Project Number: 99-LS-o0

Final Report 2000

Almond Board of California

Measurement of Potential Tree Water Stress Effects on Almond Tree Growth and Yield

Larry Schwankl John Edstrom Ken Shackel Terry Prichard Jan Hopmans

Introduction

The 20-acre Marine Avenue almond planting of the Nickel's Soils Laboratory near Arbuckle, CA was established in 1990 to compare the response of 4 almond varieties (Butte, Monterey, Nonpareil, and Carmel) to irrigation by various microirrigation systems (surface drip, subsurface drip, and microsprinklers). A key component of the comparison has been to apply the same amount of water since planting with each of the different microirrigation systems. Thus, what is being compared is the response of the trees to the various microirrigation methods; not differences in the amount of applied water.

Previous years of investigation indicated that there was a strong trend toward a yield and tree growth advantage associated with use of microsprinklers. To investigate a possible cause of this difference - differential water stress among trees irrigated with different microirrigation methods - a project was undertaken during the summer of 1998. This project used the pressure bomb to measure the water status across the season of Nonpareil almond trees irrigated by various microirrigation systems (microsprinklers, surface drip, and subsurface drip).

During the 1999 growing season, the project was continued with some minor changes in the trees / microirrigation systems being monitored. In addition, detailed soil moisture monitoring (using a neutron probe) was done around a surface drip irrigated tree and around a microsprinkler-irrigated tree. The soil moisture monitoring was undertaken to draw comparisons between soil moisture information and leaf water potential measurements.

Experimental Procedures

To determine if there were different levels of water stress occurring between trees irrigated with different microirrigation systems, we monitored Nonpareil almond trees irrigated with surface drip (15 trees), double-line surface drip irrigated at 200% almond evapotranspiration (12 trees), microsprinklers (18 trees), and microsprinklers irrigated at 120% almond evapotranspiration (9 trees). The same trees were monitored weekly from May through September for midday leaf stem water potential using a pressure bomb device. Three trees in the same Nonpareil row in each monitored plot were measured (see fig. 1). In addition, a flow meter was installed in each of the lateral lines being monitored and flow meter readings, to determine applied irrigation water, were taken when leaf water potential was measured.

The majority of the trees monitored for leaf water potential during the 1999 season were also monitored during the 1998 season; except for the "double-line surface drip irrigated at 200% ET" treatment. This was a new treatment added to the Marine Ave. orchard in 1999 by converting the existing single-line subsurface drip treatment to double-line surface drip. The single-line subsurface drip treatment was experiencing significant root intrusion / emitter clogging problems resulting in the trees only receiving 70% of the applied water as compared to other treatments. The trees in the single-line, subsurface drip treatment have historically been lower yielding with smaller trunk crossectional areas. Conversion to a double-line surface drip treatment irrigated at 200% ET, will provide future information on the effect on almond yield and growth of "rehabilitating" trees by keeping them under very well-watered conditions.

Seasonal measurements of soil moisture were made around one surface drip-irrigated tree and around one microsprinkler-irrigated tree. Near the drip-irrigated tree, 25 neutron probe access tubes, 36" deep, were installed and monitored weekly. At the 36" depth, a dense soil layer occurs which restricts downward water movement and is too compacted to auger through. In a quarter quadrant of the microsprinkler-irrigated tree's planted area, 25 access tubes were installed in a 2-foot spaced grid to a depth of 30". At the microsprinkler tree site, the depth to the restricting layer was 30".

Results

Almond Growth and Yield

Tables 1 and 2 summarize the almond tree growth and yields at the Marine Ave. orchard. While the 1999 trunk crossectional area measurements have not been statistically evaluated for significance, the microsprinkler-irrigated trees continue to be somewhat larger than the drip-irrigated trees. The differences seem to be decreasing as the orchard has reached full canopy development.

At this time, only the 1999 Nonpareil trees' yield is available. There does not appear to be any significant difference between the 1999 yields for the various microirrigation treatments in the Nonpareil almonds. In fact, the microsprinkler treatment average is slightly (5%) less than the average yield of the surface drip irrigation treatment.

Irrigation and Tree Water Status

The seasonal water applications for the various microirrigation treatments and the estimated almond tree evapotranspiration (ET) are shown in fig. 2. The Marine Ave. field manager did an excellent job of matching the irrigations to the 1999 almond ET estimates (CIMIS). The microsprinkler and surface drip treatments put on nearly identical seasonal amounts of water. The seasonal irrigation applications were slightly greater (10%) than the almond ET estimates to account for irrigation inefficiencies. As harvest approached, irrigation applications were cut back slightly to aid in hull split.

Of particular interest is the double-line surface drip treatment irrigated at 200% of ET (surface drip 200% ET). This treatment was imposed in early June, 1999. Note on fig. 2 that the "surface drip 200% ET" treatment's plotted cumulative irrigation application began to exceed the other irrigation treatments' and the almond ET following the conversion.

Tree Water Status

Fig. 3 shows the midday leaf water potential measurements taken on a weekly basis at Marine Ave. The "Well-Watered CIMIS" line on fig. 3 denotes a theoretical leaf water status which reflects the weather conditions and represents a minimal to no water stress condition. Items of note in fig. 3 include:

1. Generally, none of the irrigation treatments exhibited elevated leaf water potential levels until the end of August. Greater pressure bomb measurements (more negative leaf water potential measurements) would indicate greater water stress in the tree. At the end of August, irrigation applications were slightly cut back to increase water stress to aid in hull split.
2. Even though water stress was imposed beginning at the end of August, it was not an extreme stress. The average pressure bomb measurements for both the surface drip and microsprinkler treatments remained below 15 bars.
3. The pressure bomb measurements for the trees in the double-line surface drip 200% ET treatments showed minimal stress throughout the season. The water applications of this treatment were reduced beginning at the end of August by shutting off one of the two lateral lines per tree row. It is likely that stored soil moisture supplemented irrigations through harvest and the trees did not exhibit increased (more negative) leaf water potential levels.

Figures 4 to 6 show the weekly pressure bomb measurements, the weekly irrigation amounts, and the weekly almond tree ET for the 1999 growing season. Three items of note in figs. 4 - 6 include:

1. It is evident that there is a very definite reflection of irrigation practices in leaf water potential measurements. Irrigating at less than tree ET estimates results in increased pressure bomb measurements (greater water stress), and vice versa.
2. The previous observation holds for time periods other than the end of the season (mid-August on). Leaf water potentials rose (became more negative) at the end of August even though irrigations matched ET estimates. These leaf water potentials were still not exceptionally high (12 bars or less). It was not until the beginning to mid-September when pressure bomb measurements rose to near 15 bars. This was due to the intentional under-irrigation imposed at that time.
3. The irrigation amounts for the double-line surface drip 200% ET treatments (fig. 6) were much greater (approximately double) that of the almond ET estimates through much of the season. It wasn't until the beginning of September that almond ET exceeded irrigations. This intentional under-irrigation did not result in increased leaf water potentials though. It is likely that there were substantial soil moisture reserves for the tree to draw on during this period of under-irrigation.

Soil Moisture Measurements

Soil moisture measurements were taken on a weekly basis around both a microsprinkler-irrigated tree and one irrigated by surface drippers. At both trees, a grid of neutron probe access tubes (25 access tubes per tree) were installed and measurements taken at 6-inch depth increments. The access tubes were installed to the depth at which a highly compacted, restricting layer was reached - 36 inches at the surface drip-irrigated tree, and 30 inches at the microsprinkler-irrigated tree.

Much of the season's neutron probe information is still being evaluated, but figs. 7 and 8 show the seasonal change in soil moisture within the monitored soil volumes. There are a number of observations of note on figs. 7 and 8.

1. Soil moisture reserves decreased across the season for both the surface drip and microsprinkler treatments. Much of this soil moisture depletion occurred in the soil volumes not being refilled by the drippers or microsprinkler.
2. Irrigations exceeding almond ET during a week period resulted in an increase in the stored soil moisture. The opposite was also true. Work is on-going investigating where in the root zone (depth and position relative to the tree) soil moisture is being depleted and refilled across the season.
3. During the season, the amount of stored soil moisture relative to the early season, fully recharged, soil moisture condition, decreased to a greater extent around the surface drip irrigated trees than it did around the microsprinkler-irrigated tree. The microsprinkler system has a larger wetted area (and volume) than does the drip system. Soil moisture measurements indicate that the drippers actually keep the soil wetter in the volume they recharge than does a microsprinkler, but that wetted volume is smaller for a drip system.

Summary Comments

1. Now that the Marine Ave. orchard canopy has reached full cover, it appears that there is less difference in almond production between the microsprinkler- and drip-irrigated trees.
2. Even though the irrigation intervals during the peak water use periods differ for the drip-irrigated (daily irrigations) and the microsprinkler-irrigated (3-day interval) trees, the leaf water potential levels remain nearly the same. There was no difference across the season in tree water stress between the microsprinkler- and surface drip-irrigated trees.
3. Preliminary analysis of leaf water potential and neutron probe measurements indicate that a 3-day irrigation interval between mid-summer microsprinkler irrigation is appropriate. Extending the irrigation interval to 4 days or longer, under the low waterholding capacity

soil conditions at Marine Ave., resulted in increased pressure bomb levels (increased water stress levels).

4. The double-line surface drip 200% ET treatment very effectively minimized tree water stress, but it over-irrigated the trees. In addition, the orchard floor in the 200% ET plots was wet enough that it made it difficult to do other orchard cultural tasks (e.g. spraying) in the plots.

   The 1999 yield and trunk crossectional areas for the 200% ET treatment trees remained significantly below those of the other treatments. This was a residual effect of the previous single-line subsurface drip system. It will be interesting to see if those trees can be brought up in future years to the same size and yield levels as the rest of the orchard through good water management.
5. Root intrusion has definitely become a problem in the subsurface drip products which are not trifluralin-impregnated. Discharge rates in the subsurface drip tubing experiencing root intrusion have dropped by 30% or more. The trifluralin-impregnated drip tubing has not suffered a drop in discharge rate and there is no evidence of root intrusion problems.

The authors would like to express their appreciation to Stan Cutter, Nickel's Soils Lab Field Manager, for his excellent assistance.

Table 1. Mean almond tree trunk crossectional area (square inches) by irrigation treatment and almond variety for 1994 - 1999. Statistical comparison of mean trunk diameters done by variety and by year. Numbers followed by the same letter are not significantly different at the 5% level.

1994

Irrigation Treatment		**Almond Variety**		
	Carmel	**Butte**	**Nonpareil**	**Monterey**
Surface drip	17.7 *b*	22.2 *b*	20.3 *c*	21.2 *a*
Microsprinklers	19.2 *a*	24.3 *a*	24.3 *a*	21.7 *a*
Subsurface drip	17.1 *b*	22.2 *b*	21.3 *b*	21.4 *a*

1995

Irrigation Treatment		**Almond Variety**		
	Carmel	**Butte**	**Nonpareil**	**Monterey**
Surface drip	23.0 *b*	33.8 *b*	29.8 *b*	28.7 *b*
Microsprinklers	26.0 *a*	37.5 *a*	31.8 *a*	35.6 *a*
Subsurface drip	24.4 *b*	35.3 *b*	29.8 *b*	29.4 *b*

1996

Irrigation Treatment		**Almond Variety**		
	Carmel	**Butte**	**Nonpareil**	**Monterey**
Surface drip	30.9 *b*	44.6 *b*	40.0 *b*	36.2 *b*
Microsprinklers	35.6 *a*	52.9 *a*	43.4 *a*	48.9 *a*
Subsurface drip	30.4 *b*	46.7 *b*	38.1 *b*	36.7 *b*

1997

Irrigation Treatment		**Almond Variety**		
	Carmel	**Butte**	**Nonpareil**	**Monterey**
Surface drip	35.9 *a*	52.0 *b*	47.2 *b*	41.6 *b*
Microsprinklers	38.2 *a*	55.9 *a*	49.7 *a*	53.4 *a*
Subsurface drip	36.7 *a*	48.4 *c*	45.8 *b*	39.7 *b*

1998

Irrigation Treatment		**Almond Variety**		
	Carmel	**Butte**	**Nonpareil**	**Monterey**
Surface drip	39.6 *a*	56.4a	52.6 *b*	46.9 *a*
Microsprinklers	45.2 *b*	65.0 *b*	55.2 *b*	60.5 *b*
Subsurface drip	39.9 *a*	55.8 *a*	49.4 *a*	46.0 *a*

1999

Irrigation Treatment		**Almond Variety**		
	Carmel	**Butte**	**Nonpareil**	**Monterey**
Surface drip	46.0	62.7	56.2	49.8
Microsprinklers	47.7	71.0	58.0	64.0
Subsurface drip	44.6	61.1	51.7	49.0

Table 2. Almond dry nut yields (lbs/acre) by almond variety and irrigation treatment. Statistical comparison of yield was done by variety and by year. Numbers followed by the same letter are not significantly different at the 5% level.

Almond Yield (lbs/acre)

1994

Irrigation Treatment	Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip		1047 *b*	1053 *c*	
Microsprinklers		1543 *a*	1532 *a*	
Subsurface drip		1235 *b*	1234 *b*	

1995

Irrigation Treatment	Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip	752 *a*	745 *a*	920 *a*	1293 *a*
Microsprinklers	715 *a*	726 *a*	983 *a*	1332 *a*
Subsurface drip	873 *a*	701 *a*	639 *b*	1241 *a*

1996

Irrigation Treatment	Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip	1777 *a*	1924 *a*	2362 *a*	2492 *a b*
Microsprinklers	1748 *a*	2276 *b*	2708 *a*	2884 *a*
Subsurface drip	1673 *a*	1845 *a*	2350 *a*	2231 *a b*

1997

Irrigation Treatment	Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip	2002 *a*	2468 *a*	1991 *a*	1948 *a b*
Microsprinklers	1888 *a*	2513 *a*	2179 *a*	2252 *a*
Subsurface drip	1829 *a*	2422 *a*	1846 *a*	1714 *b*

1998

Irrigation Treatment	Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip	1726 *a*	2822 *a*	2419 *ab*	2244 *a*
Microsprinklers	1891 *a*	2984 *a*	2736 *b*	2270 *a*
Subsurface drip	1601 *a*	2768 *a*	2339 *a*	1958 *a*

1999

Irrigation Treatment	Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip	2155 *a*	2657 *b*	2688 *a*	2384 *a*
Microsprinklers	2134 *a*	2303 *a*	2530 *a*	2273 *a*
Subsurface drip	2123 *a*	2326 *a*	2430 *a*	2277 *a*

Figure 1.

Pump and Filters

Nickel's Soils Laboratory - Marine Ave. Orchard
Irrigation System Layout - 1996

5/99

B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M
PB1 Surface Drip PB2 1 PB3 FM1	Double Micro- Sprinklers 2	Dbl-Line PB10 Surf. Drip 8 gph/tree 200% ET PB11 3 PB12 FM4	PB27 Micro- Sprinklers PB26 4 PB25 FM9	Geoflow Sub-drip Double-line 4' from Tree 5 FM10A	Double-line Surface Drip 6	PB40 Surface Drip PB41 7 PB42 FM14	Double PB51 Micro- Sprinklers 1.2X PB50 8 PB49 FM17	Netafim Sub-drip Double-line 4' from Tree 9
FM2 Double PB4 Micro- Sprinklers 1.2X PB5 10 PB6	FM3 PB9 Dbl-Line Surf. Drip 8 gph/tree 200% ET PB8 11 PB7	Double-line Surface Drip 12	FM9A Geoflow Sub-drip Double-line 4' from Tree 13	FM10 PB28 Surface Drip PB29 14 PB30	Double Micro- Sprinklers 15	FM14A Netafim Sub-drip Double-line 4' from Tree 16	FM14B Double-line Surface Drip 10 gph/tree 100% ET 17	FM18 PB52 Micro- Sprinklers PB53 18 PB54

B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M	B N C B N M
Netafim Sub-drip Double-line 4' from Tree 19	Double Micro- Sprinklers 20	PB13 Surface Drip PB14 21 * PB15 FM5	PB24 Dbl-Line Surf. Drip 8 gph/tree 200% ET PB23 22 PB22 FM8	PB31* Micro- Sprinklers PB32 23 PB33 FM11	Double-line Surface Drip 24	PB43 Micro- Sprinklers PB44 25 PB45 FM15	Geoflow Sub-drip Double-line 4' from Tree 26 FM16A	Double-line Surface Drip 27
Netafim Sub-drip Double-line 4' from Tree 28	Double-line Surface Drip 10 gph/tree 100% ET 29	FM6 Double PB16 Micro- Sprinklers 1.2X PB17 30 PB18	FM7 PB21 Surface Drip PB20 31 PB19	FM12 PB34 Micro- Sprinklers PB35 32 PB36	FM13 PB39 Dbl-Line Surf. Drip 8 gph/tree 200% ET PB38 33 PB37	FM15A Geoflow Sub-drip Double-line 4' from Tree 34	FM16 PB48 Micro- Sprinklers PB47 35 PB46	FM19 Surface Drip 36

B = Butte
N = Nonpareil

C= Carmel
M = Monterey

Tree Spacing = 16' x 22'
124 Trees / acre

Total area = 21.7 acres
Block = 11 trees long (180') by six trees wide (132')

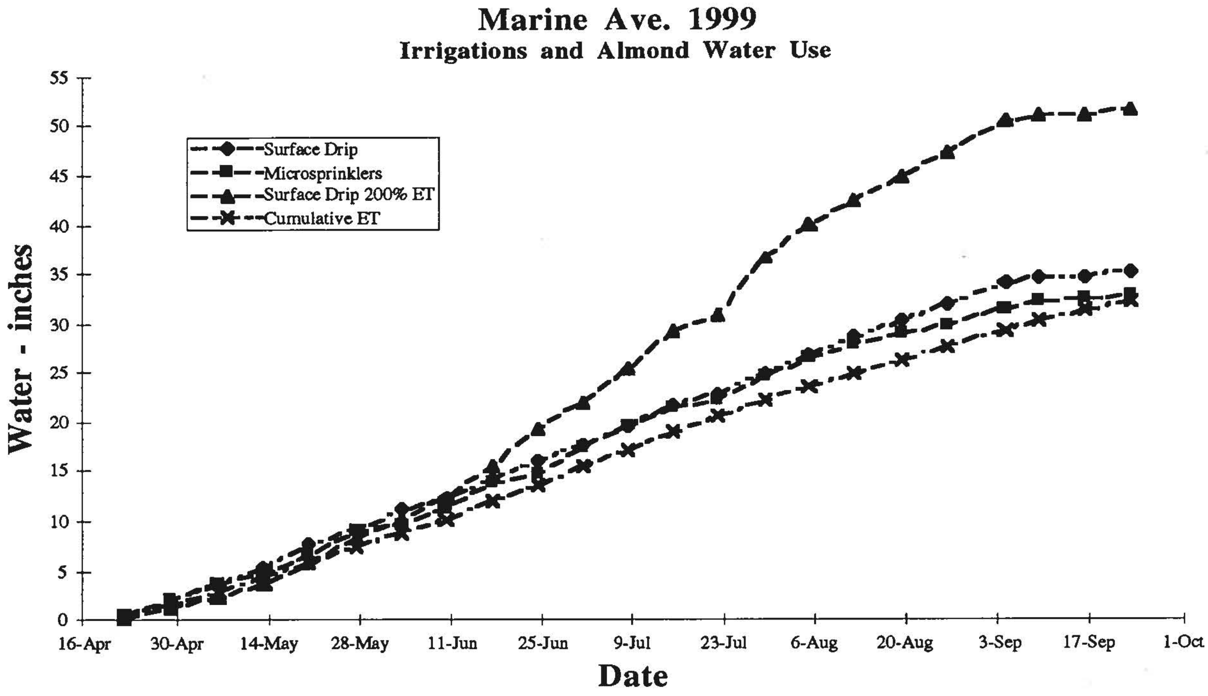

Fig. 2. Applied irrigation water and almond tree evapotranspiration at Nickel's Soils Lab - Marine Ave. orchard.

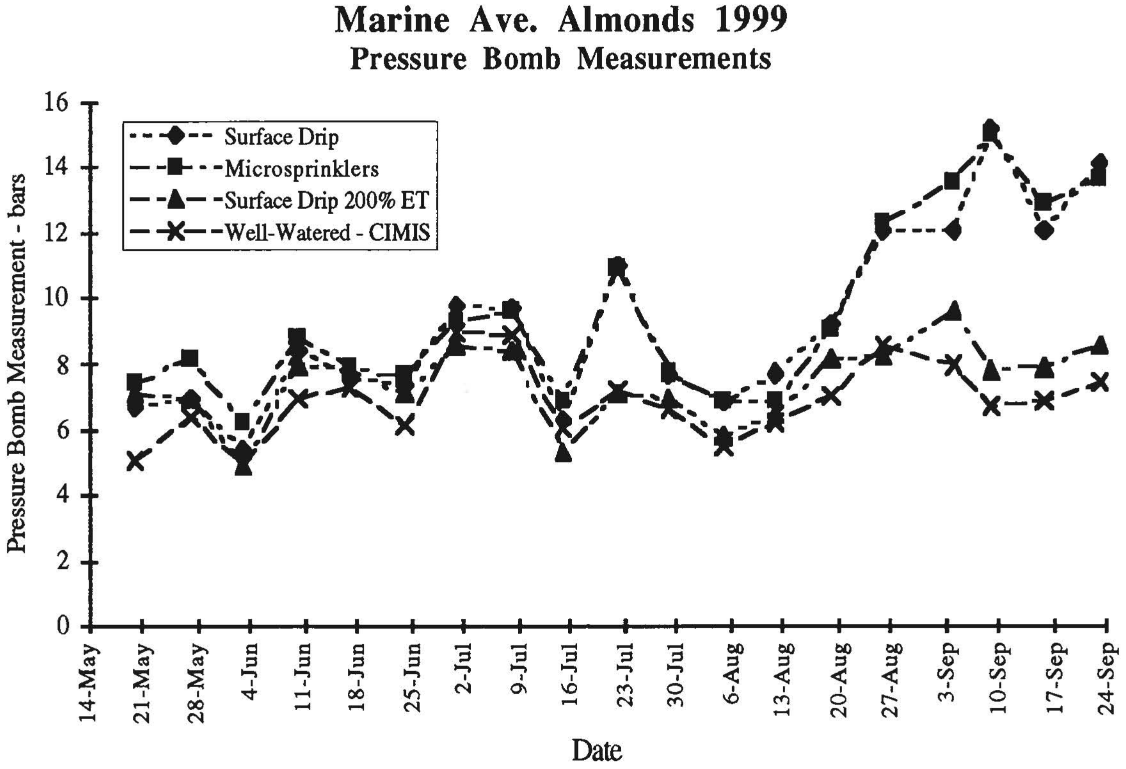

Figure 3. Pressure bomb measurements at the Nickel's Soils Lab - Marine Ave. orchard.

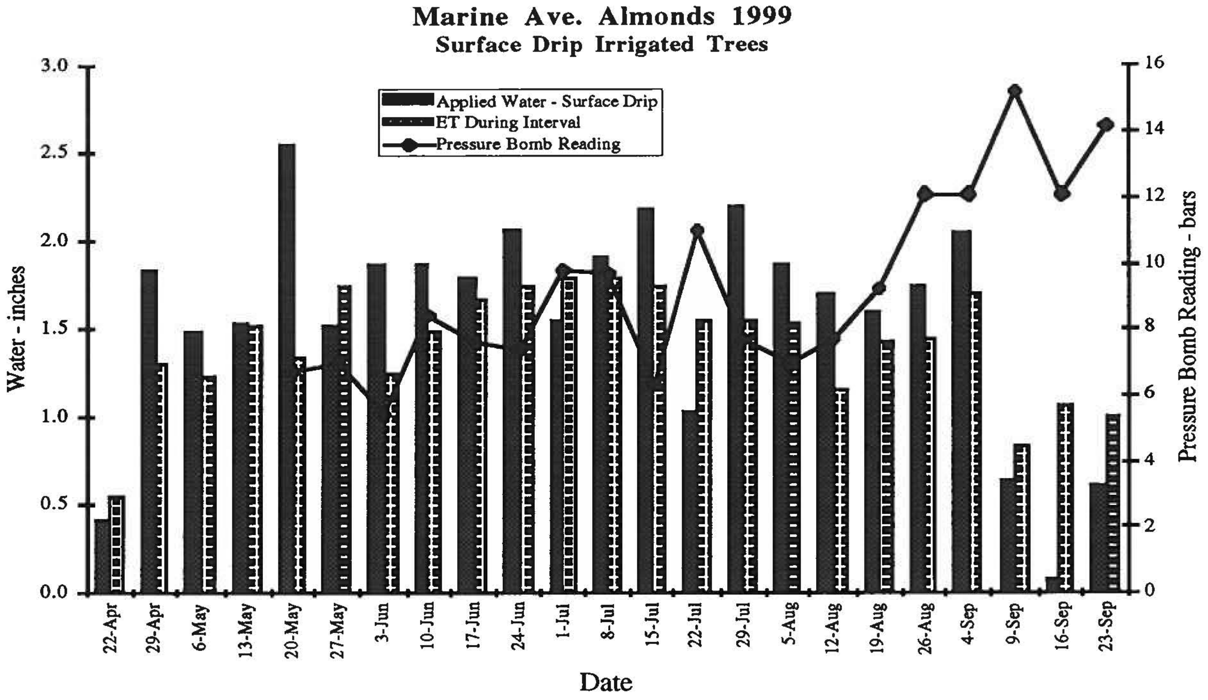

Fig. 4. Applied water, almond tree ET, and pressure bomb readings for the surface drip irrigation treatment at the Nickel's Soils Lab - Marine Ave. orchard.

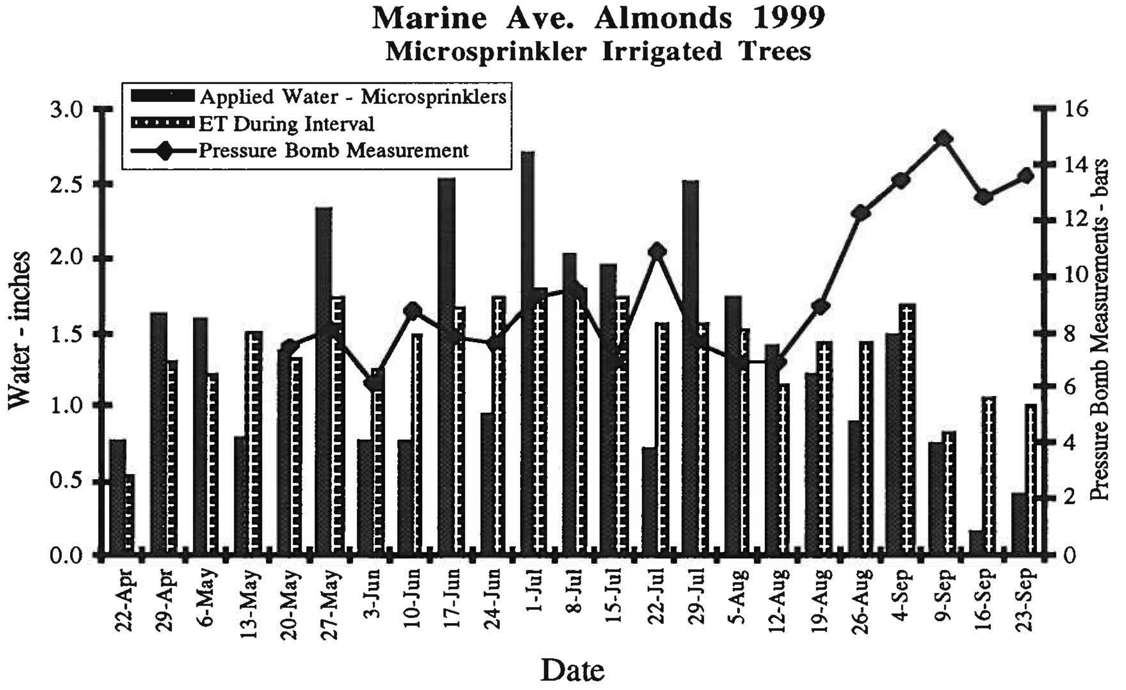

Fig. 5. Applied water, almond tree ET, and pressure bomb readings for the microsprinkler irrigation treatment at the Nickel's Soils Lab - Marine Ave. orchard.

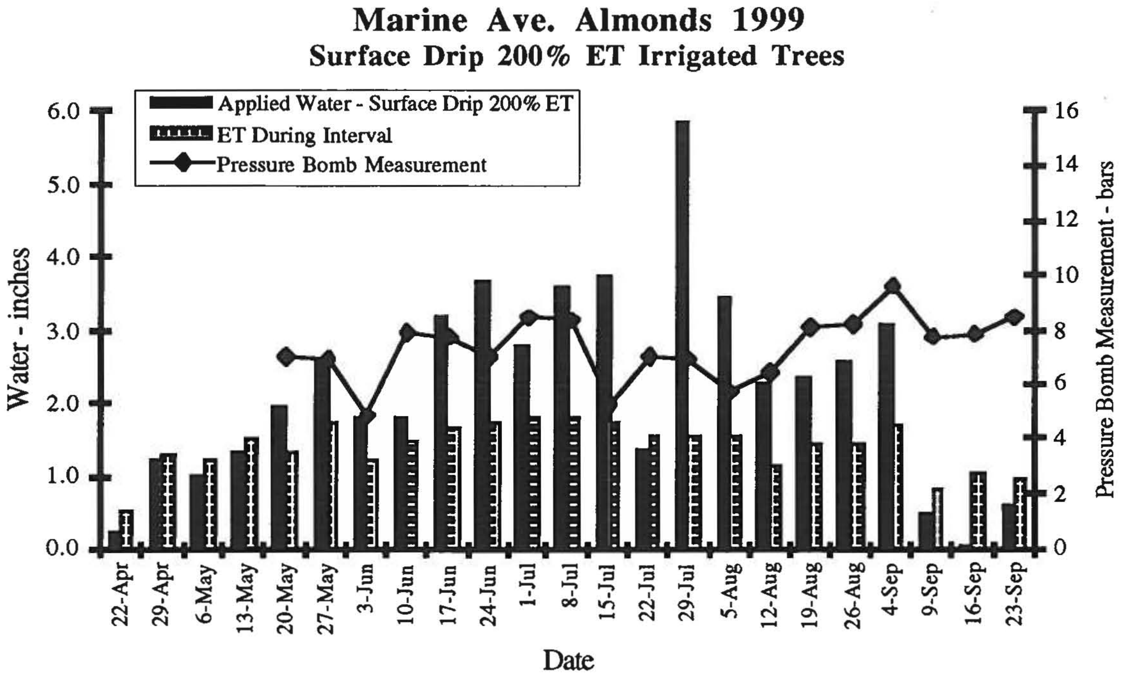

Fig. 6. Applied water, almond tree ET, and pressure bomb readings for the double-line surface drip 200% ET irrigation treatment at the Nickel's Soils Lab - Marine Ave. orchard.

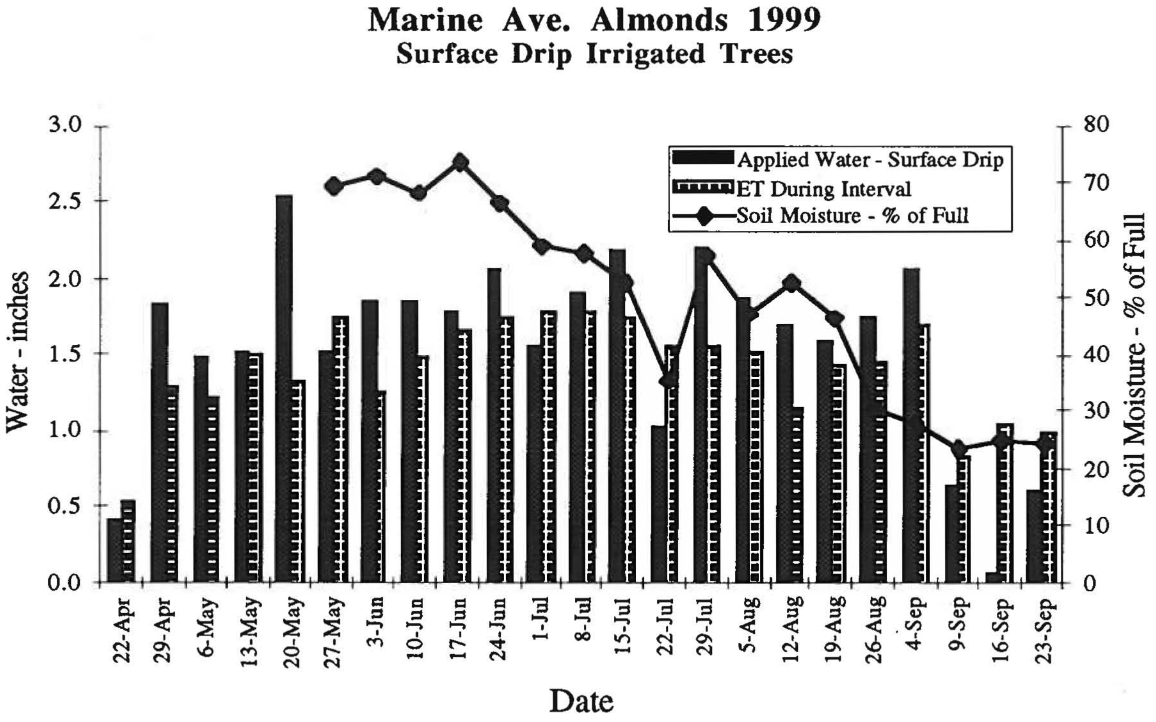

Fig. 7. Applied irrigation water, almond tree ET, and soil moisture for the drip irrigated treatment at the Nickel's Soils Laboratory - Marine Ave. orchard.

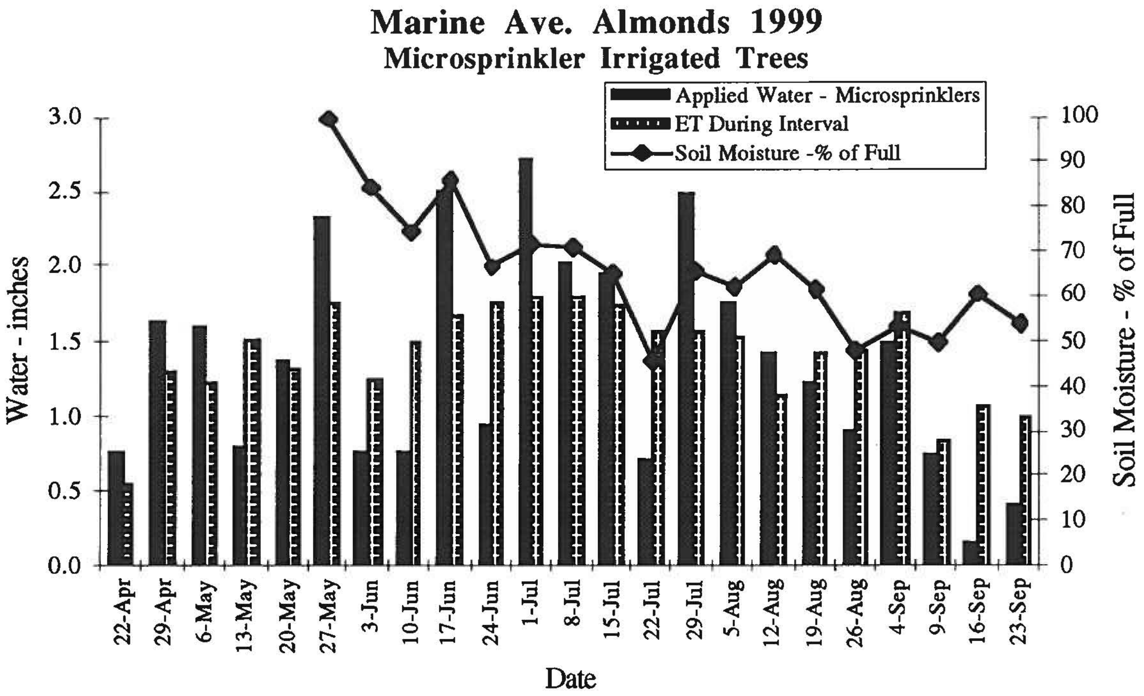

Fig. 8. Applied irrigation water, almond tree ET, and soil moisture for the drip irrigated treatment at the Nickel's Soils Laboratory - Marine Ave. orchard