DEVELOPMENT OF DRIP IRRIGATION SCHEDULES IN THE SAN JOAQUIN VALLEY UTILIZING FORECASTS OF EVAPOTRANSPIRATION BASED ON LONG TERM AVERAGES

William L. Peacock, L. Peter Christensen, Harry L. Andris

Abstract

A drip irrigation schedule was developed for a Thompson Seedless raisin vineyard in California's San Joaquin Valley utilizing forecasts of evapotranspiration (ET) based on long term averages. ET was determined by: ET = ETo x Kc where ETo = ET of the reference crop alfalfa, and Kc = crop coefficient. Kc values were developed using canopy measurement and the subsequent ET values experimentally evaluated for accuracy in the field. Additionally, the effect of drip irrigation amounts ranging from 1/2-1 1/3 ET on soil-water plant relationships was evaluated. Shoot growth was reduced with both high and low water regimes. Leaf water potential (Ψ_L) increased with increasing ET. A 25% decrease in yield occurred at 1/2 ET; whereas, maturity was delayed at 1 1/3 ET. Water use efficiency (WUE) (vine production per unit water transpired) was greatest at 1/2 ET.

Introduction

Evaporative demand in California's San Joaquin Valley during the summer months varies little from year to year. Evapotranspiration based on long term averages is within 10% of actual ET 90% of the time (3). The constancy of evaporative demand and absence of rainfall in summer make long term or historical weather parameters a useful tool for developing

practical drip irrigation schedules for management purposes. Once developed, an irrigation schedule based on historical ET could be used seasonally with only slight modification (3,4).

For this study, historical ETo values for the reference crop alfalfa were obtained from the National Weather Service for the southern San Joaquin Valley developed with the Jensen-Haise energy balance equation (1,9,10,16). The primary objective of this study was to develop accurate Kc values where grape ET = Kc x ETo, where Kc is the crop coefficient. Additional objectives of this research were to measure the response of grapevines to irrigation amounts ranging from deficit to excess. Particular emphasis was placed on the response of increasing ET on shoot elongation, soil and leaf water potential and yield.

Shoot growth is very sensitive to changes in the vines water status (11,13,23) as is yield and fruit quality (6,7,11,12,13,19,23). Leaf water potential decreases under deficit conditions and leaf water potential (Ψ_L) has received wide acceptance as a measurement of plant water stress (18,19,20). Critical threshold values for stomatal closure and photosynthesis have been reported for grapes (13,14,19), ranging from -14 and -12 bars. Final objective of this project was to determine effects of varying ET on water use efficiencies, yield per unit of water transpired, (WUE). Maximizing WUE would be of greater importance in areas where water rather than land is in short supply (15).

Materials and Methods

The experimental vineyard selected for this study was mature, clean cultivated and located near Fresno, California on Delhi loamy sand, a wind-modified alluvial soil (22). Canes were tied on a single wire, vertical trellis, extending 1.35 m from ground level; and, fruit was dried in the field for raisin production.

This vineyard was selected because its leaf canopy development and size was typical of most wine and raisin grape vineyards in the San Joaquin Valley. The evapotranspiration, ET, of the experimental vineyard was calculated as follows: ET = ETo x Kc where ETo is the historical ET for the reference crop alfalfa provided by the National Weather Service using the Jensen-Haise energy balance equation and Kc is the crop coefficient.

To determine Kc values, the leaf canopy's weekly development was measured by the percent of ground area shaded with the sun directly overhead. This value was reduced by 25 percent to calculate Kc values: Kc = % ground area shaded x .75 (16). Values for historical ETo, canopy measurements, Kc and ET are given in table 1.

The ET values were evaluated for accuracy using the following methods. The experiment was designed as a completely randomized block with three treatments and eight blocks. Plots consisted of 18 vines, 6 vines within three adjacent rows with 3.6 m (12 ft) between rows and 2.1 m (7 ft) between vines. The middle row served for data collection and the outside rows as borders. Irrigation treatments were 50%, 100%, and 133% of ET

using ET values given in table 1.

A drip irrigation system was installed with two emitters per vine. The 1/2, 1 and 1 1/3 ET treatments utilized emitters with 1.9, 3.8, and 5.0 L/h flow, respectively.

The experiment was initiated on 5/9/80 and continued thru the 1981 season. Irrigations took place daily controlled by time clock, electric valve, and pressure regulator. Irrigations were scheduled so that the 1.0 ET treatment received the appropriate amount, ET Table 1, and concurrently the 0.5 and 1.33 ET treatment also received the correct amounts because of the varying emitter flow rates. A pressure regulator, water meter, and frequent field checks of emission assured that emission uniformly and water application was accurate and consistent for the duration of the experiment.

Soil-water potential was monitored using tensiometers placed at 60 cm and 120 cm depth and positioned 20 cm from the emitter; tensiometers were read weekly.

Leaf-water potential was measured with a portable pressure chamber (Model 3005 Soil-Moisture Equipment Company, Santa Barbara, California). Newly, matured leaves fully exposed to sunlight were excised from the vine and analyzed within 15 seconds. The procedure was practiced until analysis time was consistent, within a few seconds variation. Leaf-water potential was measured between 1200-~~0200~~ 1400 hour.

All treatments within a block were measured within 10 minutes to minimize differences between treatments resulting from diurnal fluctuations. Differences between treatments not blocks was the

primary concern.

Shoot elongation was measured by tagging three shoots in every plot and shoot elongation was measured weekly (24).

One hundred berries were sampled from each plot on 9/4/81 to determine berry weight and °Brix. Yield data was collected by harvesting and drying fruit on paper trays in the vine row. Raisin yield was weighed for each plot and all raisin weights were adjusted to a common 15% moisture.

The development of the leaf canopy was characterized by measuring the height and width beginning in early April until changes were negligible, mid-July. Measurement occurred when the sun was directly overhead so that estimation of canopy density could also be made by measuring the ground area shaded below the canopy. The canopy was characterized as: Canopy = (height + width) x % density, where % density is the % shaded area beneath the vine, and height and width measurement were average measurements sighting down the row.

For comparison, the canopy of a very vigorous table Thompson Seedless vineyard was measured supported with an extensive trellis. The trellis consisted of a vertical stake, 1.65 meters above ground level, with a 1.05 meter cross arm and three wires and a 0.6 meter cross arm with two wires placed at the top of the stake and .45 meters from the top, respectively. The canes were tied at the lower cross arm. This vineyard's canopy represents a large canopy compared to most wine and raisin vineyards but is typical of many table grape vineyards.

Results and Discussion

Soil-Water Potential

Soil-water potentials were similar for the 1980 and 1981 irrigation season. Average values for the 1981 season at the 60 and 120 cm depth are shown in Figure 1 and Figure 2, respectively. At the 60 cm depth, the 1 and 1 1/3 ET treatment were similar for the entire season fluctuating between -5 and -10 centibars. The 0.5 ET treatment potential gradually decreased and by mid-July the tensiometers broke suction when soil-water potential climbed above the operating range of the instrument, (approx. -60 centibars).

At the 120 cm depth, the soil-water potential of the 1 1/3 ET treatment was consistently 5 centibars higher than the 1 ET treatment, whereas the soil-water potential of the 0.5 ET treatment was much lower decreasing to -55 centibars by mid-September.

These data indicate that the 1 ET schedule was very close to the actual ET. The decreasing soil-water potential for the 0.5 ET treatment indicate deficit irrigation and the higher readings at the 120 cm depth for the 1 1/3 ET treatment compared to the 1 ET treatment indicated increased flow below the 120 cm depth and irrigations in excess of ET. Soil-water potential for the 1 ET treatment was consistent for both seasons at the 60 and 120 cm depth at approximately -10 centibars and -20 centibars, respectively, indicating that rate of water application was in equilibrium with evapotranspiration.

Vine Growth

The effect of irrigation treatment on shoot growth was similar for the 1980 and 1981 seasons. Figure 3 compares the cumulative shoot growth from 6/25/81 to 8/20/81 for the three ET treatments. The 1/2 ET treatment reduced shoot growth (after tagging) by 78% compared to the 1 ET treatment. The 1 1/3 ET treatment also reduced shoot growth by 43% compared to the 1 ET treatment. Reduced growth for the 1 1/3 ET treatment was surprising but occurred both years. Two additional and similar experiments conducted by the authors using different vineyards and soil types over two years also showed reduced shoot growth with the 1 1/3 treatment. The data indicates that the seasonal applications of water in excess of ET with drip irrigation reduces shoot growth, and application of 1/2 ET greatly reduces shoot growth.

Shoot growth data also indicates that for the 1980 and 1981 season the historical ET, table 1, schedules were very close to actual ET, since maximum growth occurred with the 1 ET treatment. The sensitivity of shoot growth to the vines water status has been widely noted (12,14,24) and these results support those conclusions.

Vine Production

The effect of irrigation treatments on yield, berry weight, Brix and irrigation efficiency are shown in table 2. There was no significant difference in raisin yield comparing the 1 and 1 1/3 ET treatment. The 1/2 ET treatment yield was reduced 25% compared to the 1 ET treatment and 19% compared to the 1 1/3 ET

treatment. However, when considering irrigation efficiency or the amount of water required per unit of production, the 1/2 ET treatment was 33% and 53% more efficient than the 1 and 1 1/3 ET treatments, respectively.

There was no significant difference in berry weight between treatments. To account for yield differences, then it must be assumed that cluster weight, number of clusters/vine, or number of berries per cluster varied. However, these parameters were not measured. The °Brix was not significantly different between the 1/2 and 1 ET treatments, however the 1 1/3 ET treatment delayed maturity as indicated by a significant reduction in °Brix. Vaadia and Kasimatis found no significant differences in °Brix between wet and dry irrigation treatments although there was a trend for the wetter treatments to contain less soluble solids. Our data suggest that, to maximize maturity, irrigation should not be applied in excess of ET. Mild stress (1/2 - 2/3 ET) after verasian or 3-5 weeks prior to harvest may be desirable (24). The degree and timing of water stress using drip irrigation needed to facilitate maturity without sacrificing yield should be investigated using drip irrigation.

Canopy Development

Figure 4 shows the seasonal canopy development comparing the average canopied experimental raisin vineyard with the large canopied table grape vineyard. Canopy development was similar until late June when the canopy of the experimental raisin vineyard remained constant while the table grape canopy continued to develop until mid July before leveling off. The raisin

vineyard and table vineyard had final canopy measurements of 3.3 m and 4.4 m, a 25% difference.

Because of similar canopies, the ET for the raisin (average canopy) vineyard and the table (large canopy) vineyard should be similar until late May. Then, the ET of the table vineyard should correspondingly increase with the canopy until mid-July when its ET is greater than the raisin vineyard (proportional to differences in canopy size).

Kc and ET values were developed for the large canopied table grape vineyard and are given in table 3. The ET values for the large canopied table vineyard were tested during the 1981 season in the identical fashion as the raisin vineyard and found to be close to actual ET. Further testing of the large canopied ET values and formal presentation of the data is necessary, but the authors would like to present these values for consideration.

Leaf-Water Potential

Leaf-water potential was measured on four sampling dates in 1980 and also in 1981. These data were analyzed as a split-plot design with irrigation treatments assigned to main plots and the eight sampling dates assigned as sub-plots. Since the experimental design included eight blocks at each sampling date, the result was a sensitive analysis of variance with 191 total degrees of freedom.

Mean values for irrigation treatments and sampling dates are given in table 4. There was a significant difference at 5% between irrigation treatments with values of -1.03, -0.92 and -0.86 MPa for the 1/2 ET, 1 ET and 1 1/3 ET treatments.

It is interesting to note that the 1 1/3 ET leaf-water potential was higher than the 1 ET leaf-water potential with subsequent reductions in shoot growth and fruit maturity. Leaf-water potential of -1.2 to -1.3 MPa in grapevines can cause stomatal closure and a cessation of photosynthesis (15.20), and this threshold was approached by the 1/2 ET treatment. However, this data suggests that there may also be adverse effects to plant growth and production when leaf-water potentials are consistently too high.

Interpretation of significant differences between sampling dates is valueless because of diurnal fluctuations and variation in sampling time.

Consumptive Water Use

Crop factors, Kc, have been proven accurate during the course of this experimentation, relative to the historical ETo values utilized, table 1. These Kc values, as well as the Kc values proposed for a large canopied vineyard, table 3, are much lower than those proposed by Doorebos and Pruitt (1977) who gave crop coefficients KC (ET/ETo) for clean cultivated grapes under infrequent irrigations or the Department of Water Resources, California, 1975, who give Kc values for Thompson Seedless in the southern San Joaquin Valley (1,2).

In this study, applying the crop factors for the average and large canopied vineyards to the historical ETo values results in a net seasonal comsumptive use of 49.4 and 62.8 cm, respectively, again considerable lower than Department of Water Resource Values, even when allowing for available water from winter

rainfall. Practical application by growers in the southern San Joaquin Valley of these schedules has given additional support to their accuracy. The authors, therefore, propose that consumptive water use for grapevines in the San Joaquin Valley is lower than past information suggests.

Conclusions

Scheduling drip irrigation based on long term averages of ET is a simplified, practical approach to irrigation scheduling. Grapevine ET and corresponding Kc values, where Kc = ET/ETo, were developed and evaluated by this research for an average canopied, Thompson Seedless raisin vineyard in the San Joaquin Valley. ETo for the reference crop alfalfa was estimated by the Jensen-Haise method. This method may underestimate ET under dry, high-wind conditions; but, by using historical, average values and adjusting ET values using field developed Kc, a very practical and useful ET schedule for grapevines was developed.

With drip, applying irrigation in excess of ET throughout the season had negative effects on vine growth and production. Shoot growth was reduced and fruit maturity delayed; also, reduced yield was indicated but was not significant.

Inducing water stress during fruit maturation may improve fruit maturity and elleviate bunch rot. More work is needed on raisin, table and wine grapes to determine when stress should be initiated and to what degree. Drip irrigation offers a sensitive and immediate control over the vines water status and more information is needed to take full advantage.

Seasonal drip application at 1/2 ET reduced yield by 25%,

but increased water use efficiency (WUE). In areas where land is plentiful but water is in short supply; maximising production per unit of water would be a primary importance. More work is needed to determine what level of ET maximizes WUE when using drip irrigation.

Literature Cited

1) Department of water Resources State of California (1975). The Resources Agency. Vegetative water use in California, 1974. Bulletin No. 113-3 April 1975.

2) Doorenbs, J., and W. O. Pruitt (1977). Guidelines for predicting crop water requirements. Irrigation and Drainage paper 24, FAO. Rome. 179 pp.

3) Fereres, E., P.M. Kitlas, R.E. Goldfien, W.O. Pruitt, and R. M. Hagan. Simplified but scientific irrigation scheduling. California Agriculture, May-June, 1981, pp 19-21.

4) Fereres, E., P.A. Kitlas, W.O. Pruitt, and R.M. Hagan. 1980. Development of irrigation management programs. Final Report, Agreement No. B53142, Calif. Dept. Water Resource. University of Calif., Davis.

5) Hardie, W.J. and J.A. Considine, 1976. Response of grapes to water deficit stress in particular stages of development. Amer. J. Enol. Viticult. 27, 55-61.

6) Hendrickson, A.H., and F.J. Veihmeyer. Irrigation experiments with grapes. Calif. Agr. Exp. Sta. Bult. 728 (1950).

7) Hendrickson, A.J., and F.J. Veihmeyer. Irrigation experiments with grapes. J. Am. Soc. Hort. Sci.

8) Interagency Drought Task Force. 1977.

9) Jensen, E.M. Consumptive use of water and irrigation water requirements. American Society of Civil Engineers, 345 East 47th Street, New York, N.Y. 10017. 1973. 73 pp.

10) Jensen, M.E., and Haise, H.R. 1963. Estimating evapotranspiration from solar radiation. J. Irrig. and Drain. Div. Am. Soc. Civ. Engr., 89:15-41.

11) Kasimatis, A.N., 1967. Grapes in irrigation of agricultural lands (Eds. R.M. Hagan, H.R. Haise and T.W. Edminster) Agron. Series II, 719-739. Am. Soc. Agron. Madison, Wisconsin.

12) Kliewer, W.M., and A.J. Antcliff. Influence of defoliation, leaf darkening and cluster shading on the growth and composition of Sultana grapes. Am. J. Enol. Viticult. 21:26-36.

13) Kliewer, W. Mark, Brian M. Freeman and Charles Hossom. Effect of irrigation, crop level and potassium fertilizer on Carignane vines. I. Degree of water stress and effect on growth and yield. Am. J. Enol. Vitic., Vol. 34, No. 3, 1983.

14) Kriedmann, P.E., and R.E. Smart. Effects of irradiance, temperature and leaf water potential or photosynthesis of vine leaves. Photosynthetica 5:6-15 (1971).

15) Peacock, W.L., D.E. Rolston, F.K. Aljibury, and R.S. Rauschkolb. Evaluating drip, flood and sprinkler irrigation of wine grapes. Am. J. Enol. Vitic., Vol. 28, No. 4, 1977.

16) Pehrson, J. Irrigation in citrus with water use estimates (1980) University of Calif. Tulare County publication. Visalia, CA.

17) Rudich, J., E. Rendon-Poblete, M.A. Stevens, and A. Ambri. Use of leaf water potential to determine water stress in field grown tomatoe plants. J. Amer.Soc. Hort. Sci. 106 (6):732--736. 1981.

18) Schneider, R.W. and W. E. Pendery. Stalk rot of corn: mechanism of predisposition by an early season water stress. Phytopathology Vol. 73, No. 6. 1983.

19) Smart, R.E. Aspects of water relations of the grapevine. Am. J. Enol. Viticult. 25:84-91. 1974.

20) Smart, R.E., C.R. Turkington and J.C. Evans. (1974a). Grapevine reponse to furrow and trickle irrigation. A.J. Enol. Vit. 25:62-7.

21) State of California, Department of Water Resources, San Joaquin District and Univ. of Calif. Coop. Exten. Crop water use, Appendix B. 1981.

22) United States Department of Agriculture, Soil Survey Eastern Fresno Area California. 1971.

23) Vaadia, Y., and A.N. Kasimatis. Vineyard irrigation trials. Amer. J. Enol. Viticult. 12:88-98.

24) VanZyl, J.L. and Van Huyssteen. Comparative studies on wine grapes on different trellis systems: I. Consumptive water use. S. Afr. J. Enol. Vitic., Vol I, No. 1. 1980.

25) Winkler, A.J., J.A. Cook, W.M. Kliewer and L.A. Lider. 1974. General Viticulture Univ. Calif. Press. Berkeley and Los Angeles, pp 104-108.

TABLE 1: PERCENT CANOPY AND Kc VALUES ESTIMATED FOR TYPICAL RAISIN VINEYARD IN SAN JOAQUIN VALLEY, ALSO HISTORICAL ETo AND SUBSEQUENT ET CALCULATIONS

Date	% Canopy[2/]	Kc[3/]	ETo[4/] CM/Day[1/]	ET[5/] CM/Day
April 1-7	.05	.04	.45	.02
8-14	.13	.10	.48	.05
15-21	.21	.16	.53	.08
22-30	.31	.23	.63	.14
May 1-7	.42	.32	.63	.20
8-14	.45	.34	.71	.24
15-21	.50	.38	.73	.28
22-31	.53	.40	.76	.30
June 1-7	.55	.41	.81	.33
8-14	.55	.41	.84	.34
15-21	.55	.41	.86	.35
22-30	.55	.41	.86	.35
July 1-7	.55	.41	.86	.35
8-14	.55	.41	.86	.35
15-21	.55	.41	1.0	.41
22-31	.55	.41	1.0	.41
Aug 1-7	.55	.41	1.0	.41
8-14	.55	.41	.86	.35
15-21	.55	.41	.68	.27
22-31	.55	.41	.68	.27
Sept 1-7	.55	.41	.68	.27
8-14	.55	.41	.68	.27
15-21	.55	.41	.50	.20
22-30	.55	.41	.50	.20
			Sum	49.4

1/ CM/day = ha-cm/ha/day

2/ Estimated as % ground area shaded with sun directly overhead

3/ Kc = % canopy x .75 where .75 is correction for evaporative characteristic of grapevine compared to alfalfa

4/ Historical ETo for alfalfa (Jensen-Haise)

5/ ET = ETo x Kc = grapevine evapotranspiration

TABLE 2. YIELD DATA AND IRRIGATION EFFICIENCY COMPARING 1/2, 1, AND 1 1/3 ET SCHEDULES, 1981

DRIP TREATMENT	(Raisin) YIELD PER VINE (Kg)	WT. PER BERRY (g)	°BRIX	TOTAL WATER APPLIED (cm)	IRRIGATION EFFICIENCY (Kg/cm)
1/2 ET	3.48 a[1/]	1.67 a	21.0	24.7	72.98 [2/]
1 ET	4.66 b	1.69 a	20.8 a	49.4	48.8
1 1/3 ET	4.28 b	1.77 a	20.0 b	65.8	33.6

1/ Values in columns not followed by a common letter are significantly different at the 5% level.

2/ Kg raisins produced per cm (ha-cm/ha of water, ~900 gals) Kg raisin yield per acre determined by yield/vine x 518 vines/acre.

TABLE 3. KC AND ET VALUES FOR A LARGE CANOPIED TABLE GRAPE VINEYARD

Date	Kc	ET 1/ (CM)	Date	Kc	ET (CM)
April 1-7	.04	.02	July 1-7	.55	.47
8-14	.10	.05	8-14	.55	.47
15-21	.16	.08	15-21	.55	.55
22-30	.23	.14	22-31	.55	.55
May 1-7	.32	.20	Aug 1-7	.55	.55
8-14	.34	.24	8-14	.55	.47
15-21	.38	.28	15-21	.55	.37
22-31	.45	.34	22-31	.55	.37
June 1-7	.49	.39	Sept 1-7	.55	.37
8-14	.52	.43	8-14	.55	.37
15-21	.54	.46	15-21	.55	.27
22-30	.55	.47	22-30	.55	.27
				Sum	62.8 cm

1/ ET = Kc x ETo where ETo is historical ETo, Table 1.

TABLE 4. ANALYSIS OF VARIANCE LEAF-WATER POTENTIAL FOR 1980 & 1981.

SOURCE	df	SS	MS	F	
Irr. x Sample Date (sub plots)	191	1098.17			
Irr. (main plots)	23	148.34	5.29		
Blocks	7	32.20	4.60	2.20	NS
Irr.	2	87.70	43.80	21.50	***
Error (a)	14	28.44	2.03		
Sample Date	7	781.60	111.60	115.00	***
Irri. x Sample Date	14	24.37	1.74	1.79	**
Error (b)	147	143.86	0.97		

MEAN IRRIGATION TREATMENT Ψ_L (-MPa)		
1/2 ET	1 ET	1 1/3 ET
1.02	0.92	0.86

All significantly different ($p = 0.05$)

FIGURE 1. SOIL WATER POTENTIAL MEASUREMENTS AT 24" DEPTH (CENTIBARS)

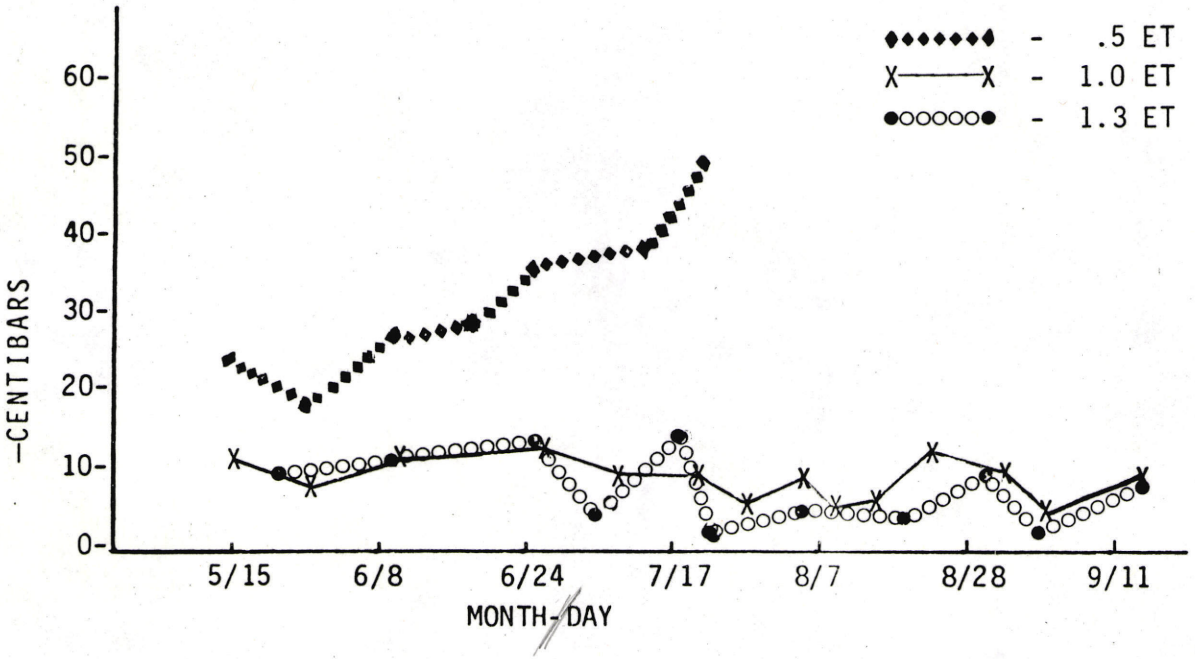


FIGURE 2. SOIL WATER POTENTIAL MEASUREMENTS AT 48 INCH DEPTH (CENTIBARS)

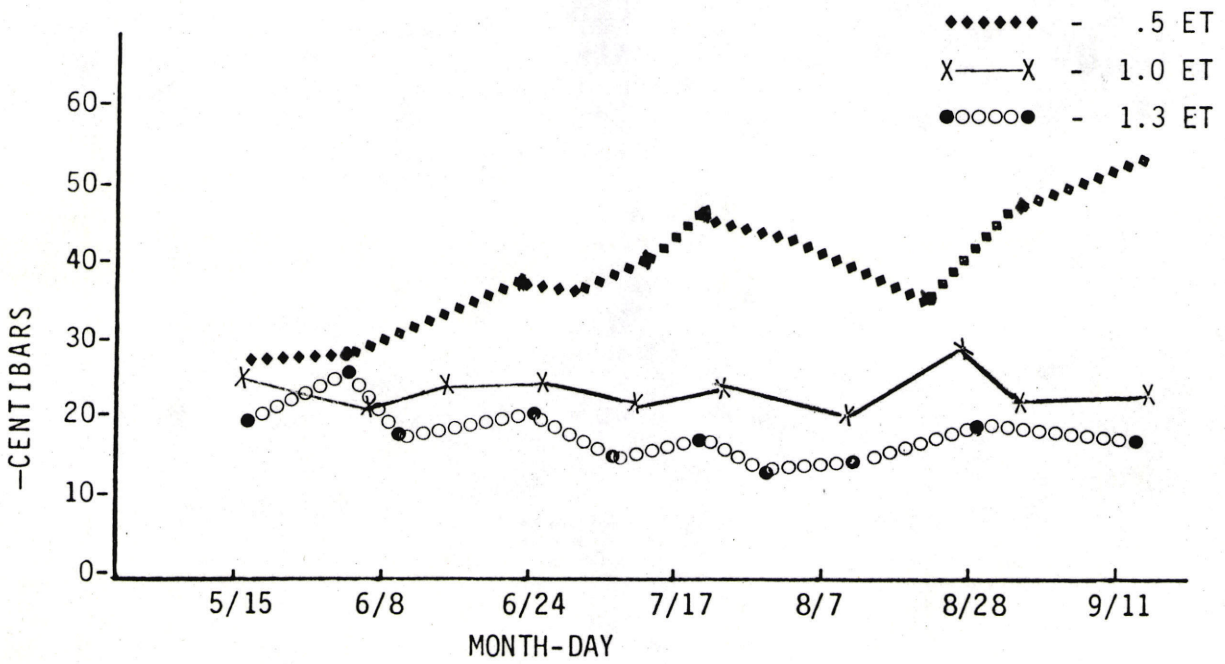


FIGURE 3. CUMULATIVE SHOOT GROWTH COMPARING 1/2, 1, AND 1 1/3 ET TREATMENTS

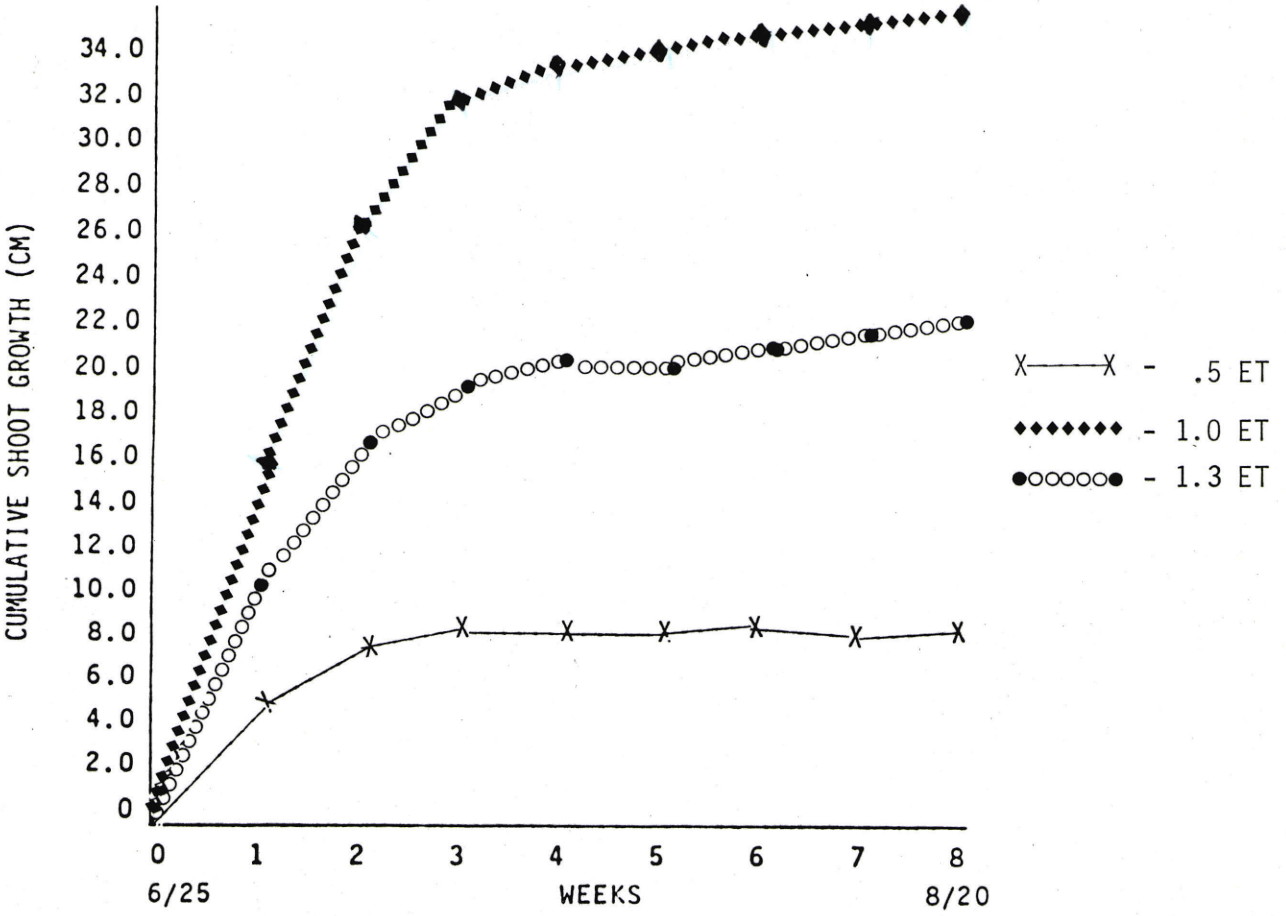


FIGURE 4. SEASONAL CANOPY DEVELOPMENT FOR LARGE & AVERAGE CANOPIED VINEYARDS

