CDR (TA/MOU/96/CA15/008) Report for 1997-1998

Drip fertigation of grapevines in arid agriculture

Isaac Klein

Institute of Horticulture, ARO, The Volcani Center,

Bet Dagan 50250, Israel

Cooperation In spring 1997 I visited Kazakhstan to set up cooperation and specific experimental work At the time Kazakhstan was undergoing a process of farm privatization The farm allocated originally for the drip irrigation experiment was privatized and was not available for the experiment The research team in Kazakhstan suggested carrying out the drip irrigation experiment in their grape breeding experimental farm, 100 km outside Alma-Ata We visited the farm and found it suitable During my visit we worked out the details of the drip irrigation experiment in Kazakhstan Dr Bondartsev was assigned to set up and manage the fieldwork The drip irrigation system was ordered purchased and shipped to Kazakhstan to be ready for the 1998 irrigation season Toward the end of 1998, I was notified that the grape breeding farm†was also privatized and was not available for experimentation therefore, the irrigation system was not set up there Later on, in spring 1999, I was notified by the team from Kazakhstan that an alternate farm was found and the experiment was set up there

Conditions in Kazakhstan were difficult at the start of the experiment and it became worse with time, particularly where fieldwork is concerned (privatization of farms, theft of equipment in the field, difficulties in local transportation, bureaucracy) It takes months for equipment to be shipped to Kazakhstan and we had to make sure that the local government does not tax it Since work in Kazakhstan progressed slowly, we did not spend all the money allocated to the research Actually we avoided drawing†money toward 1999, until the field experiment in Kazakhstan could actually start, planing to ask for a year extension to complete the project

International Travel by the Kazakhstan team In October 1997, Dr Madenow and Dr Bondartsev traveled to Israel for a visit to the experimental vineyard in the Arad plateau and my laboratory The team from Kazakhstan visited also other vineyards, irrigation projects and experiments, including a

visit to the drip and microjet irrigation companies to study the range of available irrigation equipments The team from Kazakhstan (Dr, Bondartsev and Dr Adrianova), visited Israel second time in Spring of 1999 for a follow up, to see the progress of the experiment carried out in Israel

Purchasing of equipment for Kazakhstan The irrigation system was purchased and shipped to Kazakhstan from Israel in 1997 (Ca 10 000$) Tensiometers (ca 2000$) were purchased also in 1997, in the USA, and shipped directly to Kazakhstan, In 1998 the following two scientific equipments were purchased in the USA for Kazakhstan a Ceptometer for canopy light interception measurements (3300$, Decagon Devices, WA) and a Plant Water Status Console (pressure chamber for plant water status measurements, ca 4500$, Soil Moisture Corporation, CA)

Experimental and Results (Israel)

The Irrigation experiment was set up in the semi-desert, arid region of the Arad plateau (500 m elevation), in a commercial vineyard The region is characterized by a high daily temperatures (34 C° daily average for June –August) and low night temperatures (14-18 C°), with low relative humidity (15-20% mid-day)

Drip irrigation treatments evaluated, applied to three vine cultivars (Sauvignon blanc Cabernet Sauvignon and Merlot), included raising the rate of water application after bud break, gradually, as the canopy developed, up to a pan A coefficient of 0 3, 0 4, 0 5 and 0 6 (the last treatment for Merlot only), and maintaining it at these levels thereafter

Measurements collected included vegetative development Leaf Area Index (LAI) measurements by light interception (Gap Fraction Inversion, GFI), yield, pruning weight, leaf analysis, stem water potential and photosynthesis

Canopy development and Leaf Area Index measurements

Canopy development and 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 blanc 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 calculations of correlation between total leaf area measured destructively and by light interception

LAI 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 paper presented in the conference is attached The comparative LAI of all three cultivars was measured in the same year, during_1998Æ_

Shoot length, number of leaves and leaf area was proportional to the rate of irrigation (Fig 1) Canopy development progressed until the accumulation of ca 1000 Growing Degree Days (GDD) Differences between irrigation rates in Merlot and Cabernet were evident after accumulation of 200-300 GDD In the Sauvignon the differences were evident almost from bud break The average rate of daily leaf growth was greatest in node 6-8 (Fig 2) The Relative Growth Rate (RGR) of leaves was maximal at node 12-13 The basal leaves on the cane were only 40-60 cm2, compared to 150-130 cm2 of the largest leaves, at nodes 6-8 RGR, daily growth and final leaf area tapered off toward the shoot apex (Fig 2)

Destructive sampling of vines, after full canopy development, showed no difference in the total number of shoots between irrigation treatments (Table 1) Shoot length and lateral growth, however, were affected by the irrigation rate Shoot growth increased proportionally to irrigation rate, particularly in the low†rate of irrigation which was significantly low The number of leaves was affected similarly to shoot length (Table 2) Leaf area was affected more significantly by the irrigation treatments, as compared to shoot length and leaf number Interestingly, the high vigor of the 'Cabernet' and the low vigor of the 'Merlot' are barely detectable from shoot number length measurements The destructive measurements showed that total leaf area of the three cultivars was essentially the same Differences in vigor therefore are probably reflected more in stem and shoot thickens and dry weight, rather than leaf area LAI measurement of all 3 cultivars in the same growing season (1998) was also similar (Table 3)

Estimating actual canopy coverage (LAI) from GFI, for characterizing fruit load in vinevards in relation to fruit quality, was found to be equally reliable to measurements of winter pruning

weights, offering the advantage of measurements in real time For a full description and discussion of light interception measurements, carried out in the vineyard, see the attached publication

Stem water potential Tensiometer readings showed that soil water tension differed between irrigation treatments (data collected in previous years, not presented) An alternate and preferable measure is plant water status Stem water potential of the 3 cultivars differed in 1997 (Table 4) The potential was highest in Cabernet, intermediate in Sauvignon and lowest in Merlot Differences between irrigation treatments were significant in all 3 cultivars Data on stem water potential in 1997 was collected without paying attention to the irrigation cycle in the vineyard Measurements of stem water potential were repeated in 1998, noting the relation to the irrigation cycle (Fig 3) Stem water potential of Sauvignon after irrigation was not significantly different between the irrigation treatments Before irrigation, the potential in the lowest irrigation coefficient was significantly lower than in the other two higher rates of irrigation Stem water potential of the Merlot and Cabernet in 1998, measured 3 days after irrigation, was proportionally more negative as the rate of irrigation decreased The water potential of the 0 5 and 0 6 coefficients in Merlot were identical (Fig 3) In retrospective, it can be stated with quite certainty that the in 1997 the Cabernet was probably measured immediately after irrigation, the sauvignon 2-3 days after irrigation and the Merlot 4-5 days after irrigation (or just before an irrigation) The water potential of the vines in the experimental vineyard oscillate in the 0 3 pan A irrigation coefficient, ca between –5 and –14 In the higher rates of irrigation the water potential just before irrigation are less negative The routine cycle of irrigation in the vineyard is 4-5 day intervals Stem water potential measurements are very promising and the technique should be explored more as a measure of control for irrigation timing

Photosynthesis Measurements in Sauvignon blanc in 1998 showed a decrease in net of photosynthesis and transpiration, and an increase in stomatal resistance in the lowest rate of irrigation (Table 5)

Yield, Pruning Weight and Fruit load A pan A irrigation coefficient of 0 3 reduced significantly the yield of Sauvignon and Merlot in 1997 (Table 6) Yield of Merlot was not affected in 1998 The rate of irrigation had no effect on the yield of Cabernet In contrast to yield, the pruning weight was affected in all 3 cultivars by the irrigation level (Table 6) Pruning weight increased proportionally to irrigation rate, and consequently the fruit load (yield / pruning weight) decreased as the irrigation level increased The load of the highest irrigation rate in Sauvignon (9 1 in 1997), the two lowest

irrigation rates in Merlot (9 0 and 11 8†in 1998), and the lowest irrigation rate in Cabernet (11 5 in 1997 and 8 2 in 1998) were in the optimal load range (ca 10)

Fruit quality Acidity of Sauvignon and Cabernet increased as the rate of irrigation was raised, in both years (Table 7) The Brix of the two cultivars was not consistent between years, it was raised in 1997 and reduced in 1998 as the rate of irrigation increased Acidity and the Brix of Merlot was not affected by the rate of irrigation

Cluster and berry weight (Table 8) increased as the rate of irrigation was raised, in all three cultivars and both years, but the effect was significant only in Sauvignon in 1997 (cluster and berry weight) and in Cabernet in 1998 (berry weight)

Sensory evaluation of wines Micro-vinification of 50-60 kg grapes from each replicate of Sauvignon Merlot and Cabernet was carried in 1998 After hand harvesting early in the morning, the red cultivars were crushed, and metabisulfit (50 ppm) and Sacharomyces cerevisiae yeast (60g/100 l juice) added in the vineyard By mid-day samples were transported to temperature controlled fermentation rooms in the Volcani Center Sauvignon was transported and cooled overnight before micro-vinification in the Volcani Center, without the skin Red cultivars were fermented†with the skin, mixing and wetting the skins 4-5 times a day Acidity was adjusted by tartaric acid to a 6 5 g/l Fermentation was complete after 6-8 days, skins removed by pressing, and the fermented wine collected in 25 l glass bottles, closed with air-locks Malo lactic fermentation was initiated by the addition of Leuconostock oenos EQ54 bacteria Wines were cold stabilized for two weeks at 6 C° Wines were clarified by sedimentation and siphoning, three times, every time adding 20 ppm sulfur A taste panel of 12 expert evaluated the wines, according to color, smell, taste, and an over all grade (total maximal score of 20 points) Sensory evaluation was by blocks and wines within each block were blindly randomized

The total score for all three wines and treatments was above intermediate (11-14 points) within a narrow range of up to 1 5 point in each cultivar (Table 9) In the red cultivars, Cabernet and Merlot, the lowest irrigation rate treatment received a slightly better score (1 1-1 4 point higher) than the highest rate of irrigation This difference was not statistically significant The Cabernet received slightly lower scores than the other two cultivars

Leaf Analysis The N and P fertigation in the experiment was proportional to the rate of irrigation (Table 10) Potassium was not applied, since high levels were found in soil and leaf analysis in the

vineyard in previous years Nitrogen in the blade of Merlot at harvest in 1997, and potassium in the blade of the Sauvignon at harvest in 1998 were at a deficient level (Table 11 and Table 12) No other deficiency was detected in the vineyard

In almost all cases N and P of leaf petiole and leaf blade, at flowering and at harvest, increased as the rate of irrigation-fertigation was raised Potassium concentration, which was not fertigated, increased close to harvest also, as the rate of irrigation was raised (Table 10, Table 11 and Fig 4) Potassium concentration at flowering time, however, was almost always negatively correlated to the rate of irrigation (Fig 10) The opposite trend in K tissue content, between flowering and harvest times is a well-known phenomenon Higher soil water content facilitated K solubilization, mass diffusion and uptake during the growing season The reasons for the opposite trend in tissue K, between flowering time and harvest, are not known

Table 1 The effect of irrigation rate on shoot development of three grape cultivars in a semi-arid region Destructive sampling during 1997 (Merlot and Cabernet), and 1998 (Sauvignon)

Irrigation Coeff	Number of Shoots Thin	Number of Shoots Thick	Number of Shoots Total	Shoot Length (cm) Thin	Shoot Length (cm) Thick	Shoot Length (cm) Total	Lateral growth (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 2 The effect of irrigation rate on leaf development of three grape cultivars in a semi-arid region Destructive sampling during 1997 (Merlot and Cabernet), and 1998 (Sauvignon)

Irrigation Coeff	Number of leaves / vine periphery	inside	Total	Leaf Area (m^2 / vine) 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 3 Comparative LAI of three grape cultivars grown in a semi-arid region

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 4 Stem water potential (atm) of three grape cultivars grown in a semi-arid region 1997

Irrigation Coefficient	Sauvignon 4 8 97	Merlot 4 8 97	Cabernet 13 8 97
0 3	-9 8 b	-13 6 c	-6 7 b
0 4	-7 3 a	-11 0 b	-6 3 ab
0 5	-6 6 a	-8 0 a	-5 2 a
p	0 01888	0 0005	0 0414
F	8 3	34 8	5 7

Table 5 Photosynthesis (A), transpiration (E) and stomatal resistance (S) of Sauvignon blanc grown in a semi-arid region

Irrigation Coefficient	A (mol/m ^{2}/s)	E (milimol/m^2/s)	S (m^2/s/mol)
0 3	8 2 b	1 3 b	44 a
0 4	11 4 a	2 2 a	23 b
0 5	10 9 ab	2 1 a	27 a

Table 6 Yield, pruning weight and fruit load of three grape cultivars grown in a semi-arid environment

Cultivar	Irrigation Coefficient	1997 Yield (kg/vine)	1997 Pruning (kg/vine)	1997 Load	1998 Yield (kg/vine)	1998 Pruning (kg/vine)	1998 Load
Sauvignon	0 3	6 0 b	0 4 b	16 4 a	-------	0 7 c	-------
	0 4	8 4 a	0 7 b	13 0 ab	-------	1 3 b	-------
	0 5	9 1 a	1 3 c	9 1 b	-------	1 8 a	-------
	p	0 064	0 0248	0 0212		0 0013	
Merlot	0 3	5 5 b	-------	-------	6 2 a	0 5 c	11 8 a
	0 4	7 4 a	-------	-------	7 5 a	0 8 b	9 0 ab
	0 5	8 1 a	-------	-------	6 9 a	0 9 b	7 7 bc
	0 6	8 6 a	-------	-------	7 5 a	1 2 a	6 1 c
	p	0 0054			0 6804	0 001	0 0081
Cabernet	0 3	8 2 a	0 9 b	11 5 a	8 4 a	1 1 b	8 2 a
	0 4	8 3 a	1 4 ab	6 7 b	8 0 a	1 8 a	4 1 b
	0 5	8 1 a	1 8 a	5 1 b	8 5 a	2 4 a	3 7 b
	p	0 9778	0 0634	0 0182	0 5933	0 0033	0 009

Table 7 Maturity indexes of three grape cultivars grown in a semi-arid region 1997 and 1998

	Irrigation Coefficient	pH		Brix		Acidity (g/l)		K (ppm)	
				1997					
Sauvignon	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	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	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		0Æ7916	
				1998					
Sauvignon 9/8/1998	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 10/8/1998	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 10/9/1998	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	

Table 8 Cluster and Berry weight of three grape cultivars irrigated with various pan A coefficients in a semi-arid region 1997 and 1998

cultivar	Irrigation coefficient	1997 Berry		1997 Cluster		1998 Cluster		1998 Berry	
Sauvignon	0 3	101 6	c	1 423	b	133 4	a	1 727	a
	0 4	116 5	b	1 645	a	144 1	a	1 847	a
	0 5	134 6	a	1 760	a	150 3	a	1 865	a
	p	0 0036		0 0126		0 5387		0 7644	
Merlot	0 3	118 3	a	1 164	a	104 8	a	1 158	a
	0 4	133 8	a	1 201	a	118 9	a	1 181	a
	0 5	117 0	a	1 222	a	113 7	a	1 230	a
	0 6	122 7	a	1 186	a	125 1	a	1 356	a
	p	0 5017		0 9488		0 6159		0 3755	
Cabernet	0 3	84 5	a	1 023	a	69 3	a	1 013	b
	0 4	90 2	a	1 166	a	77 5	a	1 197	a
	0 5	92 7	a	1 137	a	79 5	a	1 275	b
	p	0 6825		0 4249		0 2144		0 0195	

Table 9 Sensory evaluation of wines from three grape cultivars irrigated with various pan A coefficients in a semi-arid region

Quality Parameter	Irrigation Coefficient 0 3		0 4		0 5		0 6	
			Sauvignon					
Total	13 73	±0 08	13 70	±0 16	13 78	±0 06		
Color	2 93	±0 04	2 95	±0 02	2 94	±0 02		
Smell	3 41	±0 10	3 46	±0 07	3 51	±0 03		
Taste	6 09	±0 04	5 98	±0 11	6 04	±0 05		
Over all	1 31	±0 01	1 31	±0 03	1 29	±0 01		
			Cabernet					
Total	12 77	±0 98	12 36	±0 86	11 36	±0 71		
Color	3 27	±0 16	3 24	±0 17	2 79	±0 09		
Smell	3 45	±0 24	3 38	±0 16	3 44	±0 15		
Taste	5 76	±0 46	5 54	±0 49	5 09	±0 38		
Over all	1 29	±0 15	1 21	±0 13	1 07	±0 11		
			Merlot					
Total	14 31	±0 60	13 34	±0 47	13 85	±0 26	13 21	±0 30
Color	3 20	±0 14	3 04	±0 16	3 17	±0 09	2 88	±0 06
Smell	3 86	±0 16	3 50	±0 08	3 63	±0 13	3 36	±0 13
Taste	5 95	±0 24	5 63	±0 20	5 80	±0 11	5 72	±0 16
Harmony	1 30	±0 08	1 18	±0 08	1 25	±0 04	1 25	±0 06

Table 10 Annual nitrogen and phosphorus fertigation, applying three irrigation coefficients in the vineyard

	0 3	0 4	0 5	0 3	0 4	0 5
Sauvignon	49	65	81	5 6	7 5	9 3
Merlot	71	95	119	8 2	10 9	13 7
Cabernet	53	70	88	6	8 1	10 1

Table 11 Leaf analysis of three grape cultivars irrigated with various rates of water in a semi-arid region 1997

		N-NO3 ppm	N % DW	P % DW	S % DW	K % DW	Ca % DW	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 25a	1 89
4 8 97	0 4	1886	0 87	0 228	0 085	2 32 ab	1 92b	1 78
	0 5	1949	0 95	0 299	0 085	3 00 ab	1 80b	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 11)

		N-NO3 ppm		N % DW		P % DW	S % DW	K % DW	Ca % DW	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

Table 12 Leaf analysis of three grape cultivars irrigated with various rates of water in a semi-arid region 1998

		N-NO3 ppm	N % DW	P % DW	S % DW	K % DW	Ca % DW	Mg % DW
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 91b	2 15
27 7 98	0 4	503	1 02	0 105	0 065	0 432	1 95ab	2 19
	0 5	472	1 05	0 104	0 065	0 42	2 05a	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
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 68a	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

(continue table 12)

		N-NO3 ppm	N % DW	P % DW	S % DW	K % DW	Ca % DW	Mg % DW
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 7986
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

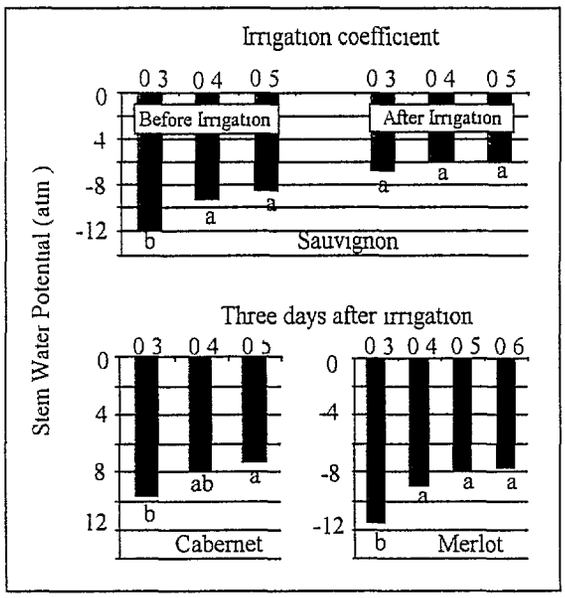


Figure 1 Stem water potential (atm) of three grape cultivars grown in a semi-arid region 1998

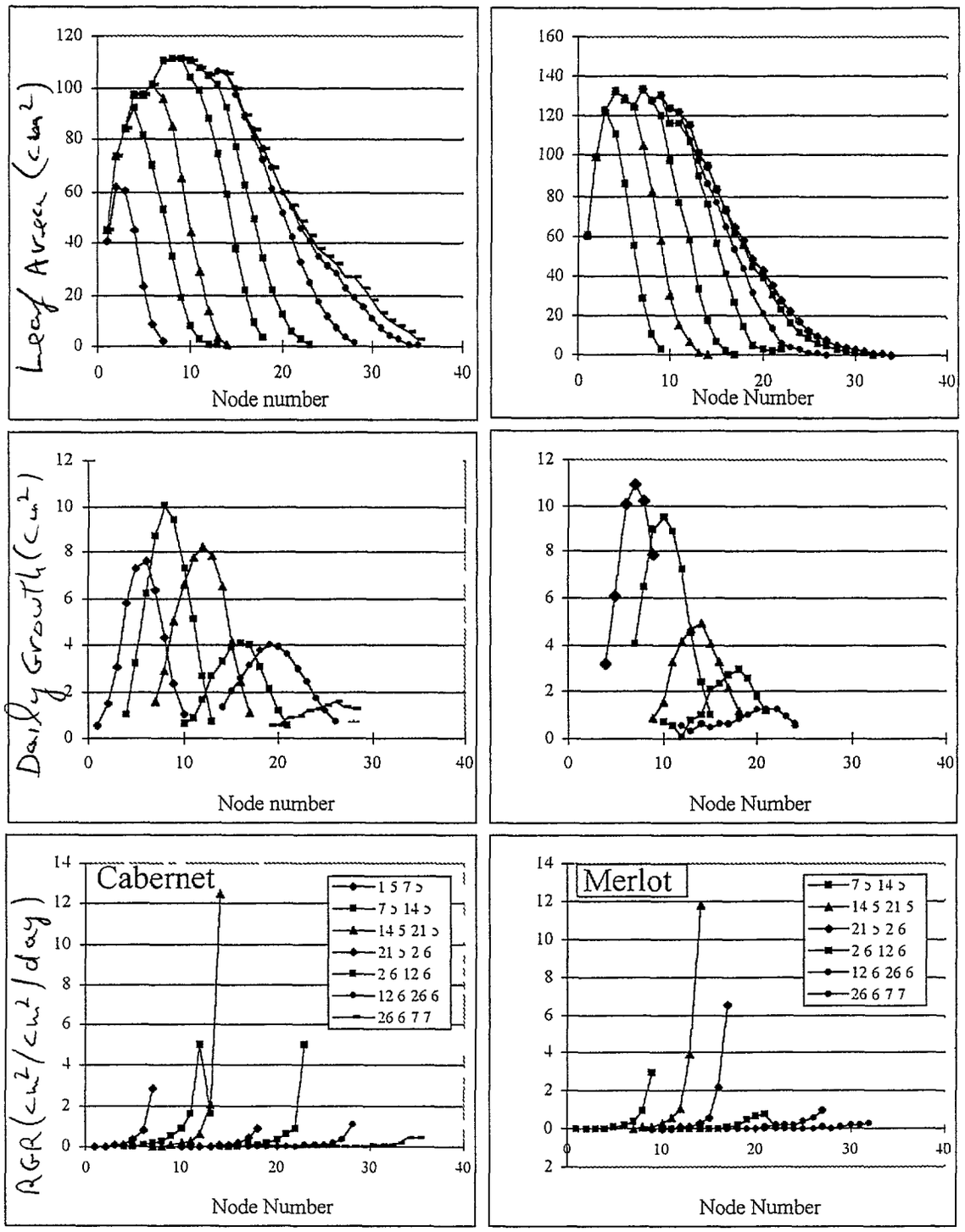


Figure 2 Leaf area, daily leaf growth and leaf relative growth rate at progressive node numbers on different dates Average for all irrigation rates (n=48 shoots)

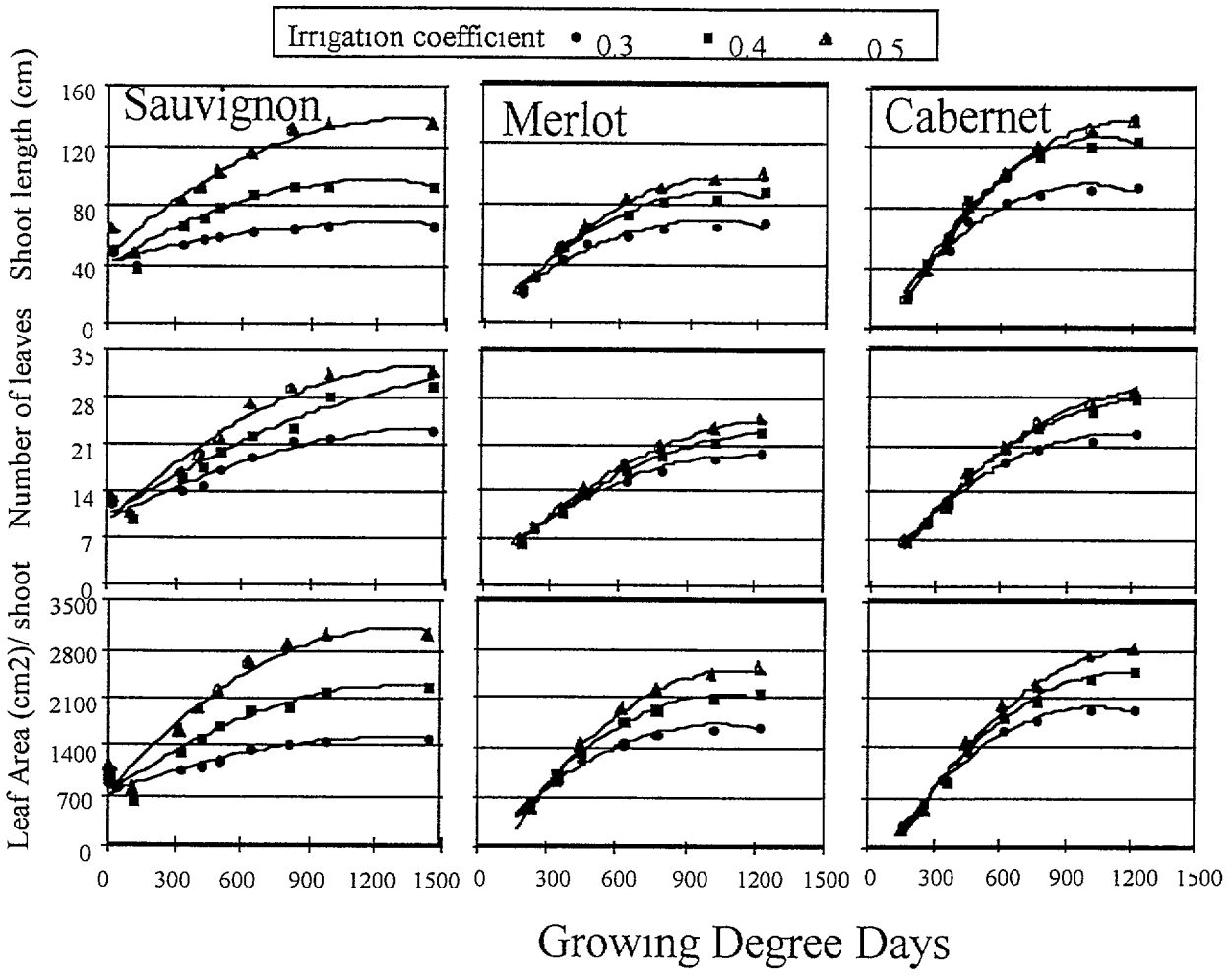


Figure 3 The effect of irrigation rate on shoot growth, leaf number and leaf area of three grape cultivars grown in a semi-arid region

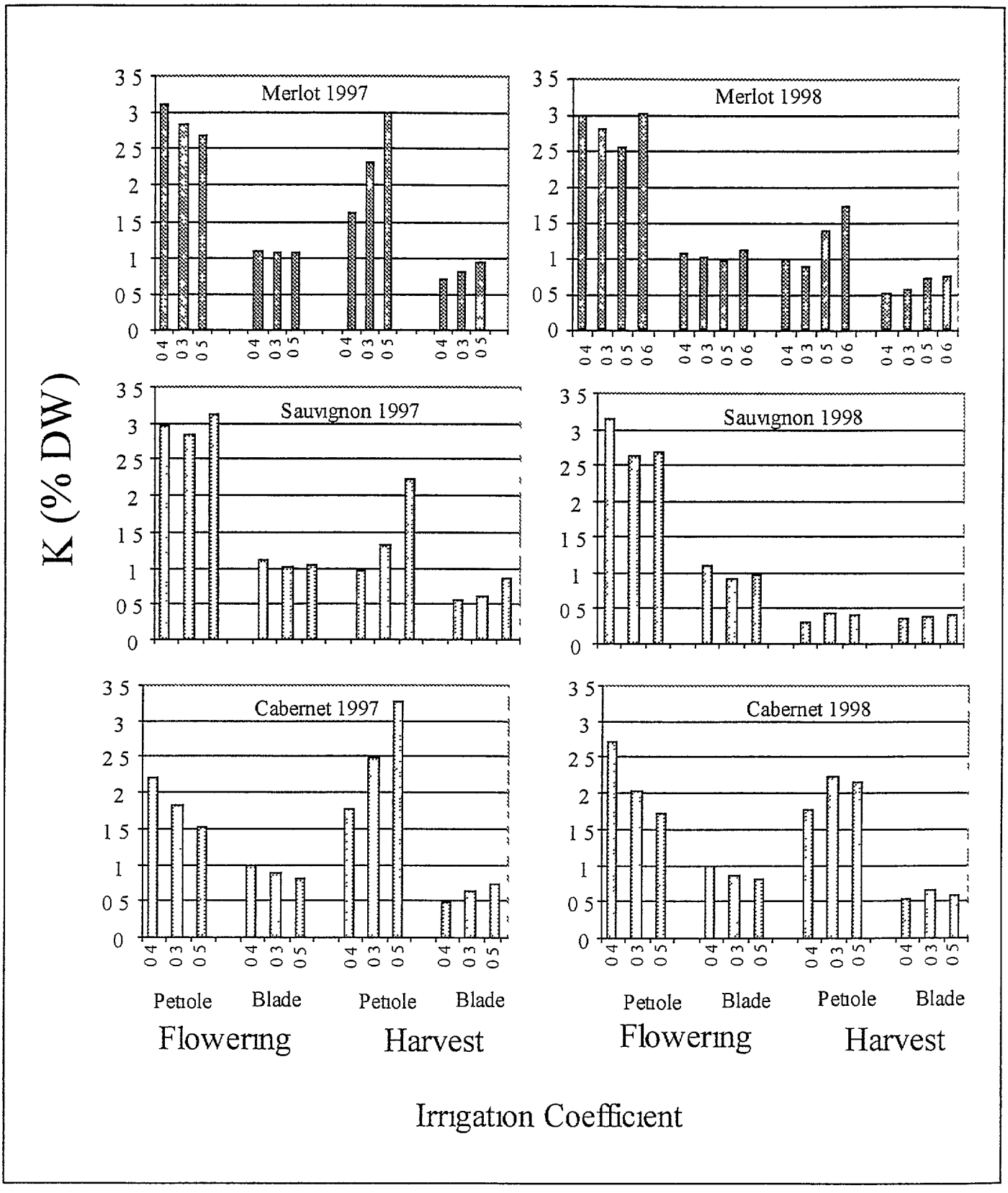


Figure 4 The effect of irrigation rate on leaf petiole and blade potassium

The Report From Kazakhstan

Attached

- The experimental layeout of the field trial in Kazakhstan and the report sent to by the
- Report sent to me from Kazakhstan

R E P O R T

on the project "Drip fertigation of grape vines in arid agriculture", Grant no TA-MOU-96-CA15-008

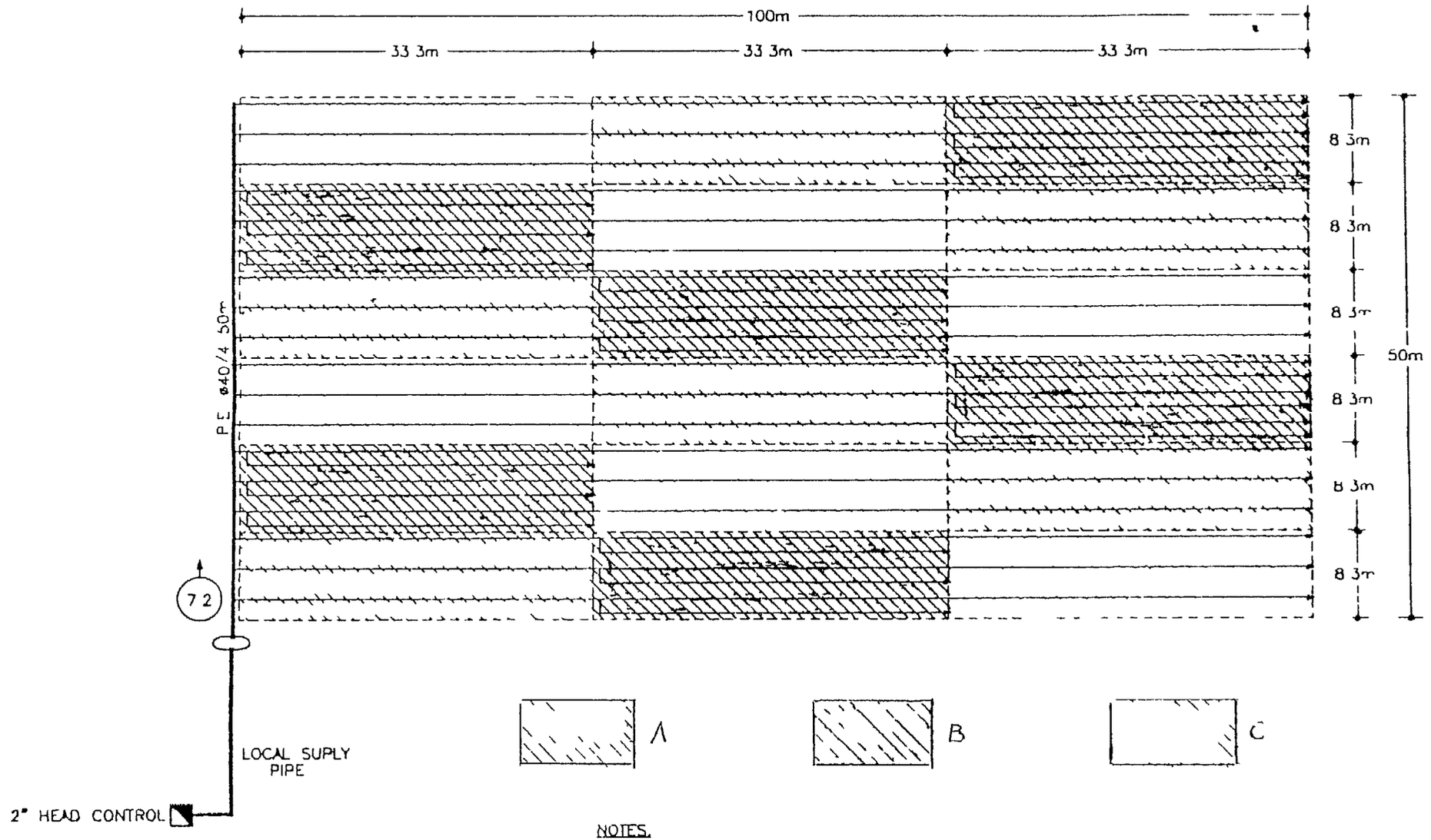
Principal Investigators:

Prof. Isaac Klein,
ARO, The Volcani Center,
Institute of Horticulture,
Israel.

Dr. Eduard Madenov,
The Kazakh Research Institute
of Fruit and Grape Growing,
Kazakhstan.

Almaty, 1997.

After collaborative discussion with Israeli investigators on the project, the experiment scheme, providing for different spaces between the drippers but with equal total water discharge for drippers according to experiment variants, was determined.
The drippers with compensate pressure and fixed water discharge of 2 and 4 l/h were foreseen.
Experiment variants:
1- one drip line with the space of 1m between drippers and water dischange of drippers 4 l/h.
2- two paralled drip lines with the space of 1m between drippers and water discharge of 2 l/h.
3- one drip line with the space of 0,5m between drippers and water dischange of 2 l/h.
Six replications in full rendomized block under one system of vine traing and with application of mineral fertilizers together with water, determined by culculated method.
The elaborated scheme of experimental drip irrigation system is shown on the Fig.1. The total water dischange with simultaneous work of drip lines is 7,2 l/h or 2 horse-power (h.p.).
According to natural-climatic, economic and agrotechnical conditions technical work-plan was carried out for the projecting the experimental system of drip irrigation and was passed to the firm Netafim for the distribution of the orders for making and delivering the irrigation equipment. The time of order making is not later than the end of February 1998, to the beginning of irrigation season the system should be mounted on the experimental plot.
For setting a fild trial on grape plantation the plot on light chestnut soils in sovkhos "Gigant" of Almaty region was determined. Soil data are characterized by rather low content of humus (1,0-1,5%) hydrolyzing nitrogen, mobile phosphorus, exchangeable zinc and mobile cobalt. The samples of grape leaves were taken from four replications on the plot. The samples of leaves with cuttings were taken at the end of vegetation - in October. The results of the analyses are given on the Table 1.
Analytical materials on leaf analysis testify to the fact, that vine plants on the plot are suffered from the deficiency of phosphorus, potassium and partially zinc. On some parts of the plot there was nitrogen deficiency. Growing conditions of grapes on the plot in 1997 because of dry and hot summer and water defit were not quite favourable.



NOTES.

1 AREA A. DESIGNED FOR P C J DRIPPERS 4L/H @ 1 0m

2. AREA B DESIGNED FOR P C J DRIPPERS 2L/H @ 0 5m
2 LATERALS PER PER ROW

1 AREA C DESIGNED FOR P C J DRIPPERS 2L/H @ 1 0m.

25

On the whole the productivity and development of vine plants in 1997 are characterized by the following indexes:

- mean mass of grape buncnes - 162,3 g.
- % of fruitful shoots - 60%
- productivity coefficient - 1,44
- yield per a bush - 10,1 kg
- yield evaluated in ha - 18,4 g.
- average shoot length - 73,2 cm.
- degree of shoot ripening - 69,2%.

On the whole according to the data of leaf analysis it is possible to expect good effect from fertilizer application under drip irrigation on grape plantation.

The investigators:

Dr. E.Madenov

Dr. A.Bondartsev

Dr. G.Adrianova

Table 1.

Leaf analysis on experimental plot (October,1997)

Variety	Replication	% of dry substance					mg/kg of dry substance				
		N	P_2O_5	K_2O	CaO	MgO	Fe	Zn	Co	Mn	B
Muscat jantarny	1.Replication	1,73	0,26	0,26	4,8	1,24	189	25,9	1,85	34,1	18,6
	2.Replication	1,62	0,26	0,36	4,6	1,13	178,2	26,8	1,62	27,2	19,0
	3.Replication	1,90	0,30	0,33	4,0	1,40	233,3	19,9	1,59	31,1	24,6
	4.Replication	1,79	0,41	0,33	4,1	1,13	175,0	19,9	1,56	27,4	28,1
	Average content on the plot	1,76	0,31	0,32	4,4	1,22	193,9	23,0	1,65	29,9	22,8
	Optimal content in grape leaves	1,79 1,9	0,38 0,40	0,43 0,61	-	-	-	26,-31	-	-	17-28

Note. in colomn "optimal content" the generalized literary and own data are given.

R E P O R T

on the scientific visit to Israel under AID cooperative project "Drip fertigation of grape vines", Grant no TA-MOU-96-CA15-008 between The Volcani Center in Bet-Dagan, Israel and The Kazakh Research Institute of Fruit and Grape Growing.

The visit to Israel of the Kazakhstan scientists Dr. E.Madenov and Dr. A.Bondartsev in September 15-22,1997 was very important for the further investigations on the project and for more precise definition of the work-plan of experiments on grape plantations, irrigation systems and the drip irrigation equipment.
In different natural-climatic conditions of Israel, in experimental--research stations, Kibbutzes, private farms, different varieties of fruits, grape, subtropical crops, advanced technologies of fruit and grape production were shown to the Kazakhstan investigators.
We got acquaintance with very interesting researches, conducted at the Institute of Horticulture, on effective methods of water and fertilizer use and drip irrigation. Profound investigations on the complex "soil-water-plant" are conducted at the Institute. The irrigation construction and the use of unproductive lands under orchards and grape plantations by means of drip fertigation impressed us greatly.
A very care of water resources in Israel predetermined the development and spreading everywhere the most economical irrigation means such as a drip irrigation. Sprinkler irrigation aslo is used in vegetable and technical crops.
During our visit to the company Netafirm and to the firm DAN, producing irrigation equipment we had the possibility to get acquaintance with many scientific and design elaborations and with production technology of wide kinds of devices for completing sprinkler and drip irrigation systems. We were greatly impressed by automatic divices for irrigation systems and distance monitoring for each element of the system, which allow to regulate quantity and frequency of water and fertilizer supplying.
Great interest represents the technology of grape production in Israel. training systems of vine bushes and their pruning, mashine harvesting of technical grape varieties, management of soils in row-spaces and within rows and so on. The selection of grape varieties, their exact distribution according to natural zones are, undoubtedly, of a great

success of Israeli scientists in grape production. Very interesting works are conducted by the investigators of the Institute of Horticulture on selection and breeding of new grape varieties, especially of seedless varieties. The authors of the report express their deep gratitude to Prof. Isaac Klein for his warm receipt and the prominent professional show of the investigations on the technology grape production, grape varieties, irrigation systems and his help in delivering drip irrigation equipment to Kazakhstan.

The advanced technology of grape production, selection and breeding of new varieties and different methods of irrigation systems, elaborated by Israeli scientists, are of great interest and very useful for the future development of the Kazakhstan viticulture.

The results of our visit to Israel were reported to the Scientific Council of the Research Institute of Fruits and Viticulture and will be published in Agricultural Science Journals of Kazakhstan.

Dr. E.Madenov

Dr. A.Bondartsev.

Experiment scheme provides for different distance between drippers but with equal sum dripper expenses according to variant of the experiment With this aim drippers are with pressure compensation and fixation of water discharge of 2 and 4 l/h

The experiment consists of the following variants

A – One drip line with the distance between drippers of 1m and water discharge of drippers 4 l/h

B – 2-paralleled drip lines with the distance between drippers of 1m and water discharge of drippers 2 l/h

C – One drip line with the distance between drippers of 0 5m and water discharge of drippers 2 l/h

Six replications in full randomized block under one system of grape bush training and the application of irrigation water simultaneously with fertilizer doses N 60 P 60 K 120 of active substances, determined for irrigated grape plantations with furrowed irrigation in south-east of Kazakhstan

Soils on experimental plot are light-chestnut, medium loamy with humus content in arable horizon of 1 5-2% and comparatively low content of hydrolyzing nitrogen, movable phosphorus and exchangeable potassium and zinc Analytical materials on grape leaf analysis, conducted in 1997 also showed the deficiency of phosphorus potassium and zinc in grape leaves, in some cases – low nitrogen content

Because of severe damage of grape bushes by spring frosts in current year the works on reproduction of grape bushes with rate setting of loads were conducted on experimental plot during summer As a result of this treatment uniformed background was created for trials according of the working program on the Project next year

In 1998 the equipment and materials for construction of water-collecting unit consisting of channel, clarifying tank, pumping station and the place for distribution unit were purchased

Because of unuseful expenses on orchard guard this year, the irrigation system with dripper lines will be mounted to the beginning of irrigation season in 1999

Principal Investigator

Dr Eduard Madenov

Investigators

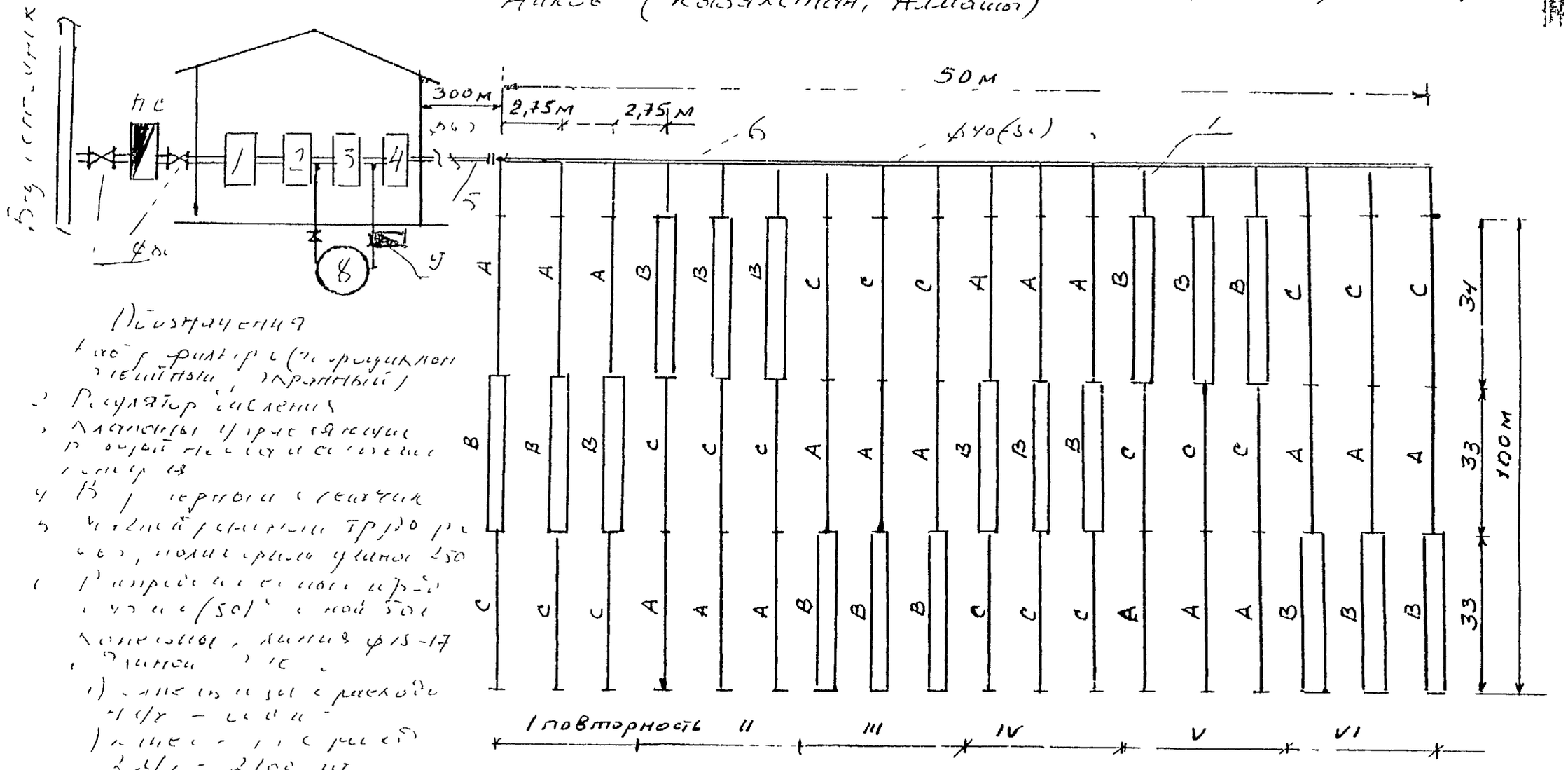
Dr Adrianova G P

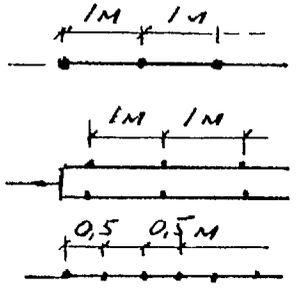
Dr Bondartsev A I

This Report [illegible]

BEST AVAILABLE COPY

Схема экспериментальной системы капельного орошения виноградников (Казахстан, Алматы)





A – [illegible] 4 л/ч

B – [illegible] 2 л/ч

C – [illegible] 2 л/ч

Обозначения

1. [illegible] (гидроциклон [illegible])
2. Регулятор давления
3. Клапаны [illegible]
4. [illegible]
5. [illegible] 250
6. [illegible] (50) [illegible] 50 [illegible] линия ф15-17 [illegible]
7. [illegible] расходо[illegible] 4 л/ч – [illegible]
8. [illegible] 2 л/ч – 2100 шт
9. [illegible]
10. [illegible]
11. [illegible]

Submitted for publication in Acta Hortic

GRAPEVINE LEAF-AREA-INDEX EVALUATION BY GAP FRACTION INVERSION

Shabtai Cohen[1], Michael J Striem[2], Moshe Bruner[3], Isaac Klein[2]

[1] Inst Soil, Water and Env Sci , Volcani Center, Bet Dagan 50250, Israel

[2] Institute of Horticulture, Volcani Center, Bet Dagan 50250, Israel

[3] Carmel, South Hebron Region 90102, Israel

Key Words *Vitis vinifera L* , canopy, irrigation, pruning weight

Abstract

Controlling the ratio of grapevine vegetative growth to yield is an important management objective, since this ratio has a consistent relationship to grape quality In this study, the relationships between several vegetative growth parameters and yield parameters were studied, on three grapevine cultivars, in the framework of irrigation trials for evaluating three Pan A irrigation coefficients for optimizing yield and wine quality in the semi-arid Arad Plateau, near the Dead Sea, Israel Leaf-Area-Index (LAI) was evaluated by Gap Fraction Inversion (GFI) measured at three zenith angles using two linear PAR probes (Ceptometer and SunLink) PAR transmittance of 12 vines in each of the cultivars Sauvignon blanc, Cabernet Sauvignon and Merlot were measured 7 to 8 times from bud-break, at 7-14 days intervals Shoot elongation, number of leaves and leaf area (evaluated form vein measurements) were measured simultaneously with GFI, on the same vines After full canopy development, destructive sampling of the vines was made to determine total leaf number and area, shoot number and length, and vine dry weight Pruning weights of 10 adjacent vines, receiving identical irrigation treatments, were recorded during winter

LAI (1 50-5 45), evaluated by GFI, was highly correlated with leaf area of tagged shoots (200-3000 cm^2/shoot) on the vine and with leaf area (5 61-15 85 m^2/vine) measured by destructive sampling

Weekly interval measurements of shoot elongation and leaf area, and total shoot length, were found to be reliable and useful tools for estimating vineyard canopy development and size Similar leaf areas of Merlot, Cabernet Sauvignon and Sauvignon blanc were associated with a wide range of winter pruning weights Estimating actual canopy coverage (LAI) from GFI, for characterizing fruit load in vineyards in relation to fruit quality, was found to be equally reliable to measurements of winter pruning weights, offering the advantage of measurements in real time

Introduction

Wine quality is highly dependent on grape quality Viticultural practices influence the quality of the fruit, through changes in vine vigor and yield The vegetative and

reproductive balance, expressed as a Crop Load (CL) value, has been correlated to wine quality (Bravdo et al , 1984, Hepner et al , 1985) The CL value is calculated as the ratio of (summer) yield to the following (winter) pruning weight of the wine For 'Carignane' and 'Cabernet Sauvignon', the optimum wine quality was at a CL value of 10-12 It is reasonable to assume that CL value differs for different cultivars, depending on their vigor Actually, photosynthesis and other metabolic processes in the leaf are responsible for changes in fruit quality, rather than pruning weight per se Therefore, the leaf area, rather than pruning weight, should be utilized for the expression of crop load Estimation of leaf area is fundamental not only for CL expression but also for calculations of ET from energy balance models, i e by implementation of the Penman-Monteith equation, for irrigation purposes (Fuchs et al , 1987)

Several protocols for estimating vineyard leaf area have been developed in the past The simplest one correlated linear measurements to total vine leaf area (Carbonneau, 1976a and 1976b, Gonzalo and Kliewer, 1983, Elsner, 1988, Grantz and Williams, 1993, Sommer, 1994, Mabrouk and Carbonneau, 1996) These measurements are tedious and time consuming Recently, with the development of gap fraction inversion (GFI) theory and appropriate commercial instrumentation (Welles and Cohen, 1996), rapid vineyard LAI measurement became feasible (Sommer and Lang, 1994)

In this research a protocol for measurement of LAI with linear photosensor array probes (Cohen et al , 1997), was adapted, tested and validated for grape vineyards The protocol involves measuring a large grid of transmittance of photosynthetic radiation through the canopy In addition, shoot leaf area and length were studied

Materials and Methods

The study was carried out on the grape cultivars Sauvignon blanc, Cabernet Sauvignon and Merlot, in a commercial vineyard in the Arad Plateau (31°18' N, 35 ° 08' E), in Israel The drip-irrigated vineyard was planted in 1989, at a planting distance of 1 5x3 m Vines were double-arm trained on a T bar (20 cm wide horizontal bar) trellis, typical for mechanically harvested wine production in Israel Shoots were growing on the vine undisturbed from bud break until ca 6 weeks, when they were repositioned by raising two wires from the ground and placing them on the horizontal bar at the top of the trellis

An experiment was set up in the vineyard in 1992, evaluating three pan A irrigation's coefficient of 0 3, 0 4 and 0 5 These coefficients established a range of canopy volumes Irrigation treatments were replicated 4 times, in a randomized block design in each of the three cultivars Each replicate consisted of 3 adjacent rows of 40 vines each Data in the irrigation trial was collected from 10 designated vines in the center row The vineyard was clean cultivated and the experimental plots received standard maintenance practices

A typical size vine was selected from the border row, in each replicate (total of 12 vines per cultivar), for canopy development measurements, for grapevine leaf-area-index evaluation by GFI, and eventually for destructive sampling Four

shoots per vine were tagged for measurements of length, number of leaves and leaf area Leaf area on the vine was calculated from equation developed on detached leaves of each cultivar, by correlating the sum of the first two lateral veins to leaf area (Carbonneau, 1976) Canopy development measurements were carried out at weekly intervals for the first month of growth after bud break and at 10-14 day intervals thereafter LAI and canopy development measurements were carried out on the same vines After growth cessation the vines were destructively sampled for measurements of total leaf area and shoot length Measurements were carried out on Merlot and Cabernet Sauvignon in 1997 and on Sauvignon blanc in 1998

Canopy transmittance measurements for gap fraction inversion (GFI) were carried out with 80 cm line photo-sensor array (LPA) probes (Decagon Ceptometer and Sunlink) The Ceptometer has two modes of operation, one that gives readings from one of the sensors, and the other gives averages for all 80 sensors The Sunlink was connected to a datalogger, which collected raw readings from all sensors These readings were converted to radiation values in offline processing using calibration coefficients for each sensor Measurements were carried out by positioning the probes on the soil surface, along lines parallel to the row (Fig 1) Measurements were made at two or three sun angles during the day depending on whether early morning cloudiness prevented measurements at large zenith angles Sun angles were chosen from a table of solar angles computed for the day of measurement and the map coordinates of the vineyard A computer program was written to calculate these angles and print the tables

In practice the three angle groups measured were 42°-50°, 25°-30°, and 10°-15° (the minimum zenith angle for the day) Morning measurements (42°-50° angle) were made every 30 cm and the remaining two, when the shade contracted, every 15 cm Measurements extended 15-30 beyond each side of the canopy shadow Two successive strips of 80 cm (total of 1 6 m) were measured per vine

Reference measurements of direct and diffuse solar irradiance were made outside of the canopy by shading individual sensors on the linear photo-sensor array (LPA) probe with an occulting disk Calibration of LPA probes was as described by (Cohen et al, 1997)

Non-beam PAR irradiance below the canopy was measured with a single sensor on the LPA probe either by positioning the sensor in the shade, or by shading the sensor from a distance of at least 50 cm without obscuring the inter-row gap Alternatively, when using the Sunlink the minimum value of the 80 sensors (placed parallel to the row) was taken as the non-beam irradiance For the purposes of this study, the two methods gave equivalent results

Transmittance of direct radiation was taken as the difference between total and non-beam PAR at the grid position, divided by the difference between global and diffuse PAR irradiance outside of the canopy These values were converted to log values In order to complete the grid for vineyard LAI, addition values of unit transmittance should be added, but since their log is zero, determination of vineyard LAI was by dividing the total

of the log values by the number of measurements needed to cover the full row Averages of logarithmically averaged transmittance for two or more solar zenith angles were used to determine LAI and mean leaf angle (Norman and Campbell, 1989)

Results

Direct determination of LAI was from destructive sampling of all leaves on 36 grapevines, i e four vines from each of three treatments in each of the three varieties Direct and GFI measurements are compared in figure 2 GFI measurements below each vine were 1 6 m long (i e one grid, see fig 1) However, linear scans of radiation below other canopies have shown that averages converge to the true average only after several meters (e g Norman and Jarvis, 1974, Cohen and Fuchs, 1987) For this reason results from measurements grids in the repetitions were combined to get scan lengths of 3 2 and 6 4 m, for two and four repetitions, respectively The latter results are also presented in fig 2, and show that the additional averaging improves measurements The implication that more than 5 m is necessary for reasonable accuracy is similar to findings for rows of corn (Cohen et al , 1997) Differences in slopes found between the varieties are discussed below

GFI estimates of LAI and shoot leaf area measured on different dates are compared with growing degree-days (GDD) in fig 3 Polynomial regression was used to fit the data, giving for LAI r^2 values >0 7 in all cases and in 3 of the 9 cases >0 9 The polynomial fits show that the GFI measurements were able to differentiate between the three irrigation levels in the three varieties On the date before the last measurements, the canopy was compacted because the outlying shoots were repositioned (see methods) This caused extreme clumping of the canopy leading to underestimates of LAI, as would be expected for extremely clumpy conditions (see Welles and Cohen, 1996)

Vegetative growth parameters of the three varieties, i e shoot length and number of leaves, and pruning weight were found to be highly correlated with shoot leaf area and GFI estimates of vineyard leaf area index (LAI) Table 1 gives the r^2 values for the three varieties, with the three irrigation treatments taken together The highest r^2 values were for the relationship of shoot leaf area to shoot length So, shoot length may be a promising parameter for monitoring vegetative development Pruning weight and LAI were both well correlated with shoot leaf area The LAI values used for computing these correlations were from two radiation transects, i e 1 6 m length It is likely that increasing the measurement length would improve the correlation However, the current results only show that correlation of measured LAI to shoot leaf area is similar to that of pruning weight

Discussion

The GFI protocol used here is designed to deal with the following problems

1 Scattering of radiation by leaves
2 Canopy clumpiness due to two factors – row structure, and branching structure

3 Simultaneous determination of LAI and leaf angle distribution

Scattering of radiation in the canopy is dealt with by using sensors in the PAR waveband, in which leaf scattering is small (approximately 15%), and subtracting measurements of non-beam radiation from the reference measurements outside of the canopy and below the canopy Under the canopy the measured non-beam component includes the small scattered component Therefore, the result after processing is actually a measure of transmittance of direct radiation, which conforms to strict application of gap fraction inversion theory

Clumpiness due to shoot and row structure is dealt with by measuring short scans (i e 80 cm scans from individual measurements with the LPA probe), converting these to the logarithm of transmittance, and averaging the full grid as logarithmic values The grid is built to evenly sample all the area of the row shadow When the full grid is averaged then the mean log value is converted back to transmittance for further processing The approach of logarithmic averaging was developed by Lang and Xiang (1986) They recommended that linear averaging length should be approximately 10*D, where D represents the characteristic leaf dimension However, Cohen et al , 1997 showed that if measurements are made parallel to the row then averaging length has only a minor influence on LAI estimation, so that the 80 cm average should be close enough to 10*D Recent comparisons of different averaging lengths for apple orchards also showed that when measurements are parallel to the row, then averaging length does not have to be precisely 10*D (Cohen et al , 1999)

Comparison of GFI estimates of LAI to direct measurements (fig 2) shows that slopes are close to unity for Merlot and Sauvignon blanc, but less than unity for Cabarnet sauvignon In addition, the intercepts for Sauvignon blanc and Cabarnet sauvignon were higher than zero Results for Merlot were the most satisfactory The difference between the three varieties was unexpected, since the GFI protocol should have general applicability to all grapevines with similar leaf sizes Possible reasons for differences would be differences in clumpiness, and the inclusion of non-leaf elements in the GFI estimates Clumpiness causes underestimation in GFI, so results for Cabarnet sauvignon indicate higher clumpiness for this variety Significant area of non-leaf elements cause a large intercept, as found for Sauvignon blanc How, characteristics of the different varieties must be corroborated by other measurements, or by additional analyses of the GFI measurements, before conclusions about the nature of the varieties can be made This awaits further research

Table 1 shows the good correlation obtained between LAI and pruning weight measured in the previous, or the following winter Pruning weight of the following winter is widely used in viticulture in relation to yield in order to balance vegetative development with fruit production (e g Smart and Robinson, 1991) Since pruning weight is only measured in the winter and it's implications with respect to vineyard management can only be applied the following year, it is clear that methods like GFI

are superior, as they can be used to evaluate vineyard development during the same year

Shoot development is one of the sensitive indicators of water stress (Hsiao, 1990), and therefore the relationship of LAI to shoot parameters indicates that GFI may have value for monitoring plant development and stress level

Conclusions

GFI estimates of LAI were highly correlated with destructive samples of LAI, but with the exception of Merlot, they did not give accurate estimates of LAI This is assumed to be due to the fact that GFI estimates include silhouette areas of non-leafy elements and also to clumpiness not adequately dealt with by the measurement and analysis protocol Further research will focus on finding ways of identifying clumpiness in the GFI measurements Meanwhile, empirical relations could be used to attain more accuracy from GFI measurements

Weekly interval measurements of shoot elongation and leaf area, and total shoot length, were found to be reliable and useful tools for monitoring vineyard canopy development and size Similar leaf areas of Merlot, Cabernet Sauvignon and Sauvignon blanc were associated with a wide range of winter pruning weights Estimating actual canopy coverage (LAI) from GFI, for characterizing fruit load in vineyards in relation to fruit quality, was found to be equally reliable to measurements of winter pruning weights, offering the advantage of measurements in real time

References

Bravdo, B , Hepner, Y , Loinger, C 1984 Effect of crop level on growth, yield and wine quality of high yielding Carignane vineyard Am J Enol Vitic 35 247-252

Carbonneau, A 1976a Analyse de la croissance des feuilles du sarment de vigne estimation de surface foliaire par echantillonnage Connaissance vigne Vin 10 141-159

Carbonneau, A 1976b Principes et Methodes de measure de la surface foliare,essai de caracterisation des types de feuilles dans lwe genre vitis Ann Amelior Plantes 26 327-343

Cohen, S , and Fuchs, M 1987 The distribution of leaf area, radiation, photosynthesis and transpiration in a shamouti orange hedgerow orchard Part I Leaf area and radiation Agric Met , 40, 123-144

Cohen, S , Sudhakara Rao, R , and Cohen, Y 1997 Canopy transmittance inversion using a line quantum probe for a row crop Agric For met 86 225-234

Cohen S , Naor, A , Wallach, A , Fusheng Li, Cohen, Y , and Meron, M 1999 Developing a Canopy Structure Measurement Protocol for Apple Orchards Final report, project no 306-0279 Chief Scientist Fund of the Israeli Ministry of Agriculture

Elsner, E A 1988 Leaf area estimation of concord grape leaves from simple linear measurements Am J Enol Vitic 39 95-97

Fuchs, M , Cohen, Y , and Moreshet, S 1987 Determining transpiration from meteorological data and crop characteristics for irrigation management Irrig Sci 8 91-99

Gonzalo, S R , Kliewer, W M 1983 Estimation of leaf area of two grapevine cultivars (Vitis vinifera L) using laminae linear measurements and fresh weight Am J Enol Vitic 34 221-226

Grantz, D A , and Williams, L E 1993 An empirical protocol for indirect measurement of leaf area index in grape (Vitis vinifera L) HortScience 28 777-779

Hepner, Y , Bravdo, B , Loinger, C , Cohen, S , Tabacman, H 1985 Effect of drip irrigation schedules on growth, yield, must composition and wine quality of Cabarnet sauvignon Am J Enol Vitic 36 77-85

Hsiao, T C 1990 Measurements of plant water status In Irrigation of Agricultural Crops, pp 243-279 American Society of Agronomy, Inc , Madison,WI

Lang, A R G and Xiang, Y 1986 Estimation of leaf area index from transmission of direct sunlight in discontinuous canopies Agric For met 37 229-243

Mabrouk, H , Carbonneau, A 1996 Une methode simple de determination de la surface foliare de la vigne (Vitis vinifera L) A simple method for determination of grapevine Vitis vinifera, L leaf area Progres Agricole et Viticole 113 392-398

Norman, J M and Campbell, G S 1989 Canopy structure In Plant physiological ecology Field methods and instrumentation, edited by R W Pearcy, et al, pp 301-326 Chapman and Hall, London

Norman, J M and Jarvis, P G 1974 Photosynthesis in Sitka Spruce (Picea sitchensis (Bong)Carr) III Measurements of canopy structure and interception of radiation J appl ecol 11 375-398

Smart, R , and Robinson, M 1991 Sunlight into wine A handbook for winegrape canopy management Winetitles, Adelaide

Sommer, K J 1994 Comparative analysis of two indirect methods of measuring leaf area index as applied to minimal and spur pruned grape vines Aust J Plant Physiol 21 197-206

Sommer, K J and Lang, A R G 1994 Comparative analysis of two indirect methods of measuring leaf area index as applied to minimal and spur pruned grape vines Aust J Plant Physiol 21 197-206

Welles, J M and Cohen, S 1996 Canopy structure measurement by gap fraction analysis using commercial instrumentation J Exp Bot 47(302) 1335-1342

Table 1 Correlations (r^2) of shoot leaf area, shoot length, LAI (from GFI) and pruning weight of three vine grape cultivars irrigated with various pan A irrigation coefficients

Cultivar	Variable	Shoot Length (m/vine)	LAI	Pruning Weight (kg/vine) 1996	1997	1998
			r^2 values			
Merlot	Leaf Area	0 978	0 707	0 798	----	0 700
	LAI	0 649		0 741	----	0 467
Cabernet Sauvignon	Leaf Area	0 992	0 756	0 882	0 922	0 925
	LAI	0 740		0 764	0 781	0 845
Sauvignon blanc	Leaf Area	0 872	0 758	----	0 746	0 575
	LAI	0 894		----	0 578	0 543

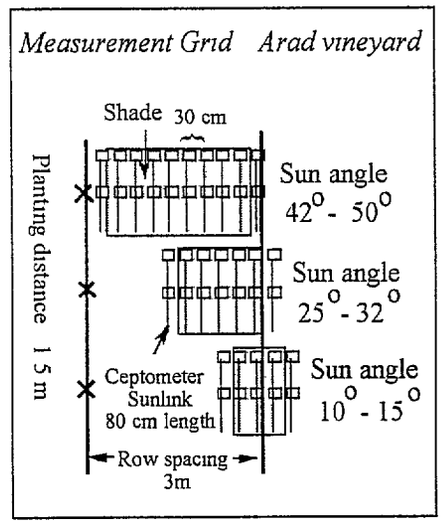


Figure 1 Schematic presentation of the measurement grid in the vineyard for LAI evaluation by GFI

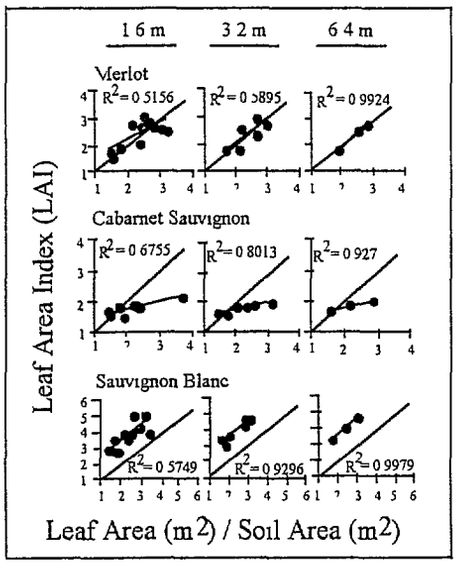


Figure 2 Direct and GFI measurements of LAI in the vineyard Direct measurements are from destructive sampling of 32 vines

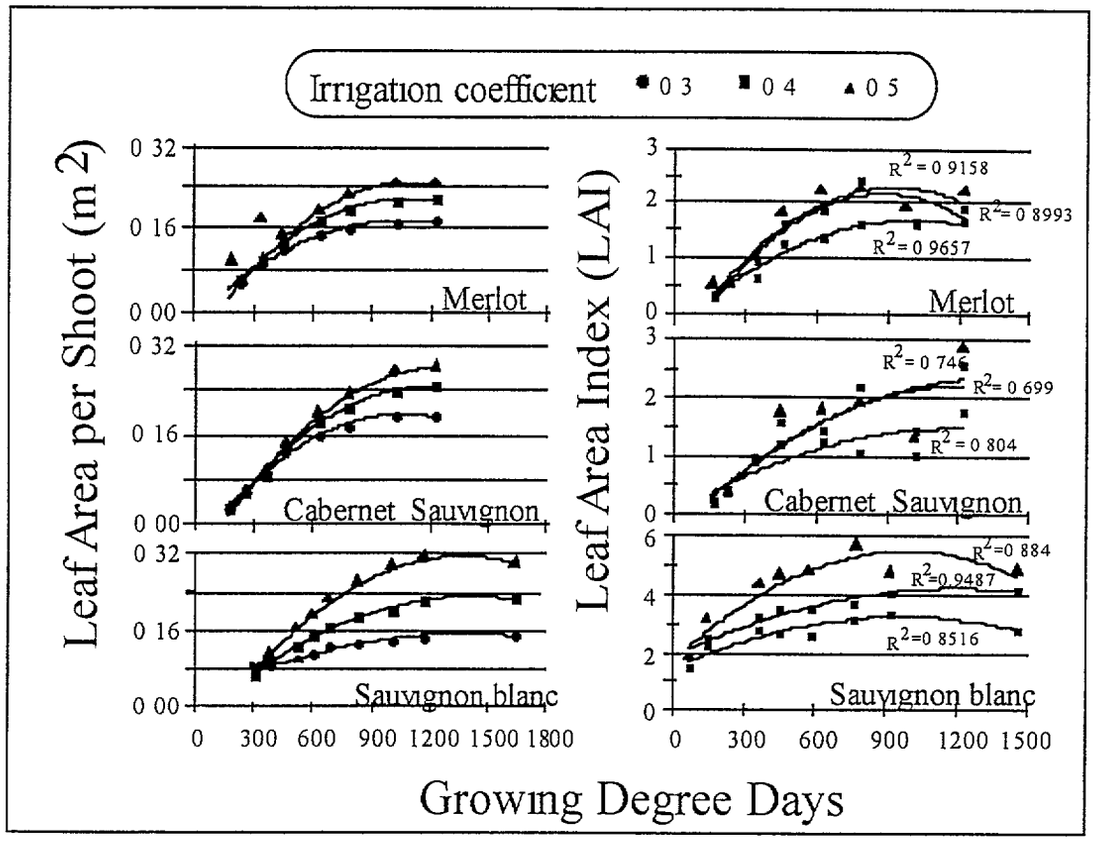


Figure 3 Shoot leaf area and LAI development during the growing season as a function of growing degree-days Shoot leaf area determined from leaf blade lengths, and LAI determined by GFI Symbols indicate pan A factor for irrigation