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Economic Analysis of Irrigation and Fertilization Management of Avocados

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***Abstract*. The effect of integrated applications of various irrigation and fertilization rates on productivity (yield and size) and returns of the 'Hass' avocado (*Persea americana* Mill.) have been analyzed from 1987 to 1991 in western Riverside County. Eighteen treatment combinations comprised of three irrigation levels [80%, 100%, and 120% crop water use (ETc)], three N fertilizer levels (0.16, 0.7, and 1.4 kg/tree per year), and Zn (0 and 0.2 kg/ tree per year) were included in the analysis. Using a partial budgeting procedure, returns after costs were calculated for each treatment combination. Costs of treatments, harvesting, hauling, and marketing were subtracted from the value of the crop. The value of the crop was calculated as the sum of crop returns in each size category. Three years of data on the relationship between irrigation and N showed 1) irrigating at 80% ETc would be ineffective even at very high water prices; 2) for groves where 100% ETc is sufficient, its application with either low or medium N would be beneficial; and 3) at higher irrigation (120% ETc), N application should be at or beyond the medium level.**

To avocado growers, water costs have increased significantly in most southern California production areas. Furthermore, the increasing urban demand for water has created concern about further water cost increases and reduced profit in agriculture. Some growers have been toying with the idea of minimizing costs by increasing fertilizer for reduced water use or maximizing productivity and returns through increased use of fertilizer and water. However, neither the relationship of yield to evapotranspiration nor the interrelationship of fertilizer and water use in avocado production are understood well enough to support the suggested economic implications.

Previous studies in San Diego and Ventura counties, Calif., analyzing the effects of variable N fertilization on 'Hass' avocado productivity have shown that yields of 'Hass' appear to be less sensitive than yields of 'Fuerte'. Also, the evidence did not indicate that a high level of N nutrition would reduce yields of 'Hass' as it did with 'Fuerte' (Embleton et al., 1968).

Another study dealing with the effect of irrigation on tree canopy size and trunk circumference in San Diego County showed significant differences in tree dimensions between cultivars. However, differences were insignificant between irrigation methods (Gustafson et al., 1979). In the same study, a comparison in evaporation loss between water application methods showed a water saving of 24% to 69% by the drip over the high-volume sprinkler system. Although it is understood that the drip system requires more labor and management for frequent check up and control of the system, the estimated savings exceed the expenses (Benoit and Takele, 1986).

Our paper analyzes the effect of integrated applications of low-volume sprinkler (sometimes referred as drip trickle irrigation) with N and Zn fertilization on 'Hass' avocados. We endeavored to determine the optimum combination of irrigation and fertilizer that would maximize returns using various water costs; thus, we evaluated several alternatives using a partial budgeting process.

Materials and Methods

In 1987, we started an experiment on mature (8-year-old) 'Hass' avocado trees on seedling rootstocks in western Riverside County, Calif., using a randomized complete-block design with irrigation as the main plot and N and Zn as split plots. The analysis included determining the relationship between the amount of water and fertilizer application on productivity (yield and size) and returns. Three irrigation, three N, and two Zn treatments (+ or –) were involved, creating 18 (3 × 3 × 2) combinations (see Table 1). Each of these treatments involved 11 trees.

The treatment applications and examination of effects were performed regularly. Meyer et al. (1990) published descriptions of the experimental plan and treatment protocols we used in this study. To summarize these aspects briefly, the irrigation system included low-volume sprinklers (one sprinkler per tree) using heads, located within 5 cm of the tree trunk, that delivered 23 liters water/h. The radius of the wetted pattern averaged 1.83 m. The system was monitored to give a distribution uniformity (DU) of >90%. DU was measured twice a year and averaged 92% during the experiment (Meyer et al., 1990).

Three irrigation levels [80% crop water use (ETc) = low, 100% ETc = medium, and 120% ETc = high] were selected. ETc was determined weekly using the equation ETc = ETo × Kc. ETo (evapotraspiration) levels were determined daily from California Irrigation Management Information System (CIMIS) at the Univ. of California–Riverside and other local weather stations and are correlated to tensiometer and neutron probe site readings (Richards and Marsh, 1961). Crop coefficient (Kc) was determined with 100% ETc, based on soil matrix potential not exceeding 30 kPa in the soil root zone of 12 to 45 cm. All of the trees were irrigated simultaneously for 24 h. The total amount of water applied per annum per hectare was ≈610, 710, and 810 ha-mm for the 80%, 100%, and 120% ETc, respectively.

Nitrogen was applied to individual trees four times (April or May, July, September, and November) during each year. The N applications included urea at 0.16 (N0), 0.7 (N1), and 1.4 kg (N2)/tree per year. Zinc was applied as a foliar spray at 0 or 0.2 kg/tree per year. Leaf tissue analysis was performed annually for each tree in September.

The economic analysis was done for the years 1989 through 1991. Each year, productivity (yield and size), total returns (TR) (i.e., crop value), and partial net returns (PNR) (i.e., returns after costs) were determined for each tree. Multiple harvests were made each year, commencing when fruit reached minimum maturity, which is defined by oil content. Oil content is determined by measuring dry weight,

Table 1. Description of irrigation and fertilization treatments for avocado trees.

Treatment no.	Irrigation ETc[z]	N level[y]	Zn level[x]
1	80	0	–
2	80	0	+
3	80	1	–
4	80	1	+
5	80	2	–
6	80	2	+
7	100	0	–
8	100	0	+
9	100	1	–
10	100	1	+
11	100	2	–
12	100	2	+
13	120	0	–
14	120	0	+
15	120	1	–
16	120	1	+
17	120	2	–
18	120	2	+

[z]Irrigation levels: 80% crop water use (ETc) = low, 100% ETc = medium, and 120% ETc = high.
[y]Nitrogen levels (kilogram per tree per year): 0.16 (N0 or low), 0.7 (N1 or medium), 1.4 (N2 or high);
[x]Zinc levels at 0 or 0.2 kg/tree per year.

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which is highly correlated with increasing oil content. Dry weight standard for acceptable flavor for 'Hass' is 22.8% (Lee et al., 1983). For the early harvests, fruit were harvested based on size (minimum fruit weight of 230 g). Harvesting usually commenced in November and was completed in June or July. Because the harvest from 11 trees was not sufficient to get packinghouse statements for the individual treatment combination, we designed a small-scale fruit grading procedure that used a sample of fruit. Each year, a large sample (using 50% of an individual tree's crop) of the harvest was graded according to packinghouse standards (i.e., each fruit from the sample was weighed and classified by size group). Then, the total crop weight was allocated according to the sample data.

Our packing process excluded no. 2 or standard fruit. From previous records, we learned that the emphasis has been on size rather than grade, and very little of the crop traditionally has been classified as no. 2 in the industry. Therefore, we did not concern ourselves in making grade distinctions. The economic analysis used a partial budgeting procedure, which means only additional costs were estimated for each treatment, while holding constant all other inputs that affect the treatments equally. These additional costs then were subtracted from the returns of each treatment. The residual return (PNR) was used to compare treatments and was calculated as follows:

$$PNR = TR - \text{costs (water + N + Zn)} - H_c(Y) - P_c(Y) - CAC\{0.04 \times [TR - H_c(Y)]\} \quad [1]$$

where TR is total return, N and Zn are costs of N and Zn fertilizers, H_c is harvesting cost per kilogram, Y is total yield (kilogram per treatment), P_c is packing cost per kilogram, and CAC is California Avocado Commission assessments fee.

Each year the TR for each treatment was calculated as the sum of the product of the amount of fruit in each size category multiplied by the corresponding prices. TR was calculated as $TR = \sum_{i=1}^{8} P_i S_i$, where P_i is the price of i^{th}-size fruit per kilogram, and S_i is the actual quantity of the i^{th}-size fruit in kilogram. Prices and volume information were obtained from the CAC computer database Avocado Marketing Research Information Center. This database provides daily prices and volumes shipped in each region. Annual weighted average prices for southern California were used for each size group.

The treatment costs included the material and application of water and fertilizer (urea and $ZnSO_4$). The amount of material of each input was multiplied by its annual average price. Input prices were obtained from various sales companies for the respective inputs in southern California. Application costs were obtained from growers. Interest on operating capital was charged at 10.2%, an average rate for short-term operating loans issued by several banks in the project region.

Harvesting and marketing costs are functions of yield; therefore, they vary with the productivity level. We used the annual average for the harvesting charges of picking and hauling (13¢ and 4¢/kg, respectively). The marketing costs, including packing at 15¢/kg and the CAC assessments, were calculated at 4% of the gross returns minus harvesting costs. Because water costs vary depending on elevation and location, returns were evaluated at various water prices.

Results

Choosing the most profitable production practices among several alternatives requires distributing each treatment's yield among sizes, evaluating the TR at the corresponding prices, and deducting the corresponding treatment costs.

A tremendous yield variability was indicated among treatments within a year and within treatments from one year to the next (Table 2). Because of the alternate bearing characteristic of avocados, which implies that in any given year some trees will be naturally yielding well and some poorly, it is difficult to distinguish the treatment effect in any single year. Our analysis used data from three consecutive years so that the productivity differences affected by the alternate bearing characteristic would be minimized and treatment effects would be expressed.

Average yield ranged from a low of 15 kg/tree to a high of 26 kg/tree (Table 2). High-yielding treatments (for example, in the top five) were those in 100% and 120% ETc. Most of the low-yielding treatments were in the 80% ETc. The 100% ETc (from the top five treatments) yielded better with N0 and N1 than with N2. The 120% ETc (from the top five treatments) showed N1 or N2 to provide better yield than N0. No Zn application was required with either 100% or 120% ETc.

Fruit size varied from year to year (Table 3). The 1989 crop was dominated by larger size fruit (48s and larger), whereas the 1990 crop was dominated by 60s and 70s. Size 60s dominated in 1991. When Meyer et al. (1990) performed a similar study, they performed analyses of variance to test for significant differences in fruit size among treatments. Means were compared using F values. We showed that increases in irrigation increased fruit size, particularly as we moved from 80% to 100% ETc. No size effect was demonstrated by either N or Zn application. There also were no significant interactive size effects of any combination.

Prices received for each size varied across the three years (Table 4). This means that those sizes receiving the highest prices in 1989 were not necessarily the highest priced sizes in 1990 or in 1991. Thus, to capture the effect of price and size variability, the annual crop value for each treatment (Eq. [1]) was calculated and averaged over the three years. The same five high-yielding treatments provided the highest TR (Table 5); however, due to the effects of varying sizes and prices, the order of the highest TR treatments was not the same as the highest-yielding treatments. Again, the five highest-yielding treatments provided the five highest PNR (Table 6). The water price used in this table was \$1 ha·mm^{-1}. The treatment combinations included 100% ETc with N0 and N1 and 120% ETc with N1 and N2. Most of the 80% ETc treatments were in the lower end of yield and returns.

Discussion

Crop returns are determined by yield, size, and the corresponding price variations. Therefore, a treatment with the highest yield would not necessarily yield a higher return. This fact can be demonstrated by comparing treatments 7 (100% ETc, N0, Zn–) and 15 (120% ETc, N1, Zn–). Although treatment 15 yielded more than treatment 7, TR was similar for the two treatments (Table 5). This relationship is even more obvious when comparing treatments 9

Table 2. Average avocado yield per tree by treatment (treatments ranked by overall average) from 1989 to 1991.

Treatment	Yield (kg/tree)			
	Year of harvest			
no.	1989	1990	1991	Overall
15	35.97	23.80	15.54	26.06
7	21.67	43.74	6.18	25.63
9	39.70	19.46	13.88	25.39
17	8.76	45.97	6.60	21.83
14	18.13	31.64	11.76	21.39
1	19.94	34.28	2.16	20.46
18	19.45	28.35	6.33	19.21
10	15.16	31.22	6.13	18.64
16	3.52	39.50	8.06	17.93
6	8.51	37.36	3.94	17.87
13	5.85	29.49	16.89	17.46
8	12.24	28.50	6.29	16.62
4	18.30	25.92	0.98	16.48
12	24.21	16.53	4.73	16.20
2	17.80	22.29	4.71	15.96
5	11.42	29.35	1.55	15.36
3	17.28	22.73	2.43	15.32
11	20.85	17.04	4.02	14.97

Table 3. Percentage distribution of avocado fruit size from 1989 to 1991.

	Fruit in class (%)						
	Size[z]						
Year	84	70	60	48	40	32	28
1989	2.76	14.96	25.83	41.14	13.39	1.40	0.52
1990	7.02	31.37	31.85	25.13	4.29	0.37	0.09
1991	2.93	23.71	44.67	26.33	2.15	0.22	0.00
Average	5.04	24.58	30.92	31.13	7.42	0.74	0.24

[z]Sizes are based by weight of fruit in grams. Weights are 99 to 135 for 84s, 135 to 177 for 70s, 177 to 213 for 60s, 213 to 269 for 48s, 269 to 326 for 40s, 326 to 354 for 36s, and 354 to 397 for 32s.

Table 4. Prices per kilogram of 'Hass' avocado for southern California region from 1989 to 1991 by fruit size[z].

Treatment size	Price ($/kg) Year of harvest 1989	1990	1991	Overall
20	0.80	1.27	0.85	0.88
24	0.85	1.20	1.02	0.93
28	0.90	1.19	0.75	0.92
32	1.13	1.32	0.86	1.05
36	1.09	1.28	0.89	1.04
40	1.02	1.26	0.95	1.04
48	0.92	1.27	1.01	1.03
60	0.78	1.16	0.96	0.93
70	0.64	1.00	0.91	0.81
84	0.44	0.83	0.72	0.61

[z]Sizes are based by weight of fruit in grams. Weights include 99 to 135 for 84s, 135 to 177 for 70s, 177 to 213 for 60s, 213 to 269 for 48s, 269 to 326 for 40s, 326 to 354 for 36s, and 354 to 397 for 32s.

Table 5. Average total returns (TR) per avocado tree by treatment from 1989 to 1991 (treatments listed from highest to lowest by overall average).

Treatment no.	TR ($/kg) Year of harvest 1989	1990	1991	Overall
7	40.36	105.41	12.75	56.85
15	69.00	61.38	3.18	56.66
17	16.59	111.38	13.79	50.60
9	72.01	45.59	27.98	50.58
14	34.00	75.46	24.48	46.66
1	38.06	82.15	4.37	45.24
16	6.15	100.72	17.10	43.74
10	26.20	79.14	12.93	42.07
18	36.40	68.47	13.18	41.97
13	10.17	77.21	35.96	41.63
6	14.61	89.43	8.17	40.33
8	23.87	69.66	12.99	37.76
4	37.30	60.34	2.02	36.34
12	45.68	41.55	9.95	34.64
5	21.56	69.22	3.22	34.15
2	31.08	50.97	9.57	32.64
11	39.49	43.22	8.63	32.63
3	30.55	50.31	5.09	31.01

Table 6. Average partial net returns (PNR) per avocado tree by treatment from 1989 to 1991 (treatments listed from highest to lowest by overall average).[z]

Treatment no.	PNR ($/kg) Year of harvest 1989	1990	1991	Overall
7	28.67	83.98	7.18	43.22
15	50.55	47.17	22.78	41.91
17	8.60	87.56	6.61	37.02
9	52.71	33.89	18.79	36.77
14	23.01	58.44	15.94	34.22
1	27.49	65.18	0.90	34.11
16	0.49	79.63	9.54	31.92
13	4.33	61.03	25.52	30.77
10	16.46	62.08	6.63	30.56
18	23.94	51.84	5.90	29.36
6	7.50	69.99	2.79	29.16
8	15.67	54.37	7.15	27.59
4	26.56	46.21	–1.71	26.23
5	13.45	53.40	–0.96	24.26
12	31.79	30.31	3.79	23.78
2	21.27	38.90	4.85	23.36
11	27.15	31.96	2.97	22.47
3	20.63	37.83	0.98	21.70

[z]Partial net returns evaluated at $1.00/ha per mm of water.

(100% ETc, N1, Zn–) and 17 (120% ETc, N2, Zn–). Treatment 9 yielded 11% more than treatment 17, but their TRs were nearly identical, which reflects the importance of crop size distribution and the corresponding price variation in determining crop value. Thus, if a treatment yields well but does not produce the favored sizes at the time, its gross returns could be lower than that with less yield and desirable sizes.

Size and price. Using any one year, we can explore the relationship between size, price, and gross returns. We use only 1 year of data to minimize the effect of supply and demand conditions on the prices, i.e., to ensure that the variations in prices are primarily associated with size and not changing market conditions.

For illustration, we use treatments 6, 7, and 15 during the 1989 season (Table 7). By dividing TR by the total yield, we obtained the weighted average price per kilogram of avocado for each treatment. The differences in the weighted average price can be used as a proxy to reflect the differences in the size distribution among the treatments. The results for the selected treatments showed that treatment 6 has a weighted price of $1.72, while treatments 7 and 15 have higher weighted prices.

Looking at the distribution of sizes shows that treatments 7 and 15 were dominated by size 48s at $2.02/kg, which tended to put an upward pressure on the weighted price compared to treatment 6, which was dominated by size 60s at $1.72/kg. Also, because 48s are more dominant in treatment 15 than in treatment 7, the price of treatment 15 was higher. Thus, in this particular year, production that was dominated by sizes 32 to 48, priced at $2.02 to $2.49/kg, would have a higher gross return per kilogram compared to production dominated by sizes 60 to 84 at $0.97 to $1.72/kg. More explicitly, in this year a hypothetical grower who produced 500 kg, all in size 32 (priced at $2.49), would have a TR of $1245 compared to another farmer who also produced 500 kg but all in size 84 (priced at $0.95). In this latter case, TR would be only $475, a reduction of >50%.

Note that our example is illustrative and does *not* suggest on which particular sizes growers should focus. Ultimately, the price is a reflection of the supply and demand conditions for each size and type of avocado. To suggest whether attempts at producing a particular size distribution is beneficial, we would need to examine the relationship between prices and sizes over the long term, a task that is beyond the scope of this paper. Our aim here was to point out that returns depend on yield and size distribution and that it is not possible to know if a high-yielding treatment is also a high-return treatment without detailed economic analysis to relate yields and sizes to corresponding prices.

Impacts of water prices. Concern over water price increases and water availability were the driving forces for our study to determine the most economical combination of input. Thus, we evaluated the effect of water price changes on PNR and the implications regarding irrigation management. Our interest was to see if irrigating at the lowest level (80% ETc) would show better net returns as water costs increase.

We analyzed the changes in PNR of water price increases up to $8.00/ha per millimeter. Even with water price increases, PNR values of the highest returning treatments in the 100% or 120% ETc were higher than that for the 80% ETc treatment (Fig.1). Rising water prices increased the advantage of the 100% ETc (treatments 7 and 9) over the 120% ETc (treatments 14, 15, and 17). The choice of ETc, however, depends on the specific need of the grove.

Conclusion

There are two important concepts that were involved in this project. First, the relation of the biological productivity measures (yield and size) vary from year to year. Therefore, it is not possible to know if a grower will be better off with higher yield and smaller fruit or vice versa without an economic analysis to relate the productivity measures (yield and size) to prices. For example, we have shown that high-yielding treatments do not necessarily mean high returns because of the effect of size distribution and the corresponding price variation. We illustrated this fact by comparing two treatments, such as treatments 9 and 17, which showed differences in yield but not in TR. The influence of costs is another factor that should be considered in treatment evaluation. Therefore, evaluating alternative treatment effects requires economic evaluation to capture the effects of yield, size, price, and cost variation on returns.

Second, because avocados are alternate bearing, differentiating the effect of this feature from the treatment effect on productivity (size and yield) would be impossible from 1 year of data. Furthermore, because prices vary from year to year, a meaningful economic result could be obtained only if the analysis covers several years. In this study, the economic analysis was performed over 3 years. Each year, TR and PNR were estimated. In that way, we were able to capture the variability of both prices and productivity from one year to the other.

Using the top five high-PNR treatments in

Table 7. Relation between avocado sizes, prices, and returns for selected treatments.

Treatment no.	Dominant size[z] Class	Proportion of total (%)	Total yield ($/treatment)	Total yield (kg/treatment)	Weighted price for treatment ($/kg)	Weighted price for dominant size ($/kg)
6	60	39	161	93.4	1.72	1.72
7	48	38	444	238	1.87	2.02
15	48	47	758	395.2	1.91	2.02

[z]Sizes are based by weight of fruit in grams; 177 to 213 for 60s and 213 to 269 for 48s.

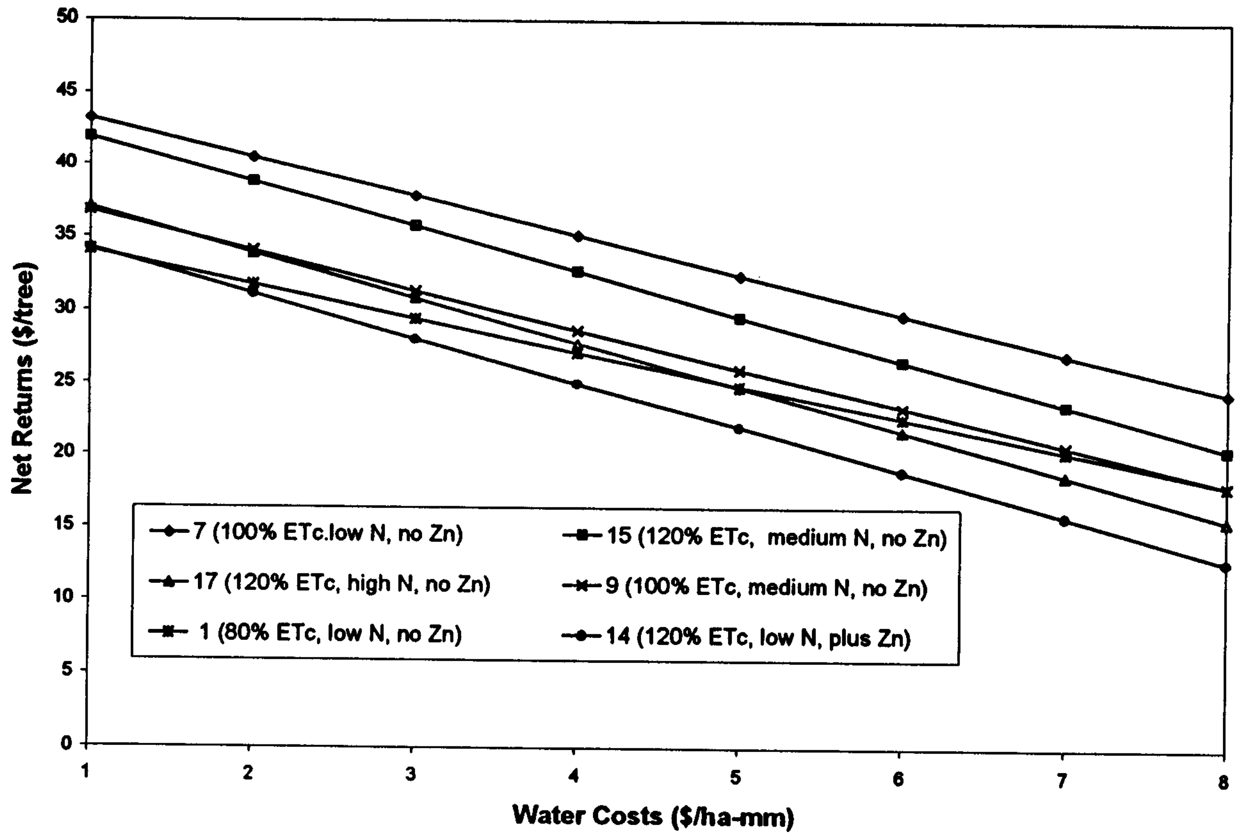

Fig. 1. Average partial net returns in relation to water cost for avocado production (selected treatments).

Table 6, we showed that the following treatment combinations would maximize returns: 100% ETc with either N0 or N1 showed better returns than its use with N2, and 120% ETc with either N1 or N2 was more effective than using N0. Zinc was not needed with these high-PNR treatments.

With avocados being alternate bearing, tremendous fluctuation of TR and PNR exists from year to year. Some growers, however, prefer a relatively stable (predictable) income rather than a highly fluctuating one, although the fluctuating income may have a higher average over time. In this regard, treatment 15 (120% ETc, N1, Zn–), which showed a relatively stable income in the three years of data, may be preferred over treatment 7, which showed the highest average but a relatively more fluctuating income.

The impact of variable water prices on PNR and the implications regarding irrigation management indicated that 100% and 120% ETc provided higher PNR than the 80% ETc, even at very high water prices. Furthermore, the advantage of 100% ETc over the 120% ETc would become more prominent with increases in water prices. However, the choice between 100% and 120% ETc depends on the irrigation need of individual groves.

Literature Cited

Benoit, G. and E. Takele. 1986. Irrigation cost comparison: Drip versus sprinkler. Univ. of California, Coop. Ext. Serv.

Embleton, T.W., W.W. Jones, M.J. Garber, and S.B. Boswell. 1968. Nitrogen fertilization of the Hass avocado. Calif. Avocado Soc. Yrbk. 52:131–134.

Gustafson, A.W., A.W. Marsh, R.L. Branson, and S. Davis. 1979. Drip irrigation on avocados. Calif. Avocado Soc. Yrbk. 63:95–134.

Lee, S.K., R.E. Young, P.M. Schiffman, and C.W. Coggins, Jr. 1983. Maturity studies of avocado fruit based on picking dates and dry weight. J. Amer. Soc. Hort. Sci. 108:390–394.

Meyer, J.L., M.V. Yates, D.E. Stottlemyer, E. Takele, M.L. Arpaia, G.S. Bender, and G. Witney. 1992. Irrigation and fertilization management of avocados, p. 281–288. In: C.J. Lovatt (ed.). Proc. World Avocado Congr. II. vol. I. Orange, Calif., 21–26 Apr. 1991.

Richards, S.S. and A.W. Marsh. 1961. Irrigation based on soil suction measurements. Proc. Soil Sci. Soc. Amer. 25:65–69.