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Drip Fertigation of Grape Vines in Arid Agriculture

Final Report

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Executive Summary

Drip fertigation of grape vines in the Republic of Kazakhstan and Israel was investigated for efficient use of water in arid zones. The aim of the investigation was to manipulate rooting volume and density, in order to optimize drip irrigation and test the nutritional consequences of the irrigation methods on grape vine vegetative growth, yield, and vine quality. Substitution of drip irrigation with current flood irrigation practices in Kazakhstan was expected to improve irrigation control and efficiency in the republic of Kazakhstan and the neighboring countries.

A field trial, evaluating 3 drip irrigation-fertigation treatments was set up in Kazakhstan to substitute current furrow irrigation with the more efficient drip irrigation system. Three treatments (variations in layout) were evaluated. Soil water tension was followed by the use of tensiometers. The evapotranspiration of the experimental grape vineyard in Kazakhstan was measured by the soil moisture balance method.

A field trial was carried out in Israel to evaluate the applicability of an irrigation model (utilizing pan A coefficients) developed for regions of moderate evaporation to environments of 50% higher evaporative demand. Three pan A irrigation coefficients were evaluated on three vine grape cultivars. The successful extrapolation of the model was found to be applicable to semi-arid environments in developing countries where water resources are scarce. The research team in Kazakhstan adjusted the model to the conditions of Kazakhstan, taking into account the contribution of summer rains to the water balance in the vineyard, and improved the model by substituting the time scale basis with cumulative evaporation data.

The following data was collected in the field trial in Israel: Leaf Area Index (LAI) measurements, stem water potential in relation to photosynthesis and stomatal conductance, yield, pruning weight, leaf analysis, fruit maturity and sensory evaluation of wine.

Collaboration included mutual visits. Klein, I. visited Kazakhstan to discuss the set up of the field trial and evaluate the needs of the irrigation and other equipment required.

Kazakhstan scientist visited Israel twice, touring the industry and getting to know the respective laboratories and conditions of work. The visit by the Kazakhstan team to Israel included detailed review of the vine grape experiment in the field and my laboratory setup, as well as professional tours of the vine grape industry and other fruit tree crops throughout Israel. The team from Kazakhstan visited also drip and micro-jet irrigation companies to study the range of available irrigation equipments.

Section I

A. Research objective. The over-all objective was to evaluate the applicability of an irrigation model (utilizing pan A coefficients) developed previously for regions of moderate evaporation to environments of 50% higher evaporative demand. The irrigation model was found to be applicable to semi-arid environments in developing countries where water resources are scarce. In Israel, we collected data in the field experiment on yield, pruning weight, leaf analysis, fruit maturity and chemical and sensory evaluation of wine. A procedure of Leaf Area Index (LAI) measurement by light interception was evaluated and adopted to the vineyard, in collaboration with Dr. S. Cohen from the Soil Science Institute in the Volcani Center. The validity of the procedure was verified by destructive sampling. In addition, the relationship between stem water potential, photosynthesis and stomatal conductance was investigated in depth in the Merlot cultivar, which had in the last two years a wider treatment range of irrigation coefficients (03-0.6).

The objective in Kazakhstan was to substitute current furrow irrigation with the more modern and efficient drip irrigation system, and measure the evapotranspiration rate of the drip irrigated vineyard.

B) Research Accomplishments – Kazakhstan

Introduction

Drip irrigation of vineyards, combined with application of mineral fertilizers (fertigation) was investigated in a field trial carried out in the vineyard of the "Wine Plant Ussyk" company, in the arid Almaty region. Drip irrigation, in contrast to traditional furrow irrigation, allowed the regulated input of water and nutrients to the soil to influence grape productivity and fruit quality. In addition, fertigation allowed a reduction in fertilizer usage, especially nitrogen and potassium.

A spring frosts in 1998 damaged severely the vines in the experimental plot. During the summer of 1998 vines were regenerated and uniform size grape vines were prepared for the experimental work of 1999 and 2000. The drip irrigation system was mounted and tested before the 1999 irrigation season. The aims of the research were:

1. To determine the quantity of water required for optimal irrigation of grapevines.
2. To reveal the rate of water-consumption at specific periods of plant development.
3. To establish the crop coefficient for grape irrigation, based on the accumulation of pan evaporation.
4. To evaluate the optimal irrigation layout (number of laterals, dripper discharge rate, and the distance between drippers).
5. To evaluate the efficiency of mineral fertilizer input (fertigation) under drip irrigation.
6. To determine grape response to drip irrigation and fertigation, compared to conventional furrow irrigation and fertilization.

Materials and Methods.

The climate in the region of investigation in Kazakhstan is sharply continental with high summer and low winter temperatures. Minimum winter temperature sometimes reaches

–35^{0}C. The average temperature of January is 13.6 ^{0}C. In summer, in some days, the temperature can reach 40-42 ^{0}C. The average temperatures of July and the beginning of August are 18.7 ^{0}C. The average annual temperature of the air is 7.2-8.9 ^{0}C.

Frost-free period is 150 -180 days. The first frost usually starts in the beginning of October, the last one - at the end of May. The sum of positive temperatures (higher than 5 ^{0}C) is 3600 ^{0}C, which is sufficient for the development of the whole vegetative and reproductive cycle of vineyards.

Snow in the winter accumulates to a height of 25-35 cm. The grape vine is trellis trained, with renewable trunks. Trunks are replaced every 3-5 years to keep them relatively thin and flexible for over-wintering in a bent position to the ground under the snow, to avoid freezing damage.

The average long-term annual precipitation is about 400 mm, and the main part of it (70%) rains in the winter-spring period.

The soil of the experimental plot is a light-chestnut, shallow, carbonated, and bedded by pebble at the depth of 100 -110 cm. Soil pH is 7.8 -7.9. Organic matter content in the 0-60 cm is 1.0% -1.9%. CO_2–carbonates are 3.7-9.5%. Cation Exchange Capacity (CEC) is 12 -16 mg per 100g of soil (80-90% of it is calcium). The total nitrogen content is 0.09% - 0.1%, phosphorus; 0.106% - 0.125% and potassium; 2.3% -3%.

The soil mechanical composition of the experimental plot is medium textured -loamy coarse-salty. Clay (< 0.01 mm) content in the first meter layer is 28% -30%. The low horizon, at a depth of 1.0-1.2 m is bedded with coarse-grained sand and pebble. The soil volume density in the top 10 cm root layer is 2.7 g|cm^3, and porosity is 52%. Water permeability of the soil in the experimental plot is intermediate. The rate of water penetration in the first hour is equal to 1.0-1.2 mm|min. The established filtration coefficient is 0.6 mm|min.

The main soil-water physical parameters, determined for one meter soil layer, were as follows: Hygroscopic water content - 58 mm. Water content at the wilting point - 83 mm, and

at field capacity - 284 mm. Water content at full saturation was 380 mm. Thus, the available water for plant growth in one-meter soil layer (difference between field capacity and wilting point) was 201 mm. For optimal plant growth, maximal soil water content depletion should not exceed 30%.

Measurements of soil water-content and tension were conducted by tensiometers, positioned at a depth of 30, 60 and 90 cm, at a distance of 30 cm from the drippers. Standard methods of investigations were followed (B.A.Dospekhov, 1979, as summarized in the publication: "Program-methodical instructions of conducting investigations with fertilizers, 1985"). Calibration of tensiometers was conducted under field conditions, in 1998, taking soil samples periodically for moisture determination by thermo-weight (gravimetric) method and comparing it to tensiometer readings. The tensiometer reading, corresponding to 201 mm soil water content (30% depletion of field capacity) was equal to -32 kPa.

Evaporation was determined by daily measurements of an open pan. The open pan surface area was 3000 cm^2 and the depth of the pan 0.65 m.

Treatments included irrigation of equal amount of water in the following irrigation layeouts:

A. Single lateral with 1 m distance between drippers and a dripper discharge rate of 4 l/h.

B. Two laterals with 1 m distance between drippers and a dripper discharge rate of 2 l/h.

C. Single lateral with 0.5 m distance between drippers and a dripper discharge rate of 2 l/h.

The experimental layout was a randomized block with 6 replicates. Vines were trained on a standard trellising system and fertigated with $N_{60}P_{60}K_{120}$ (kg/ha annual input).

Data collected included measurements of soil water balance, vegetative growth, yield, fruit quality, and mineral analysis of the plant and the soil.

Results

Climatic conditions in 1999 consisted of a rainy and cool spring, April frosts, moderate hot summer and a long and warm autumn. In the warmest month (August) the temperature reached 36-38 ^{0}C.

Compared to the long-term average precipitation, the 1999 growing season was very wet. The amount of precipitation (456 mm) was 1.4 times higher than the long-term average and in some months (i.e. July) it was 3-4 times higher (Table 1). Precipitation along the growing season was highly irregular. Pan evaporation in 1999 was 703.3 mm (Table 1), less than the long-term average evaporation of 1120 mm.

The measurement of precipitation patterns and intensities was essential because of the prevailing conditions in the pre-mountain zone of Kazakhstan, where extended slopes prevail and sometimes it rains with heavy showers. Not all of the heavy rains are available effectively to plants, as part of it is lost by runoff and by deep percolation.

Observation on soil water-resources before and after precipitations, indicated that the losses of heavy precipitations by surface runoff and deep percolation in May, June and July were 60%, and the total sum of efficient precipitations was not more that 50% for the whole 1999 yearly rainfall (Table 1).

In previous investigations (A.I.Bondartsev, 1998) it was established that the coefficient of useful precipitation (effective rainfall) depends mainly on the quantity of rain during the growing season: In wet years the coefficient of utilization of precipitation was only 0.50-0.53, in medium-wet years – 0.67-0.70, and in dry years – 0.94 or higher.

In 2000, pan evaporation was 970.8 mm (Table 2). The evaporation in both years increased as summer temperatures were rising, reaching a maximum in August, and declining toward the end of the growing season. Average daily evaporation was 1.5 and 2.5 mm|day in

October and 6.3 and 7.9 mm|day in August of 1999 and 2000, respectively (Table 3). In some hot days the evaporation reached 10-14 mm|day.

Soil water regime during the growing season was affected by the meteorological conditions and the irrigation regime.

The measurements of water resources at a depth of 30, 60 and 90 cm were conducted by tensiometers, in non-irrigated plots and under drip irrigation. Soil tension in non-irrigated plots reached its critical value (-32 kPa) in the 0-90 cm layer towards the beginning of August 1999, and by the end of October it was reduced to ca. –70 kPa (Fig.1). The highest tension was observed in the upper 0-30 cm soil layer, where moisture fluctuations were greatest.

Heavy precipitation and cool weather delayed the need for irrigation in 1999 until the beginning of August, when average soil moisture tension declined to -32 kPa. Three irrigations, totaling 110 mm, were applied in August. After that, irrigations were stopped until the end of the growing season, to facilitate better cane ripening (hardening) before the onset of the winter period. At the end of October an irrigation of 40 mm was applied (Table 1).

In the year 2000, which was a drier year, the critical tension of –32 kPa was reached a month earlier than in 1999 (Fig 2), therefore, irrigation started earlier (toward the end of June, Table 2). Irrigation in 2000 continued regularly until mid-August, applying 30-50 mm water per 10-day period.

Each irrigation cycle lasted 2-3 days. The total water applied were 150 mm and 270 mm during the growing season of 1999 and 2000, respectively (Tables 1 and 2).

Soil moisture determinations showed that until the end of June 1999 and the first part of May 2000, the evapo-transpiration in the grape vineyard consumed less water than the input from precipitation. This is indicated by the negative values of soil water depletion in Table 1 and 2 and the "negative" values of water consumptions (utilization) in Figures 2 and 3. The gain in soil moisture was 49.5 mm in 1999 (23.9 in May + 25.6 in June, Table 1) and 16.4 mm in 2000 (13.0 mm in April + 3.4 mm in May, Table 2). A gain in soil moisture was

evident also later in the season, at the end of October in both years. In the middle of the growing season there was a positive depletion of soil moisture by evapo-transpiration, which was balanced and corrected partially by irrigation. Evapo-transpiration depleted the soil moisture in 1999 by 69.1 mm, 56.9 mm, and 53.0 mm during July, August and September (total of 179 mm), respectively. A total of 110 mm water irrigated replaced part of the water lost from the soil in those months of 1999.

In 2000, evapo-transpiration depleted soil moisture by 162.9 mm during the months May – August, and a total of 270 mm was input by irrigation (Table 2).

Average daily pan evaporation (6.30 mm/day) and water consumption (5.98 mm/day) was highest in 1999 during the month of August (Table 3). In 2000, the highest evaporation (7.92 mm/day) was also in August but the highest consumption (6.49 mm/day) was in July. The overall pattern of water consumption fits the period of high evaporation when the main vegetative growth and berry development took place.

Drip irrigation reduced soil matric potential significantly, compared to the non-irrigated plots (Fig. 1 and Fig. 2). The irrigation, which was confined to periods of drought, maintained soil matric potential at approximately –30 to –35 kPa, as compared to ca. –70 kPa in the non-irrigated plots at the end of the growing season.

Soil profile wetting differed in the three drip irrigation treatments. A single lateral with 4 l/h drippers spaced 1 m (treatment A) wetted the soil to a depth of 1.2-1.4 m but on the soil surface it did not formed a continuous wetted strip. The 4 l/h drippers had on the soil surface a 0.7-0.8 m wetted circles, and a continuous wetted strip only at a depth of 0.4-0.6 m. The layout of two laterals with 2 l/h drippers, spaced 1 m along each lateral (drippers of the two laterals were displaced by 0.5 m, treatment B), caused a wide strip of 1.3-1.5 m, wetting the soil to a depth of 1.0-1.2 m. A single lateral with 2 l/h drippers spaced 0.5 m along the lateral (treatment C) formed a continuous strip of 80-90 cm width and wetting to a depth of 1.0-1.2 m.

The contribution of existing soil water (input of previous year), current year precipitation, and irrigation, to the water balance of the vineyard is presented in Table 4 and figures 5 and 6. The year-to-year carry-over of soil water constituted 18.8% and 21.2% of the total water budget in 1999 and 2000, respectively. Precipitation contributed in these two years 52.3% and 35.4%, respectively, while the source of the remaining 28.9% and 43.4% water was from irrigation. It is evident that in dry years, like 2000, the importance and contribution of irrigation was greater than in wet years.

The evapo-transpiration coefficient in years 1999 and 2000 had a similar maximal value but different time-scales (Fig. 7). In the dry year 2000 the maximal evapo-transpiration value was reached one month earlier. The shift in the time-scale can cause errors in irrigation scheduling based on evapo-transpiration coefficients calculated on the basis of a time scale. However, correlating evapo-transpiration coefficients to cumulative evaporation, rather than date, eliminated the difference between dry and wet years, up to the maximal coefficient value (Fig. 8).

The use of evapo-transpiration coefficients for Kazakhstan is a practical and useful method to schedule irrigation, because farmers do not have financial resources for more sophisticated methods. A similar but simpler method of using Irrigation Coefficients (rather than evapo-transpiration coefficients) is used in Israel, where in the absence of summer rainfalls coefficients are calculated from irrigation only. The use of an Irrigation Coefficient as practiced in Israel, however, cannot be valid for Kazakhstan because of prevailing rainfalls during the growing season. In Kazakhstan a more elaborate scheme is required to calculate Evapo-transpiration Coefficients, based on initial soil water content, precipitation, and irrigation. Evapo-transpiration Coefficient values, which takes into account climate (evaporation) and plant physiology (transpiration), can be translated regionally to quantities of water required for irrigation, from measurement of pan evaporation, taking into account the initial soil water content and current precipitation.

Nutrition regime of vineyards.

In 1999 a dose of $N_{60}P_{60}K_{120}$ kg/ha was fertigated, starting with the first irrigation at the beginning of August, and after harvest with the last irrigation of the season. In 2000 an identical dose was fertigated during a period of six weeks, from the beginning of May until mid June. This fertilizer dose is the current recommendation for furrow irrigation in the region in Kazakhstan. The high dose of K was applied because of the very low exchangeable soil potassium and the high demand for K by the grape. The soil in the experimental plot is loamy, fixing P and K. Fertilizers in drip irrigation are applied through the irrigation water, therefore the timing of nutrient application was dictated by the pattern of drought, when irrigation was required and actually applied (Tables 1 and 2, and Figs. 1- 4). The spring fertigation in 2000 was more efficient, from the standpoint of fertilization, as compared to the summer – autumn application in 1999, because it was applied during the main period of canopy development when the demand for nutrients is the highest.

Soil was sampled for analysis before harvest. In 1999 an additional sample was collected immediately after flowering. Samples were collected 40 cm from the drippers, perpendicular to the laterals, from the 0-30 cm and the 30-60 cm layers separately. Each sample was combined from several sites, for each treatment. Nutrient levels in 1999, when fertilizers were applied late in the growing season, were at a deficient level - bellow the optimum for NPK (Table 5). Soil fertility after flowering in 1999 was similar to the fertility at harvest time of 1999 (data not shown). Nutrient levels of NPK were higher in 2000, when fertigation was applied early in the growing season, as compared to 1999. Fertigation in 2000 raised soil nitrogen and phosphorus concentrations more significantly than levels of exchangeable potassium. The soil analysis in 2000 indicated optimal level of N and P but still insufficient K. For correcting soil exchangeable K level, probably more than 1-2 years of

fertigation, or a higher dose, is required. Previous investigation showed that fruit and pruning in vineyards remove 40-50 kg/ha N, 7-8 kg/ha P_2O_5 and 50-70 kg/ha K_2O.

Samples of leaf blade for N and P analysis and cluster rachis for K analysis were collected close to harvest. Leaf blades were taken from fruitful canes. The leaf blade and fruit rachis analysis in 1999 reflected the poor nitrogen and potassium fertility of the soil (Table 6). Leaf P was sufficient, although soil P was low.

Canopy development and yield was affected by shoot ripening (hardening), winter survival of buds, and by spring frosts. Late spring frost in 1999 caused cane damage, therefore average surviving shoot length was grater in 1999 than in 2000 (Table 7). Shoot hardening in autumn 1999 (91.7% - 92.8%, Table 7), and winter bud survival in 1999/2000 (60.2% - 62.5%, Table 8) were high. In addition, spring 2000 was frost-free. Consequently the yield in 2000 was higher than in 1999 (Table 9). The low yield of 1999 was caused by cumulative frost damage during two successive years (1998 and 1999). No differences were found in canopy development (Table 7), and indexes of fruitfulness (Table 9), between drip irrigation treatments.

Yield and fruit quality was affected only slightly by irrigation treatments. Yield and cluster weight of treatment B (two laterals, 2 l/h discharge rate drippers, spaced 1 m along laterals) was slightly better than in the other two treatments (Table 9). Sugar content of treatment A (a single lateral, 4 l/h discharge rate drippers, spaced 1 m along laterals) was in 2000 slightly less than in the other two treatments (Table 9). Differences in yield and fruit quality were minor, and probably not significant statistically.

Summary of investigation results in 1999-2000.

1. The efficiency of rainfall utilization varied from year to year, because of the rain intensities and losses through run-off and percolation. The utilization efficiency was approximately 50% in the wet year of 1999 and 83% in the dry year of 2000.

2. Irrigation was found to be important for supplementing the irregular rainfalls in Kazakhstan. The importance of irrigation varies from year to year and it is dependent in addition to rainfalls also on the evaporative demand. Irrigation accounted for 28.9% and 43.4% of grape (cv. Pino black) water consumption, during 1999 and 2000, respectively. The source of the remaining water consumed was from stored water in the soil and from precipitation.

3. Drip irrigation maintained soil matric potential at approximately –30 to –35 kPa, as compared to –70 kPa without irrigation.

4. The contour of soil wetting was influenced by the layout of the drip irrigation system and the discharge rate of the drippers. A layout of two laterals with 2 l/h dripper discharge rates, spaced 1 m along laterals appeared to be slightly preferable (in yield and cluster size), probably because of a wider wetted strip and less percolation. For conclusive results the various layouts has to be tested for longer periods of time.

4. Soil NPK fertility of the experimental vineyard was low. Fertigation corrected N and P nutrient status and improved the soil exchangeable K status.

5. Irrigation was scheduled and applied during dry periods in 1999 (summer – autumn) and in 2000 (spring). The application of fertilizers through the irrigation system in small and continuous doses (fertigation) is a very efficient method of fertilization. However, the ideal timing of irrigation confined to dry periods, may not be the ideal timing for fertilizer application. Therefore, fertigation can be practiced mainly when the timing of irrigation coincide with the ideal timing of fertilization. For occasions when the requirements for irrigation and fertilization do not coincide in time, alternate methods of fertilization need to be developed for drip irrigation in regions where summer rains prevail. One possibility is to apply 'technical' fertigation (fertigation during rainy periods, while the soil is wet, discharging the fertilizer in small irrigations doses of 3-5 mm).

Research Accomplishments - Israel (tables and figures attached)

Materials and Methods. The field trial in Israel was carried out in a commercial vineyard in the Arad Plateou (31°18' N, 35°08' E), 500 m above sea level. The Arad plateou has a unique, semi-arid micro-climate. Winter precipitation is ca. 160 mm, and only two third of it is effective. Night / day temperatures are 5 / 15 C° in the winter and 18 / 35 C° in mid-summer (Fig. 1), Relative humidity in the summer at night is at the dew point, and during the day is ca. 15%. The five year (1996 – 2000) average of total pan A evaporation was 1898 ± 134 mm for the 8 months of irrigation (April – October, Table 1). This value is 50% higher than in the coastal plain in Israel. The main objectives of the field trial was, therefore, to evaluate the validity of an irrigation model which was developed in the coastal plain (daily maximum evaporation of ca. 7-8 mm) for the Arad plateou (10-11 mm evaporation, Fig. 2). The model use irrigation coefficients, based on pan A evaporation (0.4 for vine grapes). The extrapolation of the model from medium to high evaporative demand had to be tested.

Treatments evaluated included raising the pan A irrigation coefficient from zero at bud break to either 0.3, 0.4 or 0.5 in the three vine cultivars Sauvignon blanc, Merlot and Cabernet sauvignon. An additional coefficient of 0.6 was tested in the Merlot in the last two years. The planting distance was 1.5x3 m (2222 vines / ha). The vineyard was trelised as a double sided cordon, trained verticaly on a T sahpe trelis of 3 wires. Shoots were positioned between wires to alow free tractor movement. Clusters were not thinned, allowing maximum potential yield. Treatments were replicated 4 times in a randomized block layeout. Each replicate consisted of three adjacent rows, 25 vines in a row (total of 75 vines per replicate). Data was collected from 10 vines in the center of the middle row.

Irrigation was by a single lateral drip line with 2.3 l / h drippers spaced 1 m apart. The vineyard was irrigated every 4-5 days. Volume of water was gradually raised from bud break (responding to soil matric potential measured by tensiometers), untill the final irrigation coefficient of each treatment was reached and remained constant thereafter. The vineyard was planted in 1989 and irrigation treatments were established in 1991. Tensiometers were used during the years of 1992-1995 to monitor soil water tension and control the gradual increase in the rate of irrigation, in order to prevent water loss by percolation. The different irrigation coefficient treatments received a proportinaly increasing dose of fertilizers (Table 2).

Petiole and leaf blade analysis at flowering and close to harvest showed a high intensity of K nutrition in the young vineyard and therefore initialy only nitrogen was fertigated. Phosphorous was included in the fertigation since 1995, after a P deficiency was diagnozed. Potassium was included in the fertigation scheme, beginning in 1999, after soil K was depleted from the root zone and a defficiency developed.

Maturity measurements started each year 3-4 weeks before the predicted harvest. Measurements started once a week and the interval shortened gradually to 2 days at harvest. At each sampling 3-4 kg fruit (whole clusters) was collected, and crushed for pH, acid, TSS, color and K determination.

Fruit was hand harvested and yield of 10 individual vines weighd. A sample of ca. 50 clusters and 200 berries was collected from each replicate and weighed for cluster and berry weight determination.

Wines were prepared and evaluated from each replicate. Fifty to sixty kg of fruit per replicate was crushed, and yiest (60g /100 l must) and sulfur (50 ppm) added. The red cultivars were crushed immediately in the field and after the addition of sulfur and yiest brought to the fermentation rooms at the Volcani Center. The Sauvignon

blank was brought to the Volcani Center and cooled (4 °C) overnight before crashing. The red cultivars were fermented with the skin, wetting them several times a day to extract color. The white cultivar was pressed to remove the skin, before fementation started. Fermentation was carried out in rooms maintained at 24 °C. The must was analyzed (pH, acidity, brix, K, color) before fermentation and acidity adjusted with tartaric acid to 6.5 g/l. After fermentation was completed (ca. one week), the skin in the red wines was removed by a mechanical press and the fermented wines transferred to 25 l glass botles stopered with air locks. Malo-lactic fermentation was initiated by adding Leuconostoc oenos EQ54 bacteria (25 mg / l wine). Wines were kept to age and settle at a16 °C room, and for one week at 6 °C. The supernatant clear wine was decanted 3 times to completely clarify it before bottling. At each decanting 20 ppm sulfur was added. Wine quality was evaluated after 8-9 months of aging by spectophotometric masurement of color (420 and 520 nm) and by a taste panel of 12-15 experts. The taste panel graded the wine for a maximum of 20 points, acording to the Davis method, based on color (4 points), smell (5 points), taste (9 points), and harmony (2 point).

Leaf blade and petioles were sampled for mineral analysis at flowering time and prior to harvest. Samples were washed, dried (70 °C) and ground to pass 30 mesh. Samples were digested with sulfuric acid for nitrogen analysis and with nitric acid for the remaining minerals. Nitrogen was determined by the Nesler color reaction and all the other minerals by plasma emision (ICP).

Canopy development and leaf area index (LAI) was measured on vines by tagging 16 shoot per treatment (4 shoots/vine x 4 replicate vines) in each cultivar and measuring light interception in the tagged vines. 'Merlot' and 'Cabernet' were measured in 1997 and 'Sauvignon' in 1998. Shoot length, number of leaves and leaf area at each node was measured at ca. weekly intervals, until growth cessation. Leaf

area on intact shoots was calculated from the length of the first two lateral veins of each leaf. The correlation of leaf area and vein length was established for each cultivar from detached leaves. Canopy development and light interception measured on the same vines enabled to follow the changes in LAI, as affected by the irrigation treatments, during canopy development. After shoot growth stooped, the vines were destructively sampled, enabling the calculations of the correlation between leaf area measured destructively and by light interception.

LAI determination by light interception was calculated by gap fraction inversion of light intercepted in the vineyard. The procedure of light measurements and LAI calculation was presented in the irrigation conference held in Lisbon, Portugal during June 28 – July 2, 1999. The comparative LAI of all three cultivars was measured in the same year, during 1998.

Stem water potential was determined by the pressure bomb (Ari-Mad, Kfar Charuv, Golan Heights, Israel) on leaves enclosed and sealed in plastic bags, covered with an aluminium foil. Leaves were enclosed for at least 2 hours to equlibrate with the stem water potential before measurement at 11:00 – 13:00 h. Two to three leaves were measured per replicate.

Photosynthesis (A), Transpiration (E) and stomatal conductance (S) were measured with the CI-301 photosynthesis instrument (CID, Inc., Wancuever, WA, USA) on 3-4 leaves per replicate .

Results

The effect of irrigation rate on vegetative growth. Shoot length, the number of leaves per shoot and leaf area per shoot was greater as the rate of irrigation increased (Fig. 3). The effect was detectable in taged shoots in the vineyard, early in the growing season, when growing degree days after bud break reached 300-500. The differences between treatments increased gradualy until growth cesation, at ca. 1000 degree days

(Fig. 3). Leaf size of 'Cabernet' and 'Merlot' increased gradually from the bottom of the cane and reached maximum size (ca. 115-130 cm) at node 6-8, when daily growth rate was ca.10 cm^2 per leaf (Fig. 4). Leaves at node number 12 had the highest Relative Growth Rate (RGR). Leaf size decreased after node 12-13 in 'Cabernet' and after node 10 in 'Merlot'.

Destructive sampling showed that leaf number and leaf area increased as the rate of irrigation was raised (Table 3). Leaf area of the three cultivars was 6.5 – 7.8 m^2/vine, 9.0 – 10.8 m^2/vine, and 11.7 – 13.3 m^2/vine in the irrigation rates of 0.3, 0.4 and 0.5 coefficients, respectively. These leaf areas are eqivalent to LAI (calculated from the destructive measurements) of 1.45 –1.73, 2.01 – 2.39, and 2.59 – 2.96, respectively. The increase in leaf area and LAI between the coefficient of 0.4 and 0.5 in 'Caberent' was relatively small. Surprisingly, leaf area and LAI of the three cultivars was very similar, although these cultivars are considered to be differing in vigor. 'Cabernet' is known to be a vigorous cultivar in contrast to the weak 'Merlot'.

Total shoot number was not affected by irrigation rate, although the distribution of thin vs thick shoots was changed in 'Merlot' and 'Cabernet' (Table 4). Average shoot length increased significantly as the irrigation rate increased. In 'Sauvignon', both thin and thick shoot length increased, while in the other two cultivars only the thick shoots length was affected. In all three cultivars the secondary, lateral, growth increased as the rate of irrigation was raised.

Pruning weight (of the following winter) is widely used in viticulture in relation to yield in order to evaluate the balance between vegetative growth and fruit production for estimating vine quality. Since pruning weight is only measured in the winter, the implication with respect to management for imroving vine quality can only be applied in the following year. Wine quality, however, is related to vine vigor within the same year. An alternative method of estimating and controling vigor

during fruit development is required in order to manipulate vine quality within the same year. Pruning weight is a justified parameter to measure because it is correlated to leaf area. Thus, for estimation of vigor in real-time a direct measurment of leaf area is preferable to pruning weight measurement. A procedure of estimating leaf area from light interception measurement has been developed in randomly distributed tree canopies (i.e. in the forest). In recent years the method was adapted to row crops (i.e. corn) and we applied it to the vineyard, collaborating with Dr. Sabtay Cohen at the Volcani Center. The validity of the light interception method for estimating LAI in the vineyard was confirmed by an independent measurements of total leaf area using destructive sampling of whole vines. The leaf area of the sampled vines was correlated to LAI measured by light interception, and to the pruning weight of the previous and the following year. The correlation to the pruning weight enabled to evaluate the usefulness of light interception measurements as a substitute for pruning weight measurements.

LAI estimate by light interception was reasonably correlated to actual LAI (measured destructively), provided the light interception measurement extended for at least 4 vines = 6 m (Fig. 5). In corn, measurement of 6-8 m row length is required in order to estimate LAI accuratly. The irrigation rate increased pruning weight of the three cultivars , similarly to the increase in total leaf area, total shoot length, and LAI (Table 5). Actual leaf area was highly correlated with shoot length in all three cultivars (r^2 = 0.872, 0.978 and 0.992 in 'Sauvignon', 'Merlot' and 'Cabernet', respectively). The correlation of actual leaf area with LAI (calculated from light interception), and with pruning weight (previous and following years) was ca. 0.7-0.8. Therefore, estimation of leaf area from light interception can substitute pruning weight measurement with equal precision, with the added advantage that the measurement is in real-time.

It should be pointed out that similar values of leaf areas of 'Sauvignon blanc', 'Merlot', and 'Cabernet sauvignon' were associated with a wide range of winter pruning weights (Table 5). Therefore, the conventional use of the fruit load parameter (kg fruit / kg pruning weight) for vine quality estimation require individual calibration of each cultivar. The use of light interception measurements to estimate leaf area, in addition to the advantage of measurement in real-time, also eliminates the need of such a calibration.

Stem water potential relation to irrigation rate, photosynthesis and stomatal conductance. Stem water potential was related to the irrigation rate (Fig. 6 and 7). Immediately after irrigation stem water potential range was ca. –5 to –7 atm. Four to five days later, before the next irrigation, mid-day stem water potential decreased to ca. –10 to –12 atm in the lowest irrigation rate (coefficient of 0.3). The relationship between irrigation rate and stem water potential was linear in 'Merlot' between a coefficient of 0.3 and 0.6, before and after irrigation (Fig. 7). Immediately after irrigation the vines recovered from water stress, as it can be seen from the change in the slope of the response curve and the pressure values attained. The recovery, however, was not complete and a minor stress, proportional to the irrigation rate, remained even after irrigation. Such a response indicated that water applied at an irrigation rate of 0.6 pan A coefficient (August 10, Fig. 7) was utilized completely, without saturating the soil and the water status within the vine.

Photosynthesis (A), Transpiration (E) and stomatal conductance (E) were affected by the rate of irrigation, in relation to stem water potential. In 'Sauvignon' a reduction in photosynthesis, transpiration and stomatal conductance was evident when irrigation rate was reduced to 0.3 coefficient and mid-day stem water potential declined to –11.8 atm (Table 7). Photosynthesis in relation to the irrigation rate was measured four times (once a monthh) in 'Merlot' in 1993 (Table 8 and Fig. 8). On

May 19, and immediately after irrigation on August 8, there were no differences in photosynthesis and stomatal conductance between irrigation rates. On August 8, stem water potential was affected significantly by the irrigation rate, but the difference between treatment was less than 2 atm and the lowest potential was only –6.6 atm (Table 8). On two other dates (June 7 and July 9), when measurements were carried out before irrigation, stem water potential, photosynthesis, transpiration and stomatal conductance were reduced as the irrigation rate was reduced. Stomatal conductance on these two dates was reduced significantly in the morning and at noon, although slightly less in the morning than during the noon measurement. In contrast, morning photosynthesis, when measured before irrigation, was not affected by the rate of irrigation, althoug a water stress of –9.2 atm (June 7) and –12.0 atm (July 9) developed at mid-day. Photosynthesis and stomatal conductance were reduced linearly with the reduction in mid-day stem water potential (Fig. 8).

Fruit quality (maturity, cluster and berry size). The irrigation rate had no consistent effect on pH and brix values of all three cultivars (Table 9). Acidity of 'Sauvignon' and 'Cabernet' increased as the rate of irrigation increased. The increase was in some cases significant only at the highest rate of irrigation, but it was consistent in all 3 years and levels of irrigation. Acidity of 'Merlot' was not affected by the irrigation rate.

Increasing the irrigation rate increased cluster and berry size of 'Sauvignon' (Table 10). The effect was significant in two out of three years (1997 and 1999). 'Cabernet' berry weight increased similarly (1998 and 1999). 'Merlot' cluster or berry weight was not affected consistently by the irrigation rate.

Yield, pruning weight and fruit load. Yield of 'Sauvignon' and 'Merlot' increased as the irrigation rate was raised. As an average, 'Sauvignon' yield increased by 39% and 65% when irrigation rate increased from 0.3 to 0.4 and 0.5 coefficients, respectively.

'Merlot' yield increased 25%, 24%, and 38% when irrigation coefficient increased from 0.3 to 0.4, 0.5 and 0.6, respectively (Table 11). Yeld of 'Cabernet' was not affected by the irrigation rate.

The three cultivars differed in their pruning weight. The 'Merlot' had the lowest pruning weights (table 11). 'Sauvignon' pruning weights were 113%, 143% and 165% greater than the 'Merlot', at the equivalent rates of 0.3, 0.4 and 0.5 irrigation coefficients, respectively. 'Cabernet' pruning weights were 186%, 205% and 212% greater than the 'Merlot', respectively. Pruning weight increased significantly in all 3 cultivars as the irrigation rate was raised. The effect was greatest in 'Sauvignon', and minimal in 'Merlot'. In 'Sauvignon' pruning weight increased 94% and 191% when irrigated with 0.4 and 0.5 coefficient, respectively, as compared to a coefficient of 0.3. In 'Cabernet' the equivalent increase was 68% and 111%, and in 'Merlot' 57% and 70%, respectively.

Fruit load decreased as the irrigation reate was raised (Table 11). Fruit loads of ca. 10 (kg fruit / kg pruning weight) is considered to be the optimal value for wine quality in 'Cabernet'. An irrigation coefficient of 0.3 in 'Cabernet' had on the average the closest value to 10. The optimal fruit load value for wine quality in the other cultivars was not reported. 'Sauvignon' had the highest fruit loads (Table 11). The comparative data in table 11 indicates that fruit loads of the various cultivars differ considerably, and the difference can be attributed mainly to pruning weight, rather than to yield. Wine quality is affected by leaf area and light exposure. Since leaf area and yield of the three cultivars was similar (Table 5) but the pruning weight differed, it can be concluded that the optimal fruit load of the three cultivars for wine quality must be different and therefore each cultivar has to be calibrated individually. In contrast, leaf area estimation by light interception measurement is a direct estimation of load which does not require calibration.

Wine quality. Total wine quality of 'Merlot' and 'Cabernet' was affected only slightly by the irrigation rate (Table 12). The minor differences could be attributed to reduced color and taste at the higher irrigation rates. Differences in color were significant while the trends in taste were not significant. The reduced color could be attributed to the higher berry size (Table 10), which reduced the skin surface to berry volume ratio. Anthocyanins are concentrated in the berry skin and increasing berry volume diluted the color. Wine quality of 'Sauvignon blank' was not affected by the rate of irrigation.

Leaf analysis and vineyard nutritional status. Leaf petiole and blade was analyzed at flowering and at harvest time, in order to estimate vineyard nutritional status and the effects of the irrigation rate on the mineral profile of the grape. There is a long standing dispute among researchers as to the appropriate tissue and timing for leaf analysis of grapes. We sampled both petiole and blade, at the two commonly used phenological stages and concluded from this study some definite conclusions. Some of the leaf analysis data regarding P and K nutrition was published (Vitis 39:55-62, 2000), analyzing the long term nutritional trends (1993-1998) of the vineyard. For the interpretation of the P nutrition we included data from an additional experiment (carried out adjacently), which compared the effects of surface and sub-surface irrigation with secondary purified recycled water in 'Merlot' and 'Cabernet'. The recycled effluent contained high phosphorus concentrations and enriched the grape tissue with P, beyond normal levels encounterd in vineyards.

Leaf petiole and blade analysis indicated that the nitrogen status of the vines was adequate (Table 13). Tissue potassium level in the young vineyard was luxurious (ca. 2-3% in petiole at harvest), reflecting abundant supply of K by the soil, while the tissue concentration of P was at a deficient level (ca. 0.1% and less in blade at harvest). Potassium levels declined as the vineyard matured, probably as a result of K depletion from the limited volume of soil

explored by the root system under drip irrigation. Low rates of phosphate fertigation (5.6-13.7 kg ha^{-1} P, annually) raised tissue P, proportionally to the rate of fertigation. Irrigation according to Pan A coefficient of 0.3, as compared to coefficients of 0.4 and 0.5, reduced significantly tissue K levels. Irrigation with recycled water (high in NPK) raised tissue P significantly. The relative depletion of K and P in leaf petiole and blade, from flowering to harvest time, was found to be a good indicator of the nutritional status of these two elements in grapes. Petiole P at flowering was polynomially and linearly correlated with petiole and blade P at harvest, respectively, under a wide range of P nutritional intensities. Leaf blade at flowering and harvest had higher priority for P under low intensity of P nutrition. Sub-optimal P nutrition could be diagnosed best by petiole P concentration at harvest. The inflection petiole concentration associated with optimum P nutrition was 0.413% P at flowering, which corresponded to 0.133% P in petiole and blade at harvest time.

C. Scientific impact of Collaboration. The impact of collaboration included the training of the team from Kazakhstan in the maintenance of the drip irrigation system and the appropriate design of experimental layouts for fertigation experiments (randomized blocks across rows, utilizing blind laterals, etc.). The collaboration was achieved through the visit of the researchers from Kazakhstan to Israel, where they inspected drip irrigation equipment (in the factory and the field) and experimental layouts in practice in the field. The experimental design in Kazakhstan was worked out in collaboration with Dr. I. Klein during his visit to Kazakhstan.

D. Description of project impact: Modern methods of irrigation were introduced to Kazakhstan. The research team in Kazakhstan successfully adopted, with appropriate modification required for the conditions in Kazakhstan, an irrigation scheme for vineyards, taking into account soil and environmental data. In Israel the validity of an irrigation model, developed for moderate environmental stress was tested and proven valid for high environmental stress region.

E. Strengthening of Developing Country Institution. The Institute of Grape Growing in Kazakhstan invested in a modern drip irrigation system, and acquired several portable scientific equipments, essential for collecting appropriate data in field experiments (plant water console for plant water potential measurements, tensiometers for soil water tension measurements and a ceptometer for light interception measurements). Institutional constrains in Kazakhstan are formidable. The way we tried to overcome it is by investing in equipment and international travel, to train researchers from learning abroad.

Section II

A. Managerial Issues. Visits of the team from Kazakhstan to Israel required the invitation of a translator, since the Kazakhstan researchers are not speaking English. This was authorized. We had to resist (with difficulties) an attempt to include in the visits to Israel the head of the institute from Kazakhstan.

Purchase and shipment of equipment to Kazakhstan is a complicated procedure. It took some efforts to avoid paying custom on equipment shipped to Kazakhstan. In Kazakhstan itself, theft of irrigation equipment (tubing, irrigation computer, pumps etc.) is a major problem, which restricted the choices of available experimental plots.

B. Budget. A request was submitted for the following change in the budget:

a. Transfer $5000 from International Travel to labour
b. Transfer $7000 from Equipment to Materials and Supplies.

The need for these budget changes was caused by expenses incurred from the harvest operation of the experimental vineyard, and the micro-vinification and the use of the taste-panel for organoleptic evaluation of the wines from the field experiment.

C. Special Concerns. None

D. Collaboration, Travel, Training, and Publication. The Israeli principal investigator (Klein, I) visited Kazakhstan during 29.6.97-6.7.97, to coordinate research activities in Kazakhstan. Two members of the Kazakh team traveled to Israel (Dr. Madenov E for 10 days and Dr. Bondartsev A. for 18 days) in the middle of September 1997. Both scientists were introduced to the grape growing industry of Israel, in the North, the Jordan Valley and in the Arad Peninsula, where the collaborative research is taking place. Dr. Bondartsev visited drip (Netafim Magal) and micro sprinkler (Dan Micro sprinkler Inc.) irrigation factories to see first hand the irrigation equipment industry. The team from Kazakhstan (Dr. Adrianova G, Dr. Bondartsev) visited Israel also in the Spring of 1998, to inspect the field experiment at flowering, study our procedures of leaf analysis, measurements of plant water tension and light interception in the vineyard.

A paper was presented in a scientific irrigation meeting in Portugal on the subject of Leaf Area Index measurement in vineyards by light interception (gap fraction inversion measurements). A second paper on mineral nutrition under fertigation was published also (I. Klein, M. Striem, L. Fanberstein and Y. Mani. 2000. Irrigation and fertigation effects on phosphorus and potassium nutrition of wine grapes. Vitis 39:55-62).

Attachments of tables and figures - Kazakhstan

Table 1. Components of soil water balance in a drip irrigated vineyard. 1999.

Month	Ten Day Interval	Evaporation (mm)	Precipitation (mm) Total	Precipitation (mm) Effective	Change in Soil water content (mm)	Irrigation (mm)	Water consumption (mm)	Evapo-transpiration coefficient
IV	3	7.5			1.8		1.8	0.25
V	1	19.9	17.4	17.4	-10.7		6.7	0.35
	2	33.1	67.9	20.3	-7.4		12.9	0.40
	3	29.7	19.3	19.3	-5.8		13.5	0.45
	sum	82.7	104.6	57.0	-23.9		33.1	
VI	1	25.6	97.4	31.6	-18.6		13.0	0.55
	2	40.2	36.9	36.9	-10.9		26.0	0.65
	3	39.2	25.3	25.3	3.9		29.2	0.75
	sum	105.0	159.6	93.8	-25.6		68.2	
VII	1	45.7	24.5	24.5	11.1		35.6	0.80
	2	50.1	106.8	36.7	8.3		45.0	0.90
	3	61.2	8.4	8.4	49.7		58.1	0.95
	sum	157.0	139.7	69.6	69.1		138.7	
VIII	1	70.3			40.3	30	70.3	1.00
	2	59.6	9.6	9.6	16.9	30	56.5	0.95
	3	65.4	9.0	9.0	-0.3	50	58.7	0.90
	sum	195.3	18.6	18.6	56.9	110	185.5	
IX	1	32.5	17.9	17.9	8.1		26.0	0.80
	2	48.6			34.0		34.0	0.70
	3	27.1	4.8	4.8	10.9		15.7	0.60
	sum	108.2	22.7	22.7	53.0		75.7	
X	1	21.3			9.5		9.5	0.45
	2	10.9			3.8		3.8	0.35
	3	15.4	10.3	10.3	-47.0	40	3.3	0.25
	sum	47.6	10.3	10.3	-33.7	40	16.6	
Total		703.3	455.5	272.0	97.6	150	519.6	0.63

Table 2. Components of soil water balance in a drip irrigated vineyard. 2000

Month	Ten Day Interval	Evaporation (mm)	Precipitation (mm) Total	Precipitation (mm) Effective	Change in Soil water content (mm)	Irrigation (mm)	Water consumption (mm)	Evapo-transpiration coefficient
IV	1		11.4					
	2		4.2					
	3	22.3	19.7	19.7	-13.0		6.7	0.30
	sum	22.3	19.7	19.7	-13.0		6.7	
V	1	41.8	22.9	20.1	-3.4		16.7	0.40
	2	55.7	27.9	25.3	5.3		30.6	0.55
	3	50.3	24.7	21.6	11.1		32.7	0.65
	sum	147.8	75.5	67	13.0		80	
VI	1	44.6	35	30.9	2.5		33.4	0.75
	2	60.2	2.4	2.4	45.8		48.2	0.80
	3	66.7	4.2	4.2	22.5	30	56.7	0.85
	sum	171.5	41.6	37.5	70.8	30	138.3	
VII	1	80.6	4.2	4.2	22.3	50	76.5	0.95
	2	60.9	17.0	17.0	-9.2	50	57.8	0.95
	3	74.2	0.5	0.5	16.3	50	66.8	0.90
	sum	215.7	21.7	21.7	29.4	150	201.1	
VIII	1	91.3	18.7	16.3	11.3	50	77.6	0.85
	2	79.8	1.0	1.0	10.9	40	51.9	0.65
	3	74.5	6.0	6.0	27.5		33.5	0.45
	sum	245.6	25.7	23.3	49.7	90	163	
IX	1	53.8			16.1		16.1	0.30
	2	56.7	1.0	1.0	10.3		11.3	0.20
	3	31.8	39.0	33.4	-30.2		3.2	0.10
	sum	142.3	40	34.4	-3.8		30.6	
X	1	25.6	39.2	16.6	-14.1		2.5	0.10
	Total	970.8	263.4	220.2	132.0	270.0	622.2	0.64

Table 3. Average daily evaporation and water consumption. mm|day

	Month							
	IV	V	VI	VII	VIII	IX	X	V-X
				Evaporation				
1999		2.66	3.50	5.06	6.30	3.60	1.52	3.72
2000	2.2	4.77	5.72	6.96	7.92	4.74	2.5	5.39
				Daily water consumption				
1999		1.07	2.07	4.47	5.98	2.52	0.53	2.75
2000	0.67	2.58	4.15	6.49	5.26	1.02	0.25	3.45

Table 4. The contribution of precipitation and irrigation to soil water content and water consumption in the vineyard

		Water consumption	Change in soil water content		Effective precipitation		Irrigation	
Year	Month	mm	mm	%	mm	%	mm	%
1999	IV	1.8	1.8	100				
	V	33.1	-23.9	-72.2	57.0	172.2		
	VI	68.2	-25.6	-37.5	93.8	137.5		
	VII	138.7	69.1	49.8	69.6	50.2		
	VIII	185.5	56.9	30.7	18.6	10.0	110	59.3
	IX	75.7	53.0	70.0	22.7	30.0		
	X	16.6	-33.7	-203.0	10.3	62.0	40	241.0
	Total	519.6	97.6	18.8	272.0	52.3	150	28.9
2000	IV	6.7	-13.0	-194.0	19.7	10.9		
	V	80.0	13.0	16.2	67	83.8		
	VI	138.3	70.8	51.2	37.5	27.1	30	21.7
	VII	201.1	29.4	14.6	21.7	10.8	150	74.6
	VIII	163.0	49.7	30.5	23.3	14.3	90	55.2
	IX	30.6	-3.8	-12.4	34.4	112.4		
	X	2.5	-14.1	-564.0	16.6	664.0		
	Total	622.2	132.0	21.2	220.2	35.4	270	43.4

Table 5. Soil analysis of the experimental vineyard. Soil sampled close to harvest.

Treatment	Layer (cm)	Humus (%)	PH	1999 N	1999 P_2O_5	1999 K_2O	2000 N	2000 P_2O_5	2000 K_2O
				(mg/100 g of soil)					
A	0-30	2.0	8.0	4.4	1.5	20.4	11.6	2.9	25.0
	30-60	1.5	7.9	2.0	0.7	12.4	10.6	1.3	16.0
B	0-30	1.9	8.0	4.0	1.8	18.0	12.0	3.4	24.5
	30-60	1.7	7.9	2.0	0.8	10.0	11.0	1.4	18.0
C	0-30	2.3	7.9	6.0	1.6	22.0	13.8	3.4	27.6
	30-60	1.9	7.8	2.0	0.8	12.0	12.5	1.5	18.0

Table 6. Nitrogen and phosphorus concentration in leaf lamina and potassium in cluster rachis of cv. Pino black grape (% dry weight), 1999.

Treatment	Nitrogen	Phosphorus	Potassium
A	2.04	0.52	2.0
B	2.04	0.54	2.2
C	1.94	0.54	2.1
Optimum	2.8-2.9	0.5-0.6	2.6-2.7

Table 7. Canopy development and shoot ripening (hardening) of cv. Pino Black .

	Drip Treatment						
Year	Number of laterals	Distance between drippers (m)	Discharge rate (l/h)	Number of shhots per vine	Total shoot length per vine (cm)	Average shoot length (cm)	Ripened shoots/vine (%)
1999	1	1	4	---	----	111	92.8
	2	1	2	---	----	123	91.7
	1	0.5	2	---	---	115	92.4
2000	1	1	4	45.7	3782	82.8	72.4
	2	1	2	44.8	4186	94.2	74.3
	1	0.5	2	45.5	3940	86.6	73.2

Table 8. Indexes of fruitfulness of the cv. Pino Black. 2000

Treatment	Surviving buds (%)	developed Shoots (%)	Fruitful shoots (%)	Inflorescences per vine (#)	Fruit bearing coefficient (K1)	Coefficient of fruitfulness (K2)
A	60.2	62.3	42.7	35.0	0.56	1.31
B	62.3	64.4	43.6	36.3	0.57	1.30
C	62.5	64.0	42.5	35.5	0.56	1.30

Table 9. Yield and fruit quality of Pino black grape under drip irrigation. 1999 and 2000.

Year	Treatment	Yield (t|ha)	Yield (kg/vine)	number of clustrs	Cluster weight (g)	Acidity (g|l)	Sugar (%)
1999	A	4.98	1.98	24.4	81	8.6	18.2
	B	5.28	2.10	23.6	89	8.2	18.4
	C	5.04	2.02	23.5	86	8.4	18.3
2000	A	8.44	3.36	34.4	101.2	9.9	18.9
	B	9.48	3.77	23.6	110.6	9.7	19.3
	C	8.99	3.57	23.5	106.1	9.7	19.4

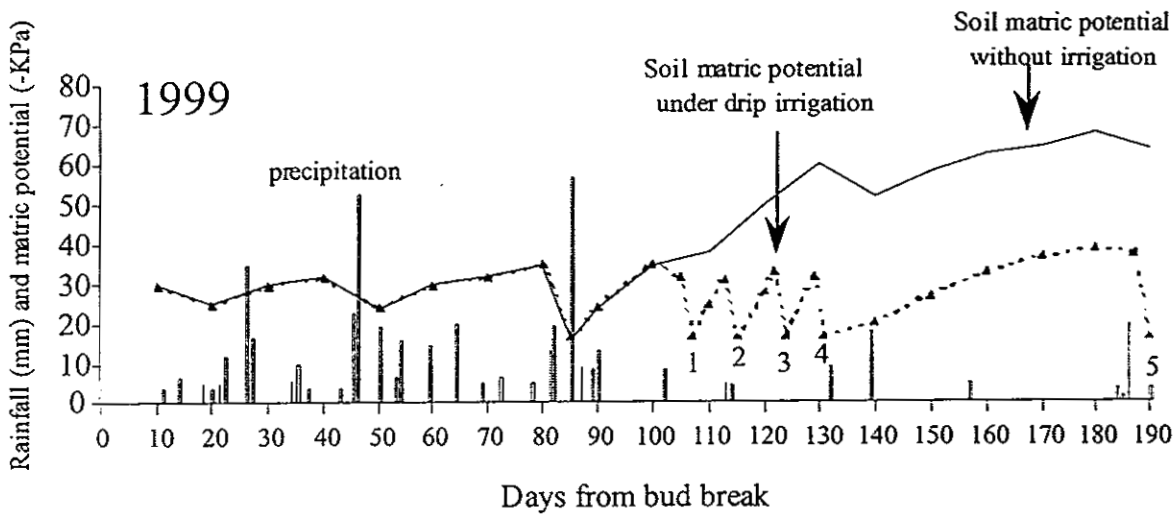

Fig 1. Rainfall and soil matric potential in the 0-90 cm layer

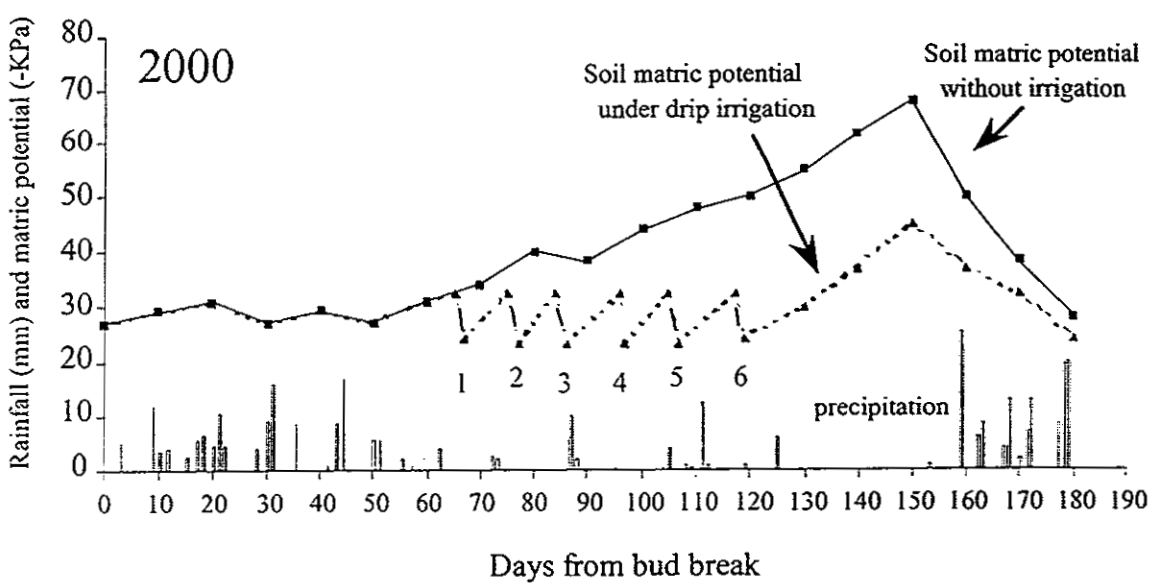

Fig 2. Rainfall and soil matrc potential in the 0-90 cm layer

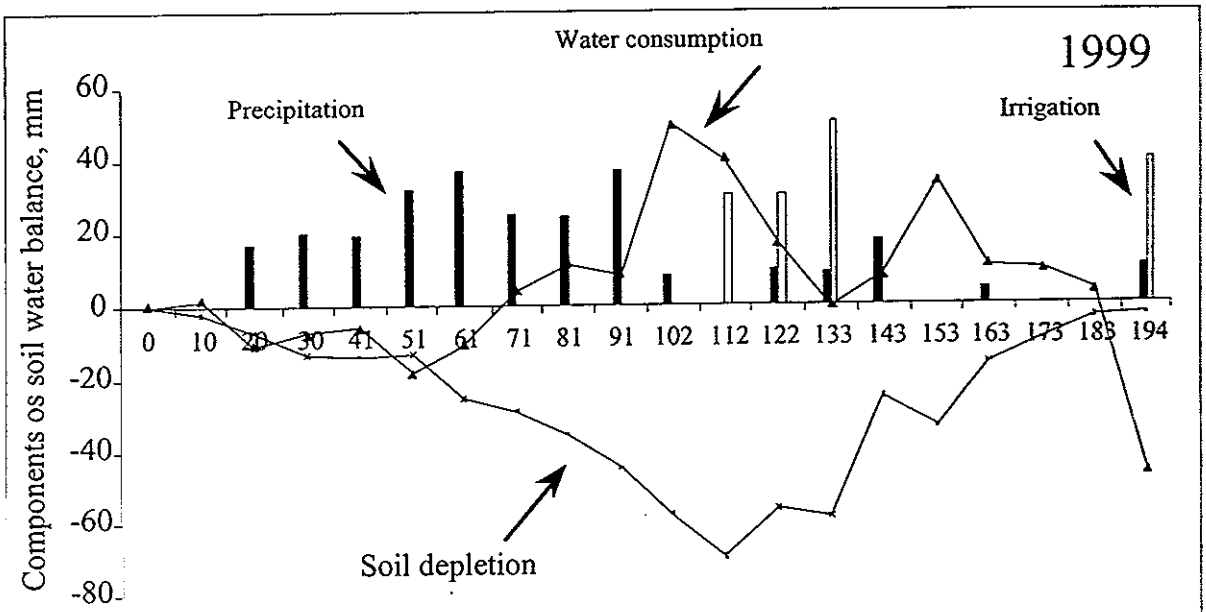

Fig. 3. Ten-day period evolution of soil water balance in the vineyard. 1999

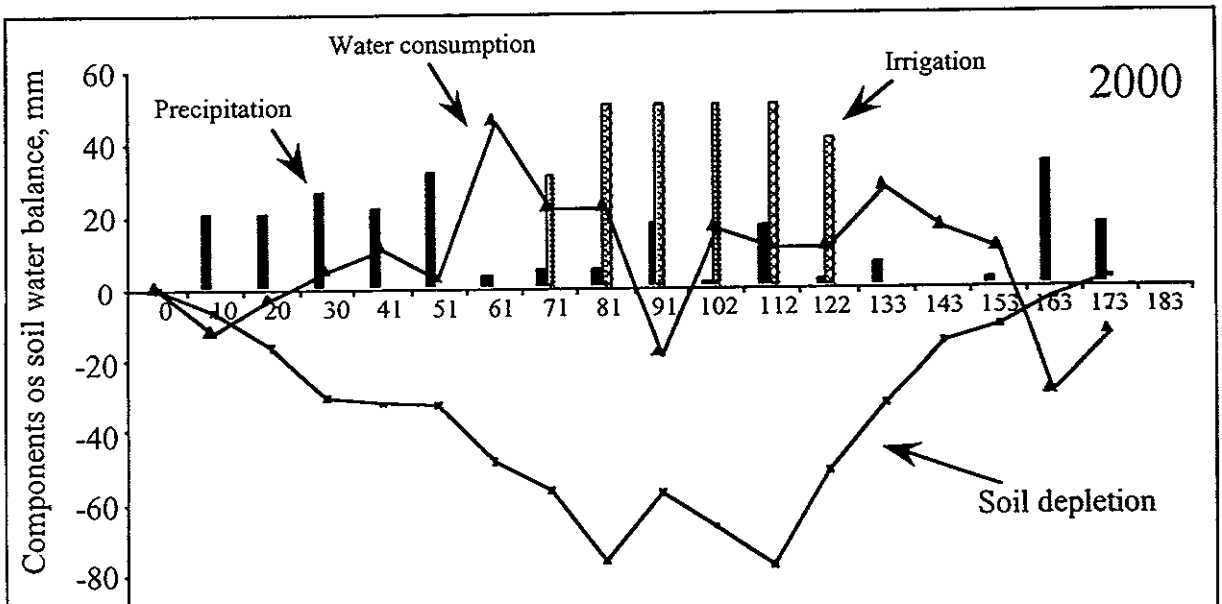

Fig. 4. Ten-day period evolution of soil water balance in the vineyard. 2000

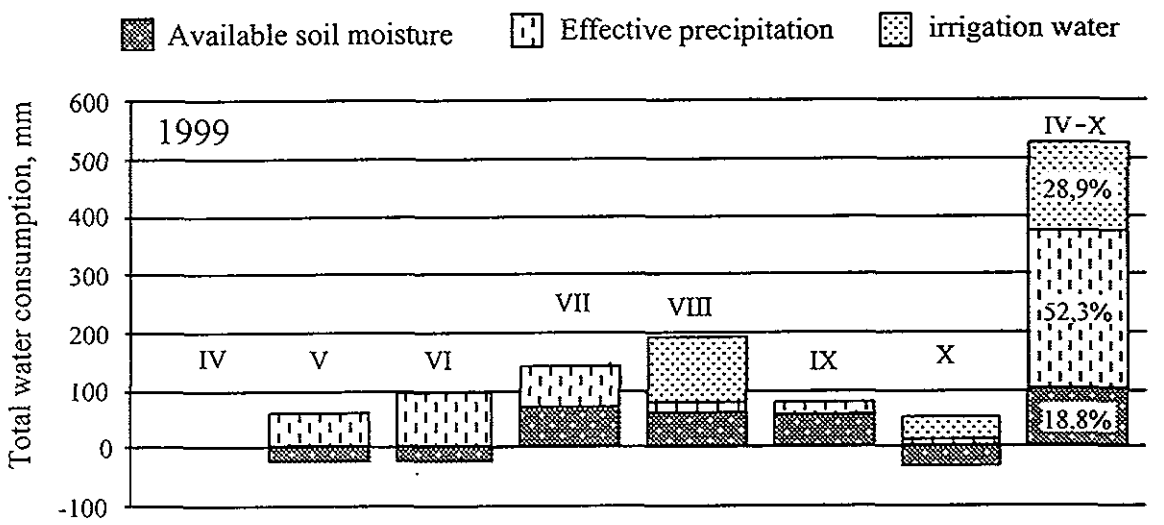

Fig. 5. The contribution of precipitation, irrigation, and available soil moisture to total water consumption

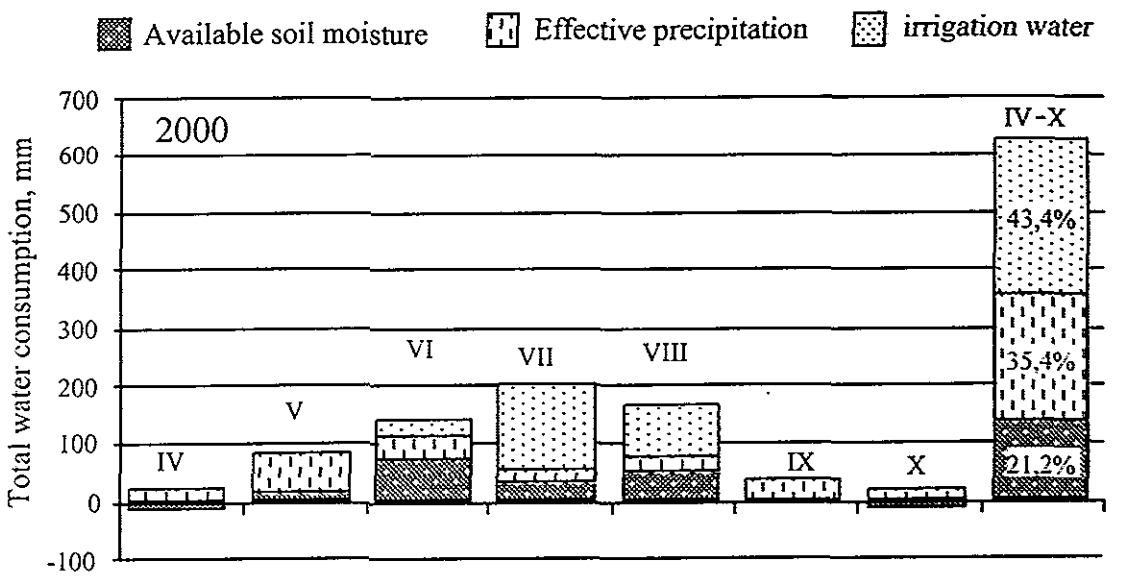

Fig. 6. The contribution of precipitation, irrigation, and available soil moisture to total water consumption

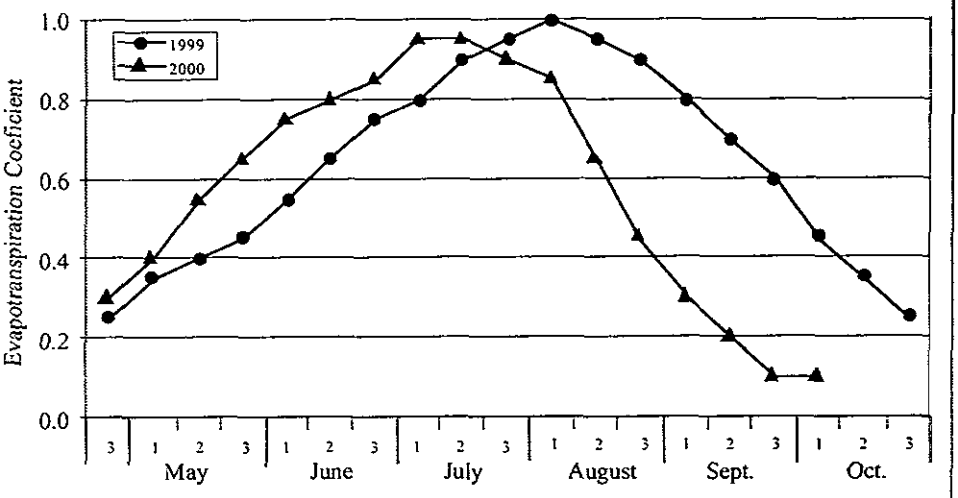

Fig. 7. The evolution of grape evapotranspiration coefficient during the growing season

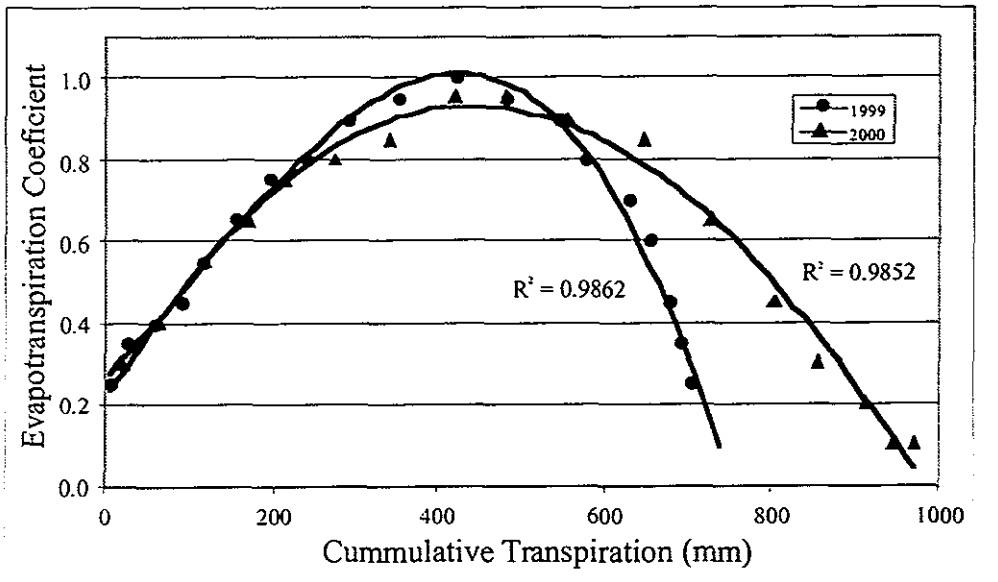

Fig. 8. The dependence of evapotranspiration coefficient on cumulative transpiration in wet and dry years

Attachment of Tables and Figures – Israel

Table 1. Pan A evaporation in the Arad Plateau. 1996-2000.

	1996	1997	1998	1999	2000	Avg	STDEV
January	43	50	62	69	75	60	13
February	89	84	72	77.2	94	83	9
March	101	111	118	165	107	120	26
April	184	170	230	210	210	201	24
May	320	281	298	321	280	300	20
June	310	310	326	300	313	312	9
July	341	333	384	336	325	344	23
August	252	262	342	304	286	289	36
September	200	249	265	275	224	243	31
October	150	169	210	259	259	210	50
November	72	119	121	194	133	128	44
December	86	72	108	162	56	97	97
Sum (Jan. - Dec.)	2148	2209	2535	2672	2361	2385	219
Sum (Apl. - Oct.)	1757	1774	2055	2006	1898	1898	134

Table 2. Annual NPK fertigation in the irrigation experiment in the Arad Plateau (kg ha^{-1} $year^{-1}$).

	Pan A Irrigation Coefficient								
Cultivar	0.3	0.4	0.5	0.3	0.4	0.5	0.3	0.4	0.5
		N			P*			K**	
Sauvignon blanc	49	65	81	6	8	9	31	41	52
Merlot	71	95	119	8	11	14	45	60	75
Cabernet Sauvignon	53	70	88	6	8	10	33	44	56

* P fertigation started in 1995.

** K fertigation started in 1999,

Table 3. The effect of irrigation rate on leaf development of three grape cultivars in the Arad Plateau. Destructive sampling during 1997 (Merlot and Cabernet), and 1998 (Sauvignon).

Irrigation Coeff.	Number of leaves / vine			Leaf Area (m^2 / vine)			
	periphery	inside	Total	periphery	inside	Total	LAI
Sauvignon							
0.3	-------	-------	-------	-------	-------	7.26 c	1.61
0.4	-------	-------	-------	-------	-------	10.77 b	2.39
0.5	-------	-------	-------	-------	-------	13.30 a	2.96
p						0.0027	
Merlot							
0.3	416 b	758 a	1174 b	2.65 b	3.86 b	6.51 b	1.45
0.4	488 b	960 a	1448 ab	3.37 ab	5.65 a	9.03 ab	2.01
0.5	940 a	893 a	1833 a	5.89 a	5.89 a	11.77 a	2.60
p	0.1098	0.0414	0.0762	0.0261	0.0144	0.007	
Cabernet							
0.3	432 b	946 b	1378 b	2.31 b	5.48 a	7.79 b	1.73
0.4	568 ab	1202 a	1770 a	3.11 ab	7.27 a	10.38 ab	2.31
0.5	771 a	1192 a	1963 a	4.56 a	7.11 a	11.67 a	2.59
p	0.059	0.0300	0.0414	0.0148	0.0761	0.176	

Table 4. The effect of irrigation rate on shoot development of three grape cultivars in the Arad Plateau. Destructive sampling during 1997 (Merlot and Cabernet), and 1998 (Sauvignon).

Irrigation Coeff.	Number of Shoots Thin		Number of Shoots Thick		Shoot Length (cm) Total		Shoot Length (cm) Thin		Shoot Length (cm) Thick		growth Total		Lateral (cm)	
						Sauvignon								
0.3	43.8	a	14.3	a	58.0	a	32.8	c	78.4	b	44.3	b	92.5	a
0.4	44.5	a	15.8	a	60.3	a	48.6	b	104.0	b	62.3	b	102.8	a
0.5	37.5	a	16.3	a	53.8	a	65.3	a	140.0	a	89.4	a	1256.8	a
p	0.5782		0.8157		0.6055		0.0051		0.0132		0.0122		0.2503	
						Merlot								
0.3	22	b	26.3	a	52.3	a	30.1	a	64.5	c	48.2	b	32.4	a
0.4	30.3	ab	20.0	a	54.3	a	34.7	a	79.4	b	63.6	a	72.3	a
0.5	36.3	a	22.0	a	62.3	a	30.2	a	101.4	a	76.7	a	179.3	a
p	0.0621		0.4419		0.1693		0.4033		0.0003		0.0081		0.2475	
						Cabernet								
0.3	31.3	a	33.5	a	68.8	a	34.1	a	82.2	b	59.2	b	61.1	a
0.4	38.5	a	23.5	b	66.0	a	37.9	a	107.3	a	84.1	a	211.1	a
0.5	41	a	21.3	b	66.3	a	39.3	a	111.0	a	89.7	a	253.8	a
p	0.1877		0.0124		0.8341		0.473		0.0101		0.0206		0.1902	

Table 5. Leaf area, shoot length, LAI and pruning weight of three vine grape cultivars irrigated with various pan A irrigation coefficients.

Pan A Irrigation Coefficient	Leaf Area (m^2/vine)	Shoots Length (m/vine)	LAI	Pruning Weight (kg/vine) 1996	1997	1998
Merlot						
0.3	6.51 b	2.54 b	1.58 b	0.39 c	---	0.54 c
0.4	9.03 ab	3.53 b	1.84 ab	0.61 b	---	0.83 ab
0.5	11.80 a	5.02 a	2.14 a	0.82 a	---	0.91 b
0.6	---	---	---	---	---	1.24 a
(R^2):						
Leaf Area		0.978	0.707	0.798	0.700	
LAI		0.649		0.741	0.467	
Cabernet Sauvignon						
0.3	6.59 b	3.54 b	1.78 b	0.77 b	0.70 b	0.66 c
0.4	10.4 a	5.78 a	2.56 a	1.37 a	0.39 a	1.84 b
0.5	11.7 a	6.17 a	2.83 a	1.84 a	1.82 a	2.40 a
(R^2):						
Leaf Area		0.992	0.756	0.882	0.922	0.925
LAI		0.740		0.764	0.781	0.845
Sauvignon blanc						
0.3	7.26 c	2.66 b	3.37 b	0.66 c	0.39 c	0.50 c
0.4	10.76 b	3.93 ab	4.10 ab	1.33 b	0.70 b	0.87 b
0.5	13.30 a	4.99 a	4.74 a	1.84 a	1.04 a	1.20 a
(R^2):						
Leaf Area		0.872	0.758	----	0.746	0.575
LAI		0.894		----	0.578	0.543

Table 6. The effect of irrigation rate on Leaf Area Index (LAI) of three grape cultivars in the Arad Plateau. LAI was calculated by gap fraction inversion of light intercepted in the vineyard.

Irrigation coefficient	Sauvignon 24.6.98	Merlot 20.7.98	Cabernet 20.7.98
0.3	3.12 a	3.74 a	3.12 c
0.4	4.11 a	4.33 a	4.12 b
0.5	4.75 a	4.27 a	4.76 a
p	0.1002	0.1209	0.0007
F	3.5	3.1	30.3

Table 7. Stem water potential (Ψ), Photosynthesis (A), transpiration (E) and stomatal conductance (S) of Sauvignon blanc grown in the irrigation experiment at the Arad Plateau.

Irrigation Coefficient	Ψ (atm)	A (mmol/m ^{2}/s)	E (milimol/m^2/s)	S (m^2/s/mol)
0.3	-11.8 b	8.2 b	1.3 b	0.0227 a
0.4	-9.2 a	11.4 a	2.2 a	0.0434 b
0.5	-8.4 a	10.9 ab	2.1 a	0.0370 b

Table 8. Stem water potential (Ψ), stomatal conductance (S), transpiration (E) and net photosynthesis (A) in Merlot wine grape irrigated with 4 pan A coefficients. Measurements at 8.8.1999 were immediately after irrigation.

	Pan A irrigation coefficient	Ψ (atm.) (atm.)	S ($m^2/s/mol$)		E ($milimol/m^2/s$)		A ($mmol/m^2/s$)	
			Morning	Noon	Morning	Noon	Morning	Noon
19.5	0.3		0.083 a	0.094 a	3.7 a	5.0 a	18.2 a	26.2 a
	0.4		0.092 a	0.098 a	3.9 a	5.6 a	17.2 b	20.3 a
	0.5		0.092 a	0.092 a	4.2 a	5.2 a	18.8 a	19.6 a
	0.6		0.091 a	0.112 a	4.1 a	6.2 a	18.3 a	18.2 a
7.6	0.3	-9.2 c	0.031 a	0.013 b	2.4 c	1.6 c	8.2 a	3.1 c
	0.4	-8.0 b	0.036 a	0.033 a	2.6 bc	2.8 b	7.9 a	6.8 b
	0.5	-6.3 a	0.052 a	0.042 a	2.9 ab	3.2 ab	7.8 a	6.7 b
	0.6	-5.9 a	0.056 a	0.057 a	3.1 a	3.8 a	8.6 a	9.4 a
9.7	0.3	-12.0 c	0.004 b	0.040 b	2.4 b	3.2 b	16.7 a	10.2 a
	0.4	-10.0 b	0.050 ab	0.051 ab	2.6 b	3.9 b	17.9 a	12.4 a
	0.5	-7.2 a	0.052 a	0.069 a	2.8 b	4.8 a	17.6 a	15.8 a
	0.6	-6.6 a	0.058 a	0.076 a	3.1 a	4.9 a	18.8 a	14.1 a
8.8	0.3	-6.6 b	0.088 a	0.083 a	5.2 a	4.5 a	10.3 a	10.3 a
	0.4	-5.6 ab	0.094 a	0.072 a	5.4 a	4.1 a	10.8 a	10.1 a
	0.5	-5.8 ab	0.094 a	0.085 a	5.4 a	4.5 a	11.6 a	11.0 a
	0.6	-4.9 a	0.102 a	0.083 a	5.9 a	4.5 a	12.7 a	11.7 a

Table 9. Maturity indexes of three grape cultivars in the irrigation experiment in the Arad Plateou

		Irrigation Coefficient	pH		Brix		Acidity (g/l)		K (ppm)	
1997	Sauvignon 10/8	0.3	3.47	ab	21.6	a	6.1	c	1596	a
		0.4	3.43	b	22.3	a	6.9	b	1581	a
		0.5	3.50	a	22.8	a	7.3	a	1669	a
		p	0.0409		0.1782		0.0005		0.8375	
	Merlot 20/8	0.3	3.50	a	22.2	a	6.5	a	-----	
		0.4	3.51	a	22.1	a	6.3	a	-----	
		0.5	3.50	a	21.6	a	6.5	a	-----	
		0.6	3.50	a	21.4	a	6.4	a	____	
		p	0.9945	0.4561	0.7182					
	Cabernet 14/9	0.3	3.53	a	22.8	a	5.7	a	1303	a
		0.4	3.49	a	23.1	a	6.0	a	1271	a
		0.5	3.46	a	23.2	a	6.5	a	1335	a
		p	0.1398		0.7997		0.3272		0.7916	
1998	Sauvignon 9/8	0.3	3.74	a	22.6	a	6.1	b	2292	a
		0.4	3.68	ab	20.4	a	6.3	ab	2109	a
		0.5	3.65	b	20.8	a	7.0	a	2200	a
		p	0.2704		0.0541		0.3527		0.0527	
	Merlot 10/8	0.3	3.68	a	20.5	a	8.9	a	2271	b
		0.4	3.71	a	20.6	a	8.3	a	2221	b
		0.5	3.71	a	20.3	a	8.7	a	2312	ab
		0.6	3.71	a	20.6	a	9.0	a	2516	a
		p	0.8101		0.8305		0.0514		0.4769	
	Cabernet 10/9	0.3	3.89	a	23.1	a	5.2	b	2129	a
		0.4	3.86	a	22.8	a	5.7	a	2129	a
		0.5	3.85	a	22.6	a	6.0	a	2210	a
		p	0.6694		0.6203		0.2952		0.0233	
1999	Sauvignon 12/8	0.3	3.43	a	17.2	b	8.4	b	---	
		0.4	3.42	a	16.8	b	8.9	b	---	
		0.5	3.45	a	18.5	a	9.9	a	---	
		p	0.6636		0.0194		0.0051		---	
	Merlot 16/8	0.3	3.59	a	21.7	a	4.4	a	---	
		0.4	3.61	a	21.6	a	4.3	a	---	
		0.5	3.61	a	21.3	a	4.7	a	---	
		0.6	3.64	a	21.4	a	4.6	a	---	
		p	0.7656		0.4275		0.3028			
Cabernet 21/9		0.3	3.68	a	19.8	a	6.2	b	2260	ab
		0.4	3.66	a	20.9	a	6.3	b	2190	b
		0.5	3.62	a	20.5	a	7.6	a	2370	a
		p	0.2007		0.2137		0.0014		0.0560	

Table 10. Cluster and Berry weight of three grape cultivars irrigated with various pan A coefficients in the Arad plateou.

Cultivar	Irrigation coefficient	1997				1998				1999			
		Cluster		Berry		Cluster		Berry		Cluster		Berry	
Sauvignon	0.3	102	c	1.42	b	133	a	1.73	a	107	b	1.72	b
	0.4	117	b	1.65	a	144	a	1.85	a	135	a	1.95	ab
	0.5	135	a	1.76	a	150	a	1.87	a	148	a	2.06	a
	p	0.0036		0.0126		0.5387		0.7644	0.0158	0.0529			
Merlot	0.3	118	a	1.16	a	105	a	1.16	a	145	a	1.21	a
	0.4	134	a	1.20	a	119	a	1.18	a	140	a	1.10	a
	0.5	117	a	1.22	a	114	a	1.23	a	148	a	1.18	a
	0.6	123	a	1.19	a	125	a	1.36	a	158	a	1.29	a
	p	0.5017		0.9488		0.6159		0.3755	0.2465	0.5852			
Cabernet	0.3	85	a	1.02	a	69	a	1.01	b	74	a	1.07	a
	0.4	90	a	1.17	a	78	a	1.20	a	80	a	1.17	b
	0.5	93	a	1.14	a	80	a	1.28	b	76	a	1.02	ab
	p	0.6825		0.4249		0.2144		0.0195	0.4780	0.0695			

Table 11. Yield, pruning weight , and fruit load (kg fruit / kg pruning) in the irrigation experiment in the Arad Plateou.

	Irrigation Coeff.	Yield (kg vine^{-1}) 1997		1998		1999		Pruning weight (kg vine^{-1}) 1997		1998		1999		Fruit load 1997		1998		1999	
Sauvignon Blank	0.3	6.0	b	--	--	8.7	c	0.39	b	0.66	c	0.37	c	16	a	--	--	24	a
	0.4	8.4	a	--	--	12.0	b	0.70	b	1.33	b	0.72	b	13	ab	--	--	20	a
	0.5	9.1	a	--	--	14.1	a	1.34	a	1.84	a	0.96	a	9	b	--	--	17	a
	p	0.0640		--	--	0.0021		0.0248		0.0013		0.0002		0.0248		--		0.0002	
Merlot	0.3	5.5	b	6.2	a	8.1	b	--	--	0.54	c	0.37	c	--	--	12	a	24	a
	0.4	7.4	a	7.5	a	9.8	ab	--	--	0.83	b	0.60	b	--	--	9	ab	17	b
	0.5	8.1	a	6.9	a	9.5	ab	--	--	0.91	b	0.64	b	--	--	8	bc	16	b
	0.6	8.6	a	7.5	a	11.2	a	--	--	1.24	a	0.90	a	--	--	6	c	13	b
	p	0.0054		0.6804		0.0534		--	--	0.0005		0.0001		--	--	0.0081		0.0027	
Cabernet sauvignon	0.3	8.2	a	8.4	a	10.2	a	0.88	b	1.05	b	0.64	b	11	a	8	a	17	a
	0.4	8.3	a	8.0	a	10.6	a	1.39	ab	1.84	a	1.09	a	7	b	4	b	11	b
	0.5	8.1	a	8.5	a	10.6	a	1.82	a	2.40	a	1.20	a	5	b	4	b	10	b
	p	0.9778		0.5933		0.6162		0.0634		0.0033		0.0009		0.0182		0.0086		0.0035	

Table 12. Sensory evaluation of wines from three grape cultivars irrigated with various pan A coefficients in The Arad Plateou.

Year	Quality Parameter	Irrigation Coefficient 0.3		0.4		0.5		0.6	
				Sauvignon					
1988	Total	13.7	±0.20	13.8	±0.25	13.6	±0.16		
	Color	2.9	±0.03	3.0	±0.02	2.9	±0.02		
	Smell	3.4	±0.09	3.4	±0.10	3.5	±0.05		
	Taste	6.1	±0.09	6.1	±0.16	6.0	±0.07		
	Over allti	1.3	±0.02	1.3	±0.04	1.3	±0.02		
1999	Total	11.8	±0.27	12.0	±0.28	11.4	±0.29		
	Color	2.4	±0.08	2.4	±0.05	2.4	±0.06		
	Smell	3.2	±0.09	3.1	±0.10	2.9	±0.13		
	Taste	5.1	±0.15	5.3	±0.16	5.1	±0.22		
	Over all	1.1	±0.05	1.1	±0.05	1.1	±0.06		
				Merlot					
1998	Total	14.3	±0.60	13.3	±0.47	13.9	±0.26	13.2	±0.30
	Color	3.2	±0.14	3.0	±0.16	3.2	±0.09	2.9	±0.06
	Smell	3.9	±0.16	3.5	±0.08	3.6	±0.13	3.4	±0.13
	Taste	6.0	±0.24	5.6	±0.20	5.8	±0.11	5.7	±0.16
	Harmony	1.3	±0.08	1.2	±0.08	1.3	±0.04	1.3	±0.06
1999	Total	12.4	±0.90	12.9	±0.0.67	12.9	±0.53	12.5	±0.09
	Color	2.9	±0.13	2.9	±0.09	2.6	±0.07	2.5	±0.08
	Smell	2.8	±0.33	3.0	±0.22	3.1	±0.23	2.9	±0.06
	Taste	5.5	±0.33	5.7	±0.27	5.9	±0.20	5.8	±0.08
	Harmony	1.1	±0.14	1.2	±0.09	1.3	±0.07	1.3	±0.02
				Cabernet					
1988	Total	12.8	±0.98	12.4	±0.86	11.4	±0.71		
	Color	3.3	±0.16	3.2	±0.17	2.8	±0.09		
	Smell	3.5	±0.24	3.4	±0.16	3.4	±0.15		
	Taste	5.8	±0.46	5.5	±0.49	5.1	±0.38		
	Over allti	1.3	±0.15	1.2	±0.13	1.1	±0.11		
1999	Total	13.6	±1.00	13.8	±0.32	13.2	±0.32		
	Color	3.0	±0.16	2.9	±0.14	2.6	±0.14		
	Smell	3.4	±0.33	4.2	±0.07	3.4	±0.07		
	Taste	5.8	±0.39	5.0	±0.13	5.9	±0.13		
	Over all	1.3	±0.12	1.3	±0.04	1.3	±0.04		

Table 13. Leaf analysis of three grape cultivars irrigated with various rates of water in a semi-arid region..

		N-NO3 ppm	N	P	S	K	Ca	Mg
			%DW					
Sauvignon								
petiole	0.3	2567	1.66 b	0.395 b	0.098	2.96	1.24	1.15
21.5.97	0.4	2726	2.38 a	0.429 b	0.091	2.85	1.25	1.17
	0.5	3090	2.53 a	0.498 a	0.096	3.12	1.21	1.08
	p	0.2388	0.0472	0.0052	0.4594	0.5229	0.5501	0.1845
blade	0.3	1380 b	3.35 b	0.233 b	0.237	1.12	1.94	0.57
	0.4	1643 b	3.49 b	0.245 ab	0.237	1.02	1.93	0.60
	0.5	2016 a	3.87 a	0.266 a	0.243	1.04	1.97	0.61
	p	0.006	0.0159	0.0374	0.8521	0.1809	0.8774	0.4277
petiole	0.3	1878 b	1.10 b	0.108 b	0.073	0.96 b	1.54	1.70
4.8.97	0.4	1754 b	1.04 b	0.141 a	0.072	1.32 b	1.50	1.72
	0.5	2439 a	1.22 a	0.230 a	0.072	2.22 a	1.39	1.54
	p	0.0006	0.0071	0.0097	0.8908	0.0083	0.1788	0.1315
blade	0.3	1540	2.18	0.122	0.188	0.55 b	2.44	0.64
	0.4	1505	2.20	0.121	0.181	0.62 b	2.24	0.57
	0.5	1605	2.12	0.146	0.208	0.87 a	2.58	0.64
	p	0.5061	0.4140	0.1380	0.4015	0.0307	0.4201	0.462
Merlot								
petiole	0.3	3733 b	1.55	0.365	0.097	3.12	1.40	1.19
21.5.97	0Æ4	4156 b	1.70	0.436	0.087	2.86	1.26	1.13
	0.5	5428 a	1.78	0.485	0.097	2.70	1.26	1.18
	p	0.0004	0.1765	0.0830	0.6668	0.5201	0.3874	0.8771
blade	0.3	3020 a	3.50	0.215 b	0.228	1.11	1.77	0.549
	0.4	2833 ab	3.64	0.234 ab	0.230	1.08	1.67	0.533
	0.5	2525 b	3.67	0.248 a	0.226	1.07	1.73	0.562
	p	0.0324	0.1447	0.0494	0.9131	0.7543	0.6594	0.7356
petiole	0.3	1941	0.94	0.158	0.094	1.63 b	2.25 a	1.89
4.8.97	0.4	1886	0.87	0.228	0.085	2.32 ab	1.92 b	1.78
	0.5	1949	0.95	0.299	0.085	3.00 ab	1.80 b	1.79
	p	0.9057	0.0830	0.0858	0.3466	0.0530	0.0142	0.7485
blade	0.3	1802	1.92 a	0.142 b	0.220	0.70	2.53	0.69
	0.4	1760	1.82 b	0.141 b	0.212	0.81	2.36	0.62
	0.5	2006	1.88 ab	0.169 a	0.220	0.94	2.43	0.66
	p	0.1514	0.0300	0.0309	0.1130	0.0776	0.4506	0.5034

(continue Table 13)

		N-NO3 ppm		N		P	S	K	Ca	Mg
				%DW						
Cabernet										
petiole	0.3	2180	b	1.32	b	0.372	0.083	2.20	1.32	0.96
21.5.97	0.4	2466	ab	1.59	a	0.403	0.128	1.83	1.30	1.03
	0.5	2618	a	1.65	a	0.423	0.124	1.52	1.27	1.02
	p	0.0715		0.0256		0.6750	0.5452	0.1119	0.8785	0.5453
blade	0.3	1348	a	3.49		0.228	0.231	0.98	1.42	0.47
	0.4	1278	ab	3.86		0.240	0.248	0.90	1.35	0.47
	0.5	1219	b	3.79		0.255	0.246	0.82	1.53	0.50
	p	0.0826		0.3102		0.223	0.2567	0.090	0.3116	0.2855
petiole	0.3	2032	b	1.36		0.100	0.067	1.78 b	2.11	1.63
19.8.97	0.4	2227	a	1.40		0.101	0.077	2.48 ab	1.92	1.61
	0.5	2352	a	1.41		0.111	0.068	3.27 a	1.78	1.46
	p	0.0048		0.7640		0.7090	0.4931	0.0569	0.2503	0.3471
blade	0.3	1647	b	2.43		0.117	0.159	0.49 b	1.86	0.49
	0.4	1804	a	2.52		0.128	0.175	0.63 ab	1.99	0.52
	0.5	1859	a	2.41		0.131	0.171	0.73 a	1.88	0.49
	p	0.0327		0.1990		0.3618	0.3059	0.0239	0.4000	0.6436
Sauvignon										
Petiole	0.3	787	c	0.78	b	0.326 b	0.077	3.15	1.23	1.06
10.5.98	0.4	917	b	0.89	a	0.387 a	0.074	2.63	1.21	1.13
	0.5	1070	a	0.91	a	0.439 a	0.074	2.69	1.16	1.02
	p	0.0144		0.0196		0.0086	0.6398	0.1722	0.1125	0.101
Blade	0.3	238		1.43	b	0.218	0.21	1.1	1.72	0.51
	0.4	245		1.51	a	0.234	0.214	0.93	1.72	0.52
	0.5	261		1.57	a	0.248	0.22	0.98	1.78	0.55
	p	0.2904		0.0103		0.1161	0.3367	0.079	0.7215	0.2819
Petiole	0.3	470		1.02		0.108	0.07	0.31	1.91 b	2.15
27.7.98	0.4	503		1.02		0.105	0.065	0.432	1.95 ab	2.19
	0.5	472		1.05		0.104	0.065	0.42	2.05 a	2.15
	p	0.6556		0.6763		0.9323	0.403	0.6972	0.0382	0.9434
Blade	0.3	410		2.48		0.113	0.179	0.345	3.05	0.81
	0.4	408		2.43		0.106	0.166	0.375	2.76	0.71
	0.5	422		2.44		0.121	0.18	0.42	3.14	0.76
	p	0.9050		0.7808		0.5413	0.5216	0.6305	0.2764	0.1808

(continue Table 13)

		N-NO3 ppm		N		P	S	K	Ca		Mg	
						%DW						
Merlot												
petiole	0.3	1012	b	2.13	c	0.439	0.092	2.98	1.7	a	1.19	a
10.5.98	0.4	1093	b	2.34	bc	0.464	0.086	2.78	1.68	a	1.31	a
	0.5	1271	a	2.69	ab	0.608	0.096	2.53	1.6	a	1.31	a
	0.6	1389	a	3.04	ab	0.481	0.091	3.01	1.4	b	1.01	b
	p	0.0003		0.0029		0.0611	0.7224	0.1594	0.0156		0.0116	
blade	0.3	326		4.33	c	0.235	0.234	1.06	2.01		0.53	
	0.4	310		4.49	bc	0.233	0.222	0.99	1.98		0.54	
	0.5	328		4.59	bc	0.263	0.218	0.95	2.19		0.6	
	0.6	286		4.92	a	0.276	0.252	1.11	1.89		0.52	
	p	0.5209		0.0008		0.3236	0.2891	0.4417	0.6643		0.5253	
petiole	0.3	579		0.95	b	0.114	0.079	0.97	2.44		2.13	
9.8.98	0.4	564		1.02	b	0.127	0.079	0.87	2.42		2.3	
	0.5	581		1.17	a	0.231	0.079	1.38	2.35		2.37	
	0.6	520		1.25	a	0.179	0.07	1.71	2.02		1.81	
	p	0.2475		0.0001		0.0908	0.7498	0.2214	0.4202		0.0754	
blade	0.3	439	bc	2.29	b	0.117	b	0.178	0.51	c	2.55	0.65
	0.4	410	c	2.24	a	0.123	b	0.185	0.55	bc	2.68	0.71
	0.5	503	b	2.59	a	0.140	a	0.182	0.7	ab	2.57	0.71
	0.6	573	a	2.56	a	0.142	a	0.187	0.73	a	2.74	0.65
	p	0.0020		0.0042		0.0049	0.7505	0.0311	0.3331		0.3336	
Cabernet												
petiole	0.3	674		1.65	b	0.325	0.074	2.71	1.4		0.82	
10.5.98	0.4	662		1.92	ab	0.399	0.075	2.02	1.29		0.87	
	0.5	677		2.08	a	0.443	0.076	1.73	1.28		0.84	
	p	0.9620		0.0417		0.0115	0.9311	0.0012	0.1652		0.798	
blade	0.3	224		3.93	b	0.227	0.228	0.99	1.72		0.46	
	0.4	235		4.27	a	0.256	0.234	0.87	1.58		0.45	
	0.5	223		4.42	a	0.272	0.235	0.81	1.55		0.45	
	p	0.0639		0.0110		0.0049	0.6044	0.0334	0.0964		0.8697	
petiole	0.3	213		1.3		0.085	0.077	1.77	2.67		1.67	
25.8.98	0.4	219		1.37		0.121	0.083	2.24	2.49		1.67	
	0.5	180		1.33		0.125	0.08	2.15	2.46		1.65	
	p	0.3807		0.4707		0.5773	0.5465	0.5729	0.6311		0.9849	
blade	0.3	102		2.21		0.104	0.15	0.538	2.16		0.483	
	0.4	95		2.26		0.112	0.158	0.647	2.19		0.515	
	0.5	102		2.28		0.113	0.151	0.58	2.04		0.465	
	p	0.8629		0.3811		0.3514	0.4412	0.1258	0.281		0.2268	

(continue Table 13)

		N-NO3 ppm	N	P	S	K	Ca	Mg
			%DW					
Sauvignon								
petiole	0.3	645	1.77 c	0.344 b	0.090	2.71	1.21	2.60
9.5.1999	0.4	629	2.02 b	0.428 a	0.095	2.56	1.21	2.65
	0.5	676	2.20 a	0.453 a	0.086	2.68	1.11	2.50
	p	0.2629	0.0005	0.0040	0.5476	0.8451	0.4525	0.4769
blade	0.3	792 a	3.44 b	0.244 b	0.220	1.05	1.51	1.12b
	0.4	736 b	3.80 b	0.266 a	0.223	0.98	1.50	1.17b
	0.5	738 b	3.92 a	0.287 a	0.220	1.04	1.55	1.26a
	p	0.0724	0.001	0.0074	0.5585	0.4665	0.5663	0.0.0181
petiole	0.3	340 b	1.55	0.085 b	0.073	0.39 ab	1.66	4.55
30.7.1999	0.4	330 b	1.55	0.118 ab	0.0723	0.29 b	1.70	5.43
	0.5	559 a	1.51	0.172 a	0.0720	0.69 a	1.68	5.20
	p	0.0016	0.8693	0.0240	0.7185	0.0486	0.6886	0.1858
blade	0.3	572	2.82	0.135	0.177	0.39 b	2.62	1.16
	0.4	589	2.87	0.132	0.192	0.35 b	2.92	1.48
	0.5	632	2.99	0.137	0.190	0.49 a	2.99	1.42
	p	0.4132	0.2396	0.6064	0.5992	0.0097	0.0899	0.2049
Merlot								
petiole	0.3	578 c	1.69 b	0.456	0.117 a	3.14 a	1.36	1.46
9.5.1999	0.4	663 ab	1.69 b	0.465	0.096 a	2.95 a	1.23	1.27
	0.5	608 bc	1.97 a	0.543	0.110 b	2.35 b	1.37	1.84
	0.6	690 a	2.08 a	0.513	0.114 b	2.31 b	1.37	1.59
	p	0.0340	0.0114	0.6159	0.3085	0.0166	0.5532	0.3740
blade	0.3	822	3.81 b	0.262	0.241 ab	1.14	1.55	0.56
	0.4	757	3.81 b	0.278	0.235 b	1.13 a	1.42	0.56
	0.5	795	4.02 a	0.299	0.244 a	1.04 ab	1.65	0.69
	06	776	4.05 a	0.288	0.245 a	0.98 b	1.55	0.64
	p	0.5122	0.0341	0.1197	0.0222	0.0188	0.3430	0.2058
petiole	0.3	283 ab	1.40	0.095	0.083	0.63	2.54	5.49
11.8.1999	0.4	268 b	1.44	0.164	0.102	1.11	2.62	8.79
	0.5	335 ab	1.51	0.287	0.110	1.29	2.60	10.11
	0.6	385 a	1.49	0.220	0.092	1.47	2.58	6.37
	p	0.1161	0.3247	0.0909	0.3745	0.4408	0.9160	0.1376
blade	0.3	1026 a	3.06	0.123	0.184	0.50	2.54	0.91
	0.4	933 b	3.05	0.126	0.185	0.53	2.52	1.00
	0.5	893 bc	3.05	0.144	0.190	0.57	2.83	1.28
	0.6	836 c	3.09	0.138	0.186	0.61	2.66	1.02
	p	0.0006	0.9795	0.2536	0.4822	0.3314	0.2894	0.1087

(continue Table 13)

		N-NO3 ppm	N	P	S	K	Ca	Mg
			%DW					
Cabernet								
petiole	0.3	496	1.38 b	0.295 b	0.079	2.64 a	1.16	0.79
9.5.1999	0.4	461	1.59 ab	0.389 a	0.082	1.56 b	1.21	1.12
	0.5	450	1.70 a	0.383 a	0.082	1.35 b	1.13	1.00
	p	0.3808	0.0655	0.0147	0.8602	0.0076	0.6166	0.0874
blade	0.3	582 ab	3.69 b	0.268	0.254	1.10 a	1.30	0.44
	0.4	561 b	3.99 a	0.291	0.270	0.84 b	1.31	0.52
	0.5	601 a	4.09 a	0.305	0.242	0.80 b	1.34	0.54
	p	0.1072	0.0003	0.0740	0.6713	0.0041	0.8677	0.3037
petiole	0.3	283 ab	1.11	0.072	0.082	0.51	2.69	4.05
11.8.1999	0.4	268 b	1.11	0.073	0.084	0.54	2.55	4.22
	0.5	318 a	1.20	0.072	0.073	0.60	2.39	3.62
	p	0.0997	0.0928	0.9669	0.0804	0.6932	0.3170	0.6319
blade	0.3	1070 a	2.23 b	0.110	0.166	0.30	2.10	0.66
	0.4	1027 ab	2.29 ab	0.111	0.170	0.34	2.12	0.72
	0.5	970 b	2.36 a	0.110	0.156	0.42	1.91	0.65
	p	0.0662	0.0373	0.9695	0.2409	0.2482	0.3134	0.7396

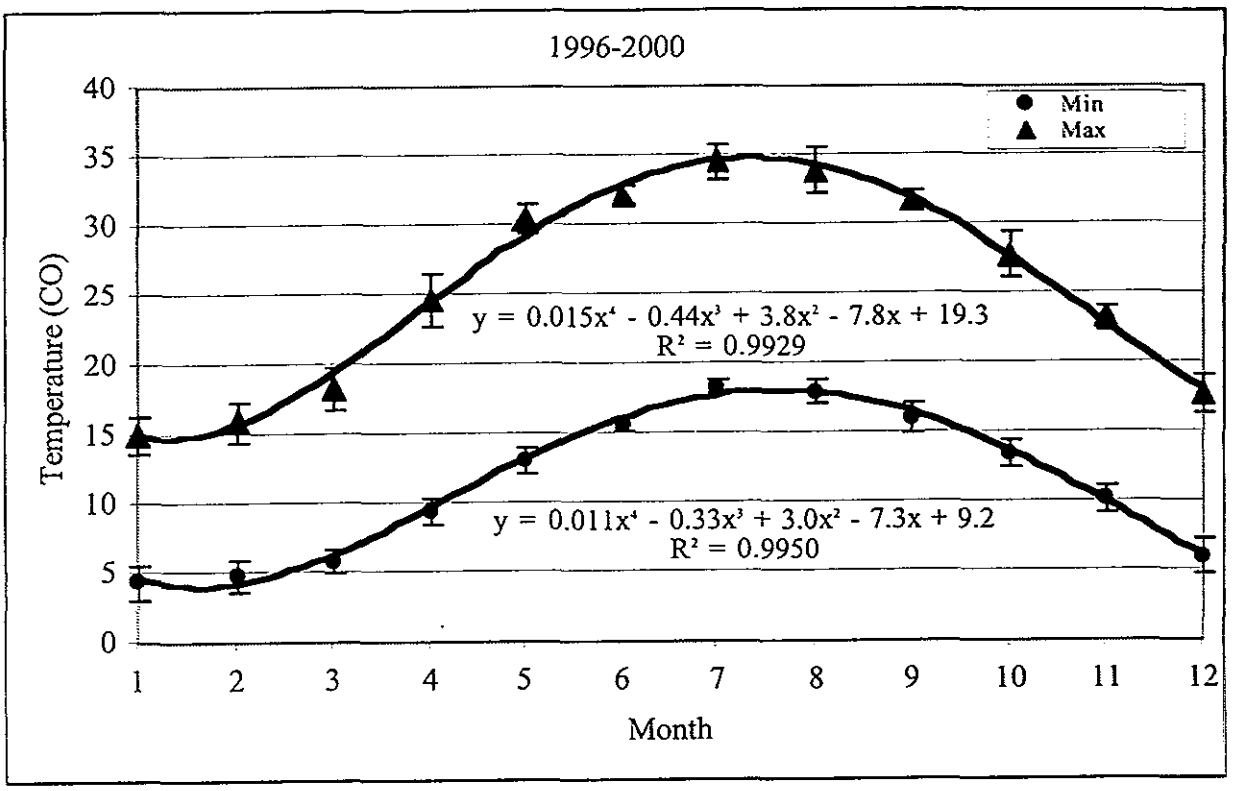

Fig. 1. Long term average (±SE) minimum and maximum temperature in the Arad Plateou.

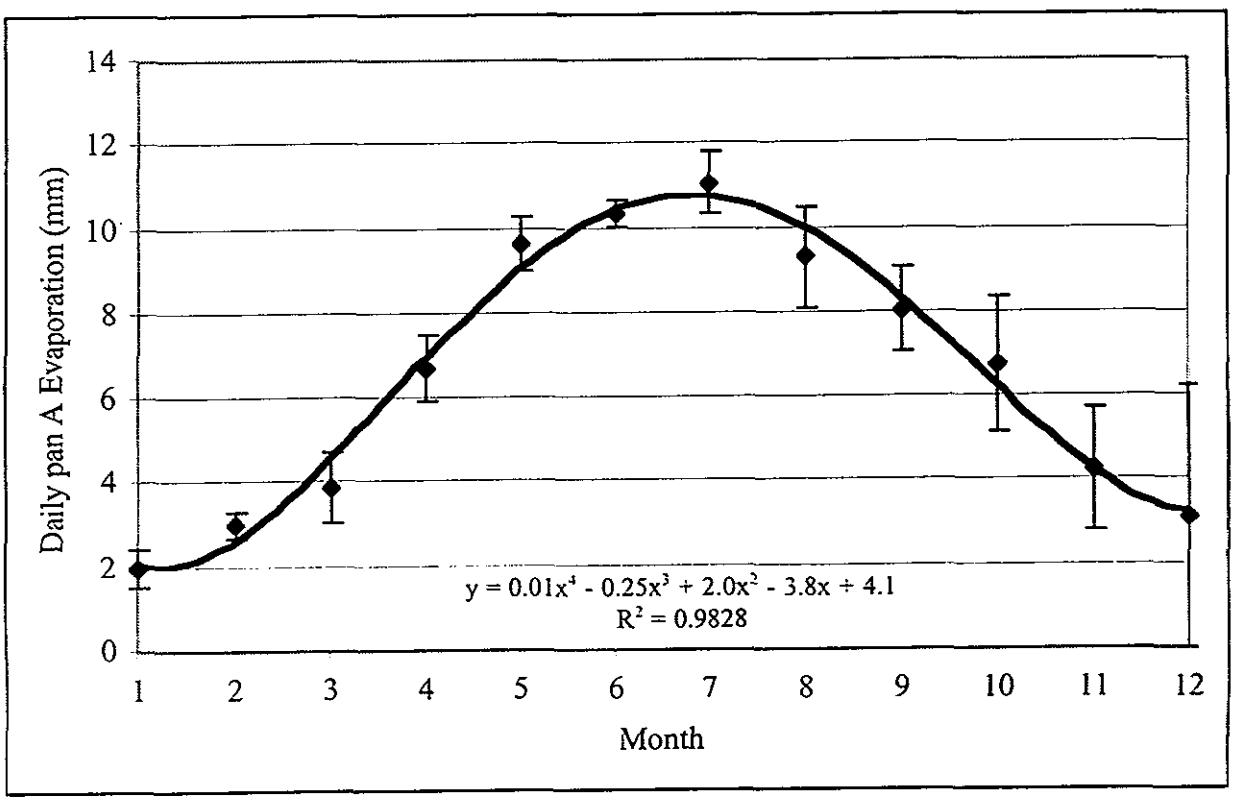

Fig. 2. Daily pan A evaporation in the Arad Plateou

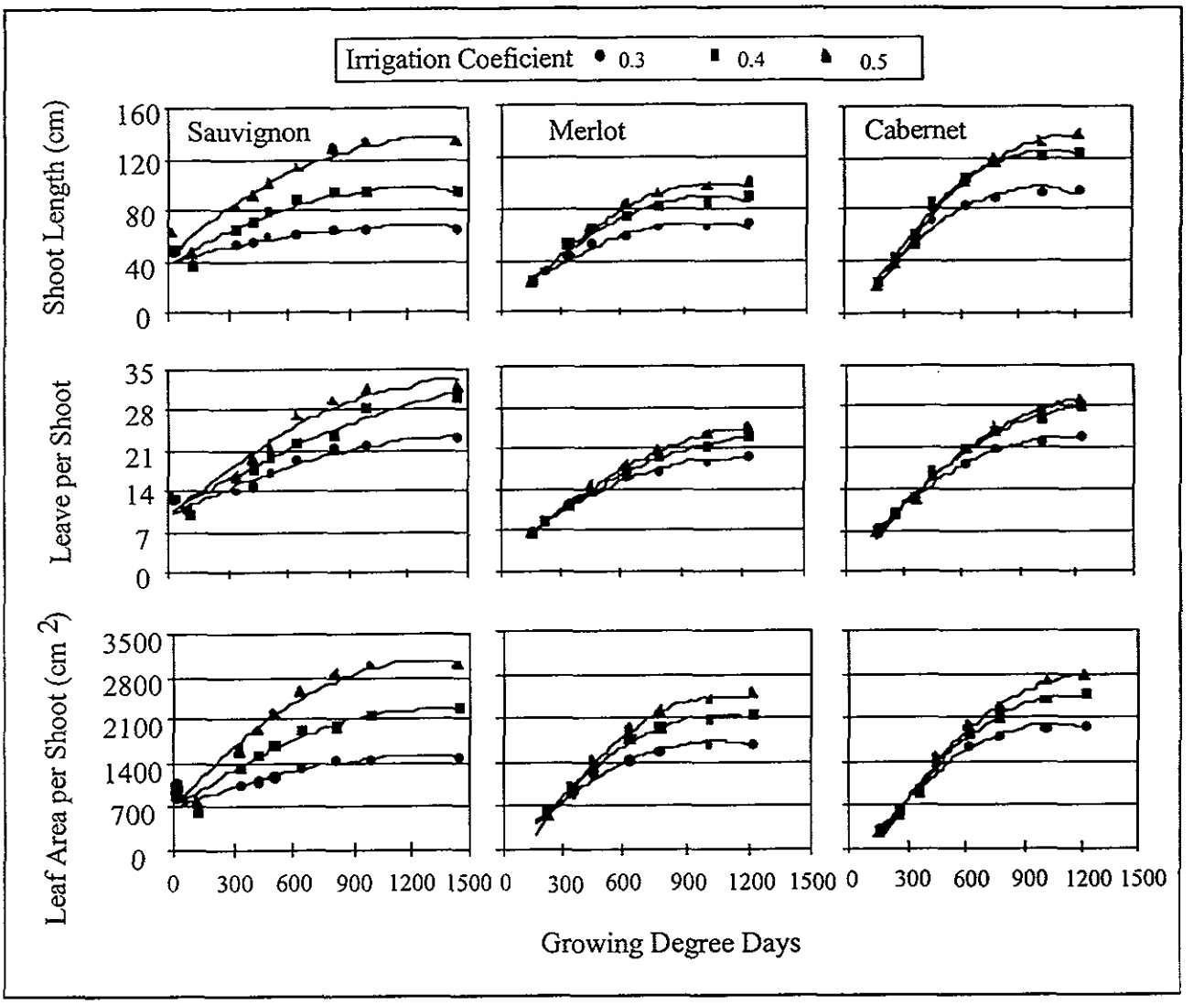

Fig. 3. The effect of irrigation rate on shoot growth, leaf number and leaf area of three grape cultivars grown in the Arad Plateou.

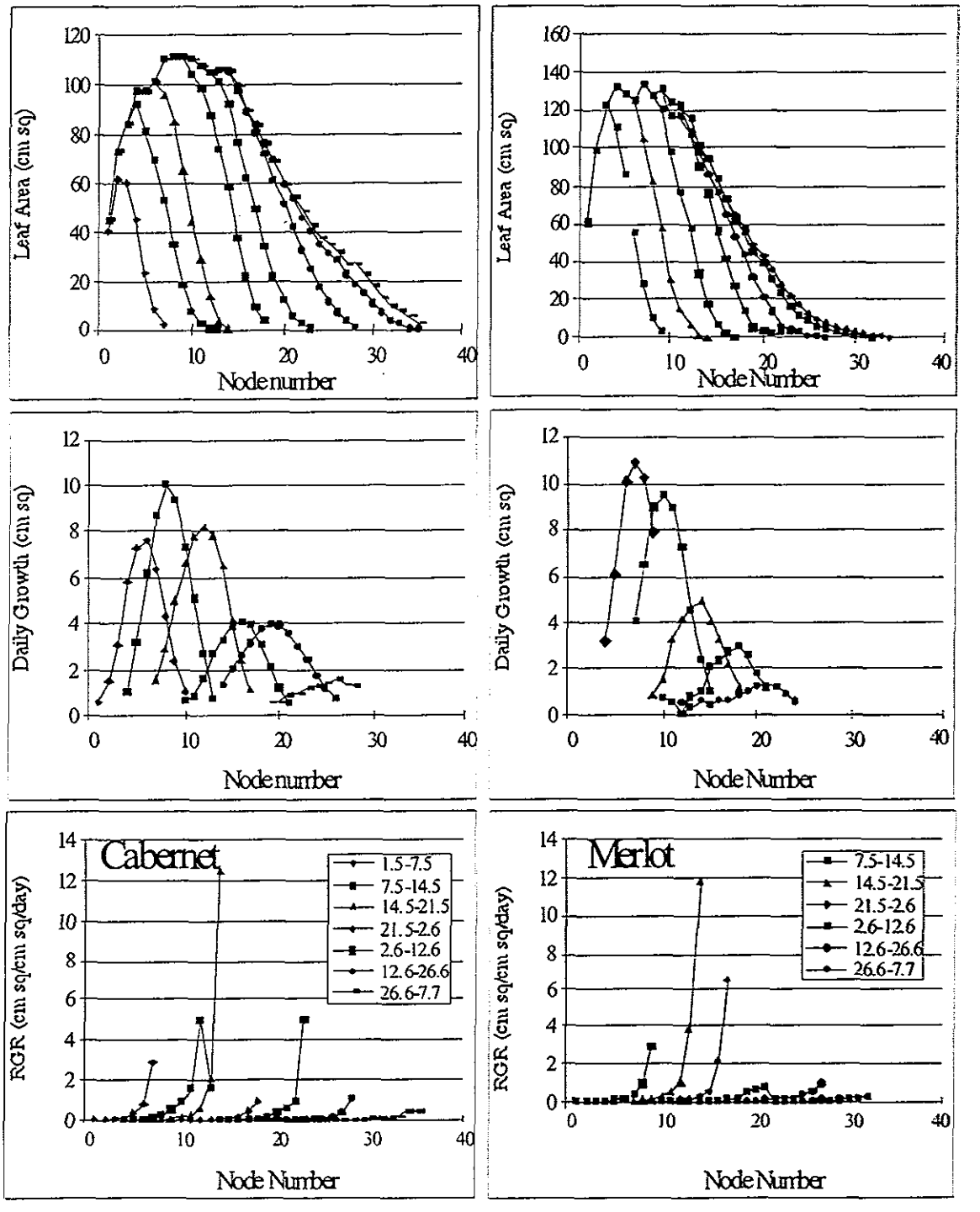

Fig. 4 . Leaf area, daily leaf growth and leaf relative growth rate at progressive node numbers on different dates. Average for all irrigation rates (n=48 shoots).

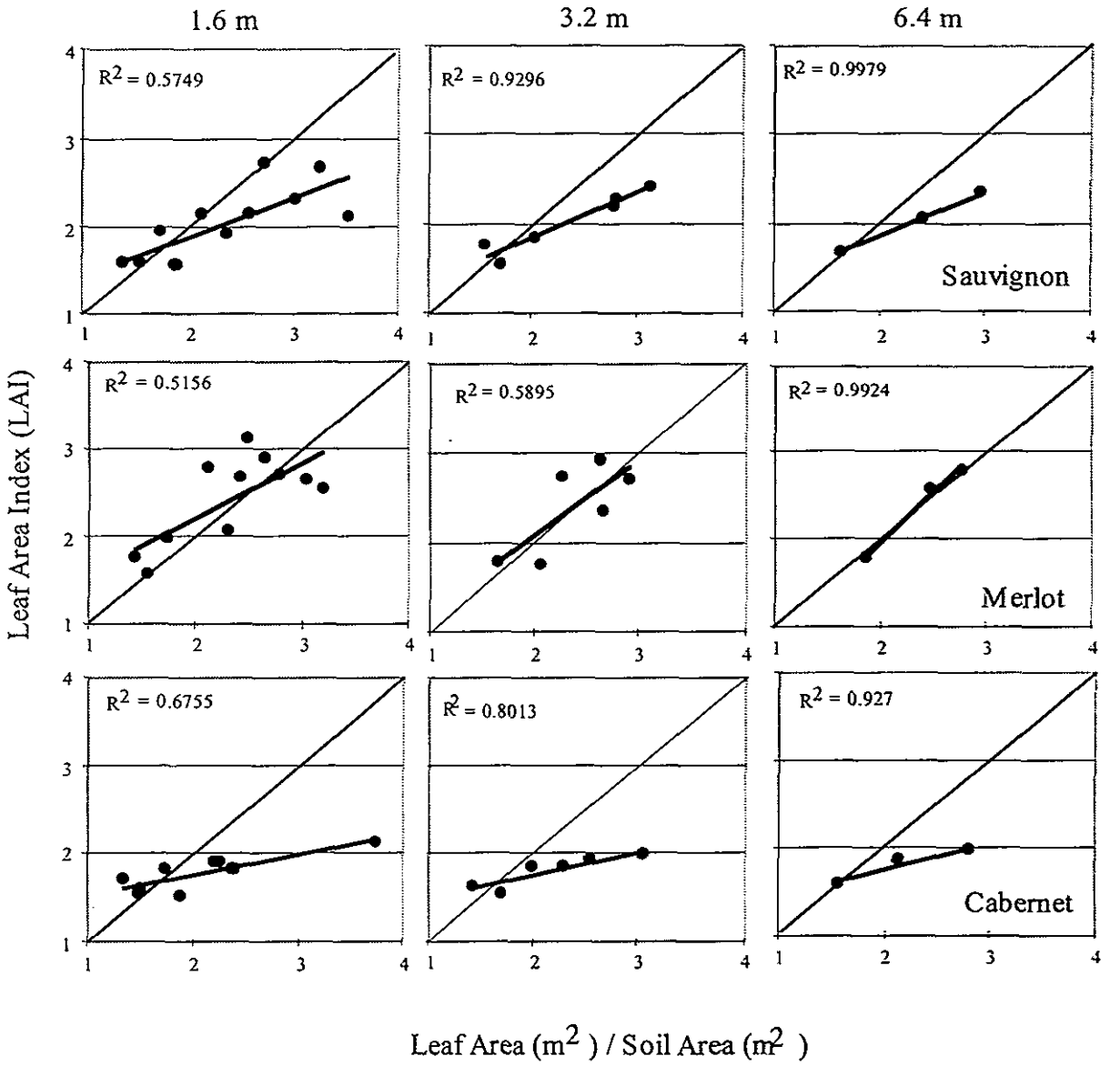

Fig. 5. Direct (Leaf Area / Soil Area) and Gap Fraction Inversion (GFI) measurement of LAI in the vineyard. Direct measurements are from destructive sampling of 32 vines.

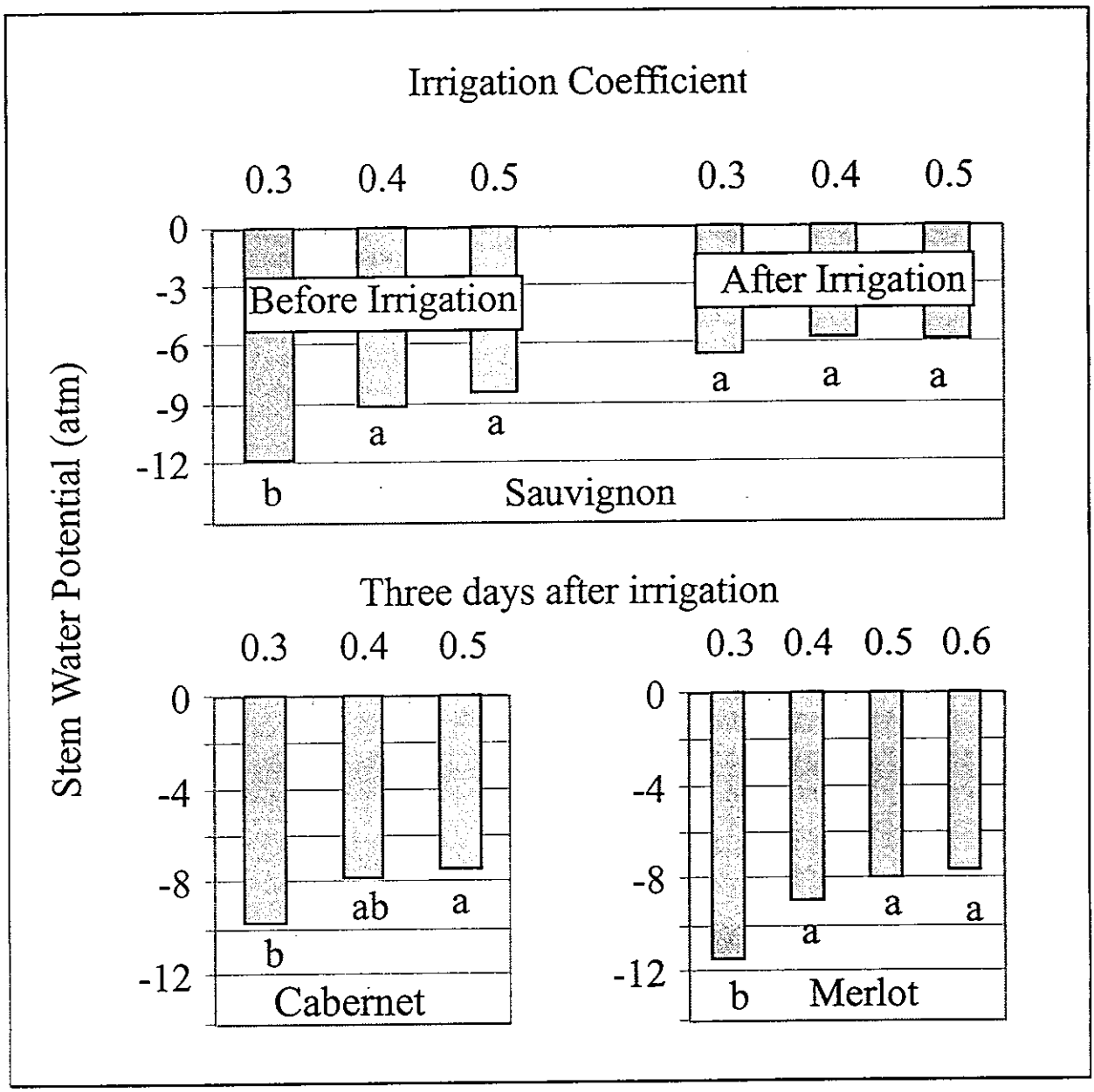

Fig 6. Stem water potential of three grape cultivars in the irrigation experiment in the Arad Plateou. Sauvignon before irrigation and Cabernet were measured on 24.6.1998, and sauvignon after irrigation and Merlot on 13.7.1998.

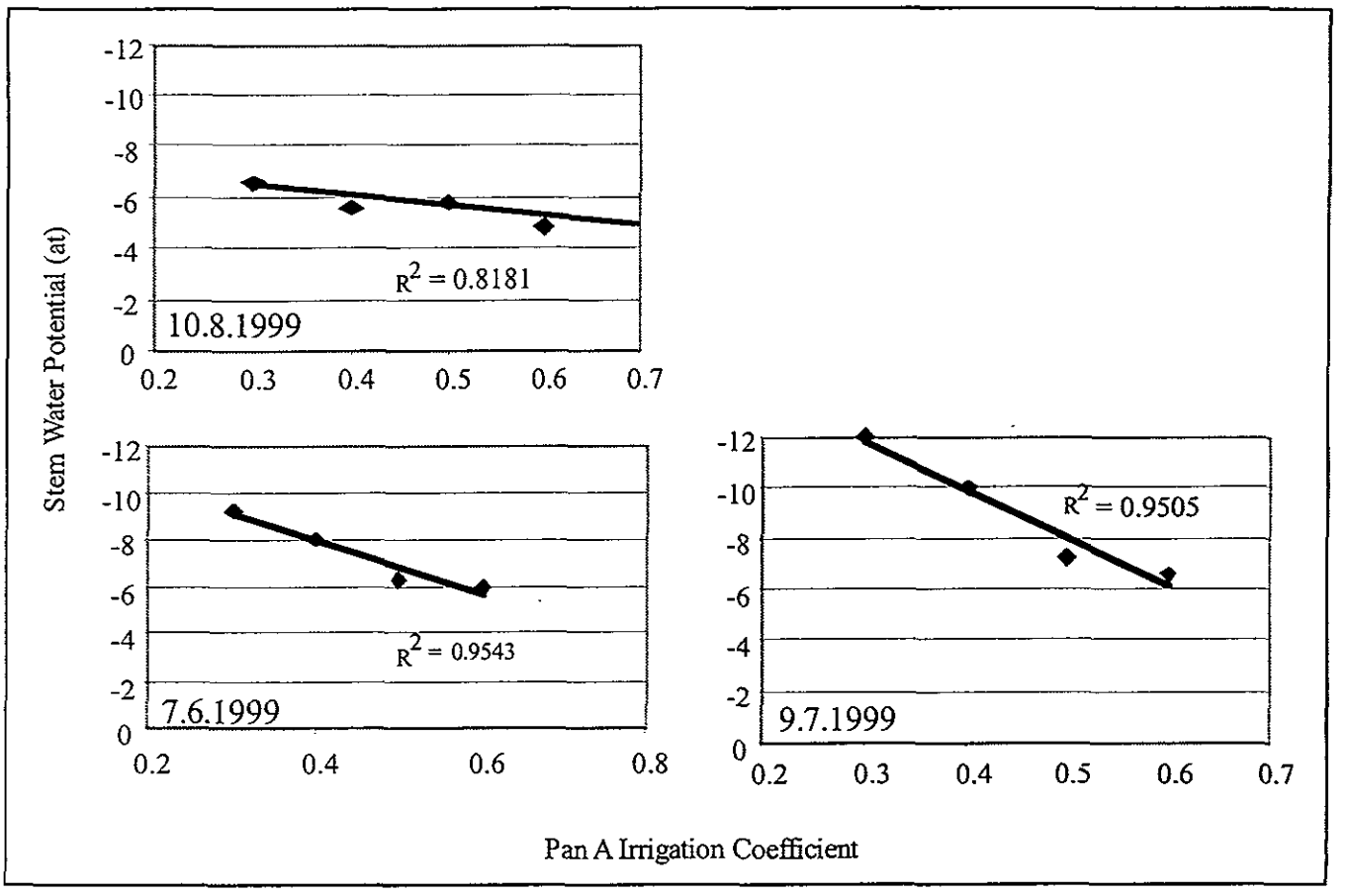

Fig 7. Mid-day stem water potential of Merlot wine grapes irrigated with various pan A coefficients. Vines were irrigated every 4-5 days. Measurements on 7.6.1999 and 9.7.1999 were on days preceding irrigation and on day 10.8.1999 following irrigation.

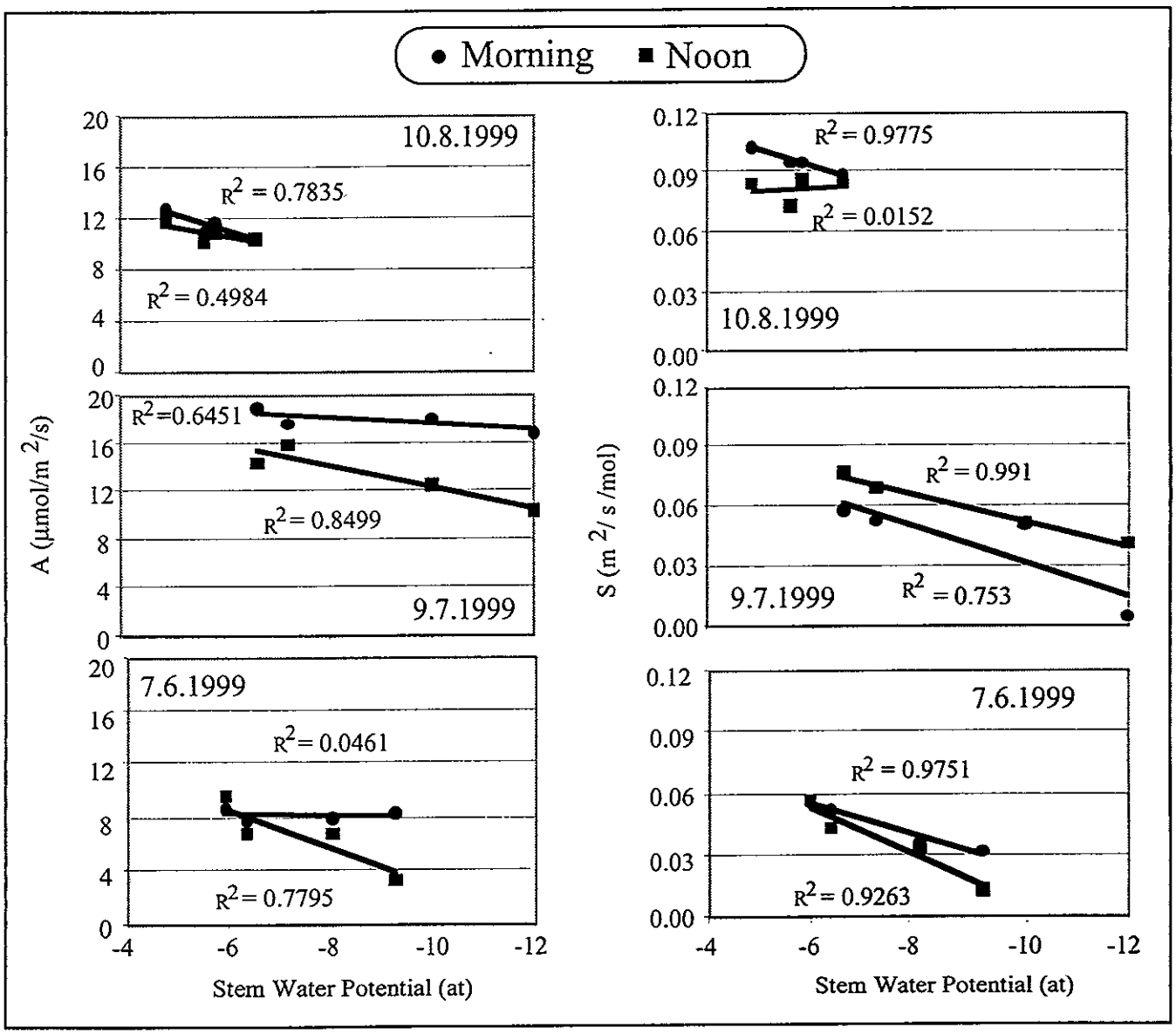

Fig 8. The relationship between mid-day stem water potential and morning and mid-day net photosynthesis (A) and stomatal conductance (S) in Merlot wine grapes. Vines were irrigated every 4-5 days. Measurements on 7.6.1999 and 9.7.1999 were on days preceding irrigation and on day 10.8.1999 following irrigation.