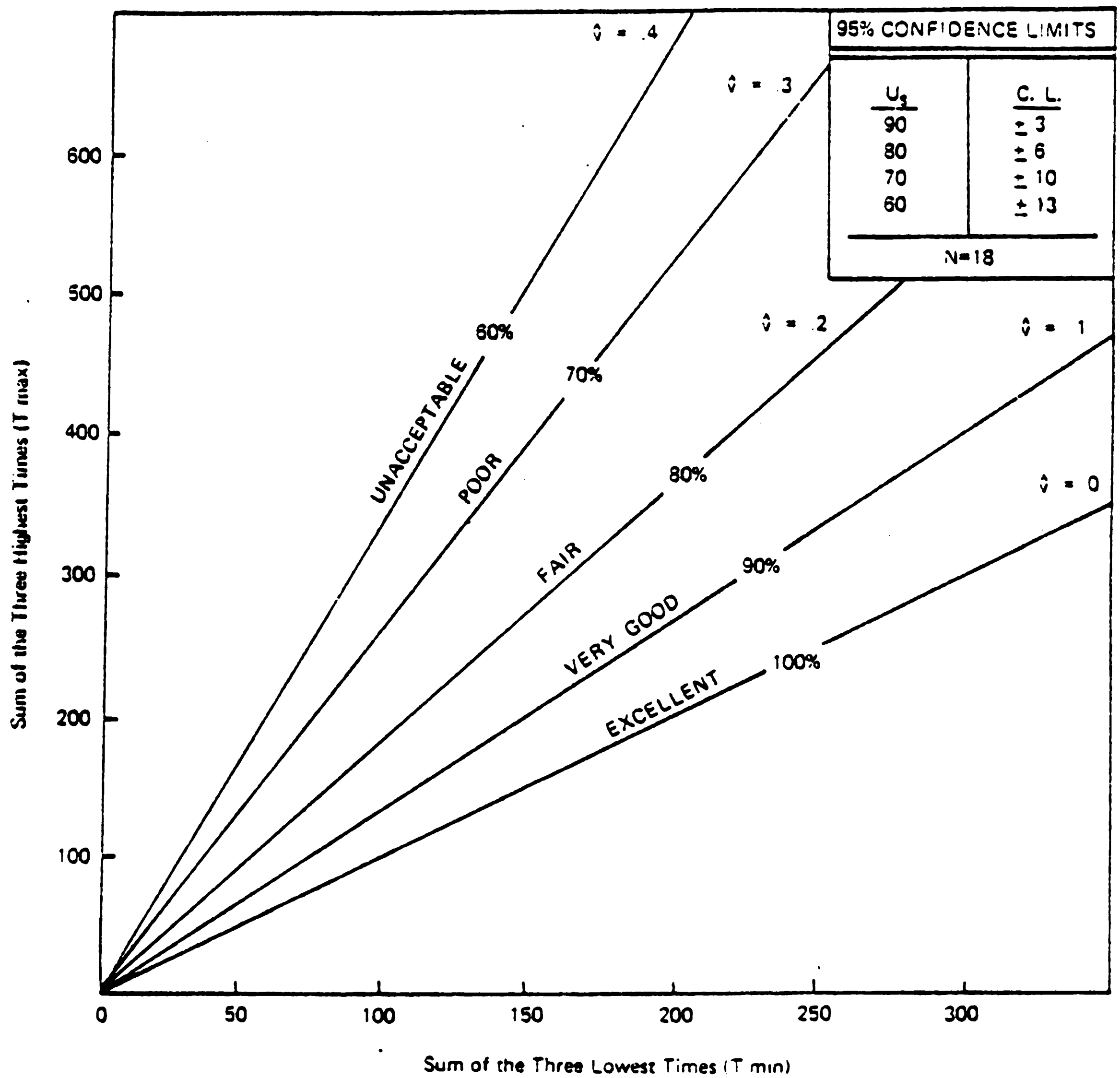

Figure 21.Drip irrigation uniformity chart (Source: Vincent Bralts).

TABLE 15. FIELD DATA FOR UNIFORMITY EVALUATION OF THE DRIP IRRIGATION AT LAWTON AND FENNVILLE, MICHIGAN.

EMITTER	LAWTON		FENNVILLE	
	PRESSURE (PSI)	TIME TO DRIP A 100 cc	PRESSURE (PSI)	TIME TO DRIP A 100 cc
1	32.0	75.6	29.0	83.5
2	29.0	78.9	26.0	71.0
3	32.0	84.5	25.5	73.0
4	26.0	81.2	24.5	91.0
5	26.0	81.6	25.0	87.0
6	24.0	87.2	25.5	74.0
7	23.0	81.8	25.0	82.0
8	21.0	85.4	25.5	70.5
9	28.0	151.8	25.5	85.0
10	26.0	83.2	27.0	79.5
11	28.0	89.5	25.0	79.5
12	28.0	87.0	25.0	81.5
13	26.0	78.9	25.0	81.0
14	23.0	92.6	24.0	92.0
15	27.0	85.4	25.5	92.5
16	23.0	73.9	24.0	76.0
17	28.0	71.0	26.0	89.5
18	24.0	92.0	26.0	73.0

TABLE 16. STATISTICAL UNIFORMITY DUE TO EMITTER FLOW RATE, HYDRAULICS, AND EMITTER PERFORMANCE.

STATISTICAL UNIFORMITY	LAWTON Us (%)	FENNVILLE Us (%)
Total (Flow rate)	80.1 + 7.3	91.0 + 1.0
Hydraulics	88.5 + 4.0	95.5 + 1.0
Emitter performance	16.3	7.5

APPENDIX B

METHODOLOGY PROBLEMS AND ALTERNATIVES

METHODOLOGY PROBLEMS AND ALTERNATIVES

SELECTION OF SOIL

Selection of the soil depends on the time required for the development of the drought stress and the duration of that stress. It is necessary to know the characteristics of the soil, its composition, texture, desorption curve, so planning of the study can be done.

In light soils (2 sand: 1 perlite: 1 loam) water loss will occur faster than in a soil with less sand and/or more clay. In Experiment I of section II the SMT occasionally could be at -0.2 bars in the morning and by the time of sunset down to -0.5 bars. Afterwards, changes occurred quickly, and the tensiometer was ineffective. Therefore, light soils are recommended only during those situations where a fast stress is required and its duration very short, otherwise severe damage could be induced in the plants. A heavier soil is suggested in the situations that do not require soil to dry fast. In such soils SMT changes are slower and one may have better control of the stress. One of the best methods of controlling soil moisture in potted experiments has been suggested by Lenz(personal communication). It is given as follows:

i) Control - watering is done to replenish 100% of the evapotranspirational losses.

ii) Stress treatments - watering can be done to replenish 75 %, 50 % or 25 % of evapotranspirational losses.

SOIL MOISTURE MEASUREMENTS

TENSIOMETERS

The use of tensiometers in potted studies is problematic. Its use in experiments of water relations should be restricted. The experience of these studies indicated that they can be used only as a guide of the soil moisture status. Even the best calibrated tensiometers were functional only up to -0.85 bars. The values obtained must be related to the area around the ceramic tip of the tensiometer (Fig.22). Therefore, there are two considerations: i) the small area that the ceramic tip covers "x" (Fig.22) and, ii) while the surface of the pot dries faster due to evaporative looses, the lower part "B" may still be in contact with higher soil moisture. This phenomena causes a reduced validity of the tensiometer reading, suggesting an overall soil moisture of the pot, while roots closer to the surface will be expose to drought sooner than those located a lower levels. Another consideration could be pot size, use of smaller pots should allow readings to be more accurate. However, this causes other problems of restricted root growth.

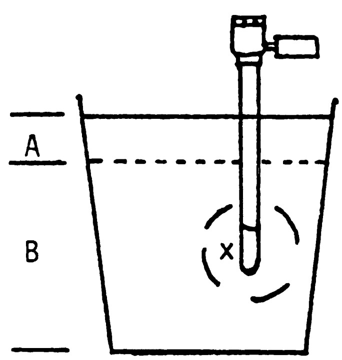

Figure 22.Soil moisture distribution in relationship with the position of the tensiometer.

GRAVIMETRIC METHOD

The gravimetric method has been reported to be among the best methods due to its accuracy. It represented a sampling problem for light soil mixtures for measuring soil moisture. Sampling with a soil moisture probe was possible only in the early stages of the study. When drought treatments were applied, the sandy soils easily fell out of the probe during sampling, thus complicating the soil moisture estimation.

LYSIMETER

Weighing of whole pots was the best method to measure soil moisture status in the pots. This was mainly because of the problems with tensimeter and that the soil fell out of the soil probe while sampling. Weight was obtained during the drought period up to the time of maximum stress. Knowing the water holding capacity of each pot (WHCP) and the fresh weight of the vine at the time of stress, weight of the pot, sticks and tensiometer the percentage of soil moisture in the pot was calculated as follows:

$$\% \text{ Soil moisture at FC} = \frac{Wa - Wb}{Wb} \quad \text{(Eq. 1)}$$

FC - Field capacity of the soil
Wa - Weight of the soil at FC
Wb - Weight of the soil when dry

field capacity of the soil was calculated by saturating with water 5 pots, covering the top of the pot to avoid evaporational losses, and allowing the gravitational water to drain. Weight was taken several times until no change occurred, at this point field capacity was achieved. The pots were oven dried, weighed again, weight of the pot substracted and weight of dry soil obtained.

During the experiment pots were weighed before, during, and at the end of stress period. The weight of the whole pots 24 hrs after watering was made was taken as the weight at FC. This and with equation 1 allowed to determine the dry weight of the soil in all experimental units, as follows:

solving for Wbl:

$$Wbl + \frac{Wbl}{FC} = \frac{Wa}{FC}$$

Then, the percentage of soil moisture was obtained by knowing the weight of the pot at the time of stress, the dry weight of the soil of each pot Wbl, substracting the weight of the plants, sticks, and tensiometers, as follows:

$$\%\ \text{soil moisture} = \frac{Ws - Wbl}{Wbl}$$

NUMBER OF PLANTS PER TREATMENT

In these studies 6 vines per treatment was not enought. For further studies it is recommended to increase the number of vines per treatment to at least 10 "selected" vines. "Selection" of vines becomes to play an important role in the development of a study of this nature. There are several ways to form an experimental block such as: Initial fresh weight before transplanting of the vine, trunk diameter, shoot lenght, rate of shoot elongation, leaf area, number of inflorescences per shoot, lenght of the flower primordia and the number of flowers per panicle. All of these variables modify the source-sink relationships of the vine. Therefore, in order to increase the accuracy of studies of water relations and different stages of developments of the berries, those variables must be considered as basis of "selection" before the initiation of the experiments.