Economic Analysis of Irrigation and Fertilization Management of Avocados

Etaferahu Takele and Jewell L. Meyer
Department of Soil and Environmental Sciences, University of California, Riverside, CA 92521

Mary L. Arpaia, David E. Stottlemeyer, and Guy W. Witney
Department of Botany and Plant Sciences, University of California, Riverside, CA 92521

Additional index words: ‘Hass’, integrated cultural practices, low-volume irrigation, Persea americana

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 fertilizer levels (0, 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, and returns were calculated starting with 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 levels (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 interaction 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/hr. 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 (evapotranspiration) 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 tensionometer 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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Irrigation ETc</th>
<th>N level</th>
<th>Zn level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>0</td>
<td>−</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>1</td>
<td>−</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>1</td>
<td>+</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td>2</td>
<td>−</td>
</tr>
<tr>
<td>6</td>
<td>80</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>0</td>
<td>−</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>1</td>
<td>−</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>1</td>
<td>+</td>
</tr>
<tr>
<td>11</td>
<td>100</td>
<td>2</td>
<td>−</td>
</tr>
<tr>
<td>12</td>
<td>100</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>13</td>
<td>120</td>
<td>0</td>
<td>−</td>
</tr>
<tr>
<td>14</td>
<td>120</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>15</td>
<td>120</td>
<td>1</td>
<td>−</td>
</tr>
<tr>
<td>16</td>
<td>120</td>
<td>1</td>
<td>+</td>
</tr>
<tr>
<td>17</td>
<td>120</td>
<td>2</td>
<td>−</td>
</tr>
<tr>
<td>18</td>
<td>120</td>
<td>2</td>
<td>+</td>
</tr>
</tbody>
</table>

*Irrigation levels: 80% crop water use (ETc) = low, 100% ETc = medium, and 120% ETc = high.

*Nitrogen levels (kilogram per tree per year): 0.16 (N0 or low), 0.7 (N1 or medium), 1.4 (N2 or high).

*Zinc levels at 0 or 0.2 kg/tree per year.
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:

\[ PNR = TR - \text{costs (water + N + Zn)} = H(Y) - P_i(Y) - CAC\{0.04 \times \left[ TR - H(Y) \right] \} \]  

where TR is total return, N and Zn are costs of N and Zn fertilizers, H is harvesting cost per kilogram, Y is total yield (kilogram per treatment), P 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 \[ TR = \sum_{i=1}^{k} P_i S_i \] where \( P_i \) is the price of \( i \)-size fruit per kilogram, and \( S_i \) is the actual quantity of the \( i \)-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 ZnSO₄). 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 obtained from growers. Interest on operating capital was charged at 10.2%, an average rate obtained from growers. Interest on operating capital was charged at 10.2%, an average rate obtained from growers. Interest on operating capital was charged at 10.2%, an average rate obtained from growers. Interest on operating capital was charged at 10.2%, an average rate obtained from growers.

### 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% ET with N0 and N1 and 120% ET 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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (kg/tree)</th>
<th>Year of harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989</td>
<td>1990</td>
</tr>
<tr>
<td>15</td>
<td>35.97</td>
<td>23.80</td>
</tr>
<tr>
<td>7</td>
<td>21.67</td>
<td>43.74</td>
</tr>
<tr>
<td>9</td>
<td>39.70</td>
<td>19.46</td>
</tr>
<tr>
<td>8</td>
<td>17.86</td>
<td>45.97</td>
</tr>
<tr>
<td>14</td>
<td>18.13</td>
<td>31.64</td>
</tr>
<tr>
<td>1</td>
<td>19.94</td>
<td>34.28</td>
</tr>
<tr>
<td>18</td>
<td>19.45</td>
<td>28.35</td>
</tr>
<tr>
<td>10</td>
<td>15.16</td>
<td>31.22</td>
</tr>
<tr>
<td>16</td>
<td>3.52</td>
<td>39.50</td>
</tr>
<tr>
<td>6</td>
<td>8.51</td>
<td>37.36</td>
</tr>
<tr>
<td>13</td>
<td>5.85</td>
<td>29.49</td>
</tr>
<tr>
<td>8</td>
<td>12.24</td>
<td>28.50</td>
</tr>
<tr>
<td>4</td>
<td>18.30</td>
<td>25.92</td>
</tr>
<tr>
<td>12</td>
<td>24.21</td>
<td>16.53</td>
</tr>
<tr>
<td>2</td>
<td>17.80</td>
<td>22.29</td>
</tr>
<tr>
<td>5</td>
<td>11.42</td>
<td>29.35</td>
</tr>
<tr>
<td>3</td>
<td>17.28</td>
<td>22.73</td>
</tr>
<tr>
<td>11</td>
<td>20.85</td>
<td>17.04</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Year</th>
<th>84</th>
<th>70</th>
<th>60</th>
<th>48</th>
<th>40</th>
<th>32</th>
<th>28</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>2.76</td>
<td>14.96</td>
<td>25.83</td>
<td>41.14</td>
<td>13.39</td>
<td>1.40</td>
<td>0.52</td>
</tr>
<tr>
<td>1990</td>
<td>7.02</td>
<td>31.37</td>
<td>31.85</td>
<td>25.13</td>
<td>4.29</td>
<td>0.37</td>
<td>0.09</td>
</tr>
<tr>
<td>1991</td>
<td>2.93</td>
<td>23.71</td>
<td>44.67</td>
<td>26.33</td>
<td>2.15</td>
<td>0.22</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size*</th>
<th>Year</th>
<th>84</th>
<th>70</th>
<th>60</th>
<th>48</th>
<th>40</th>
<th>32</th>
<th>28</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>2.76</td>
<td>14.96</td>
<td>25.83</td>
<td>41.14</td>
<td>13.39</td>
<td>1.40</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>7.02</td>
<td>31.37</td>
<td>31.85</td>
<td>25.13</td>
<td>4.29</td>
<td>0.37</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>2.93</td>
<td>23.71</td>
<td>44.67</td>
<td>26.33</td>
<td>2.15</td>
<td>0.22</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

*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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Price ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989</td>
</tr>
<tr>
<td>size</td>
<td>Year of harvest</td>
</tr>
<tr>
<td>20</td>
<td>0.80</td>
</tr>
<tr>
<td>24</td>
<td>0.82</td>
</tr>
<tr>
<td>28</td>
<td>0.90</td>
</tr>
<tr>
<td>32</td>
<td>1.13</td>
</tr>
<tr>
<td>36</td>
<td>1.09</td>
</tr>
<tr>
<td>40</td>
<td>1.02</td>
</tr>
<tr>
<td>48</td>
<td>0.92</td>
</tr>
<tr>
<td>70</td>
<td>0.78</td>
</tr>
<tr>
<td>70</td>
<td>0.94</td>
</tr>
<tr>
<td>84</td>
<td>0.44</td>
</tr>
</tbody>
</table>

*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).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TR ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>40.36</td>
</tr>
<tr>
<td>15</td>
<td>69.00</td>
</tr>
<tr>
<td>17</td>
<td>16.59</td>
</tr>
<tr>
<td>9</td>
<td>72.01</td>
</tr>
<tr>
<td>14</td>
<td>34.00</td>
</tr>
<tr>
<td>11</td>
<td>38.06</td>
</tr>
<tr>
<td>16</td>
<td>6.15</td>
</tr>
<tr>
<td>20</td>
<td>26.20</td>
</tr>
<tr>
<td>13</td>
<td>36.40</td>
</tr>
<tr>
<td>10</td>
<td>10.17</td>
</tr>
<tr>
<td>6</td>
<td>14.61</td>
</tr>
<tr>
<td>8</td>
<td>23.87</td>
</tr>
<tr>
<td>23</td>
<td>37.30</td>
</tr>
<tr>
<td>4</td>
<td>45.68</td>
</tr>
<tr>
<td>12</td>
<td>21.56</td>
</tr>
<tr>
<td>21</td>
<td>31.08</td>
</tr>
<tr>
<td>11</td>
<td>39.49</td>
</tr>
<tr>
<td>22</td>
<td>28.67</td>
</tr>
<tr>
<td>24</td>
<td>15.67</td>
</tr>
<tr>
<td>20</td>
<td>26.56</td>
</tr>
<tr>
<td>13</td>
<td>13.45</td>
</tr>
<tr>
<td>12</td>
<td>31.79</td>
</tr>
<tr>
<td>21</td>
<td>21.27</td>
</tr>
<tr>
<td>22</td>
<td>22.91</td>
</tr>
<tr>
<td>15</td>
<td>20.63</td>
</tr>
</tbody>
</table>

*Partial net returns evaluated at $1.00/ha per mm of water.

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year of harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>40.36</td>
</tr>
<tr>
<td>15</td>
<td>69.00</td>
</tr>
<tr>
<td>17</td>
<td>16.59</td>
</tr>
<tr>
<td>9</td>
<td>72.01</td>
</tr>
<tr>
<td>14</td>
<td>34.00</td>
</tr>
<tr>
<td>11</td>
<td>38.06</td>
</tr>
<tr>
<td>16</td>
<td>6.15</td>
</tr>
<tr>
<td>20</td>
<td>26.20</td>
</tr>
<tr>
<td>13</td>
<td>36.40</td>
</tr>
<tr>
<td>10</td>
<td>10.17</td>
</tr>
<tr>
<td>6</td>
<td>14.61</td>
</tr>
<tr>
<td>8</td>
<td>23.87</td>
</tr>
<tr>
<td>23</td>
<td>37.30</td>
</tr>
<tr>
<td>4</td>
<td>45.68</td>
</tr>
<tr>
<td>12</td>
<td>21.56</td>
</tr>
<tr>
<td>21</td>
<td>31.08</td>
</tr>
<tr>
<td>11</td>
<td>39.49</td>
</tr>
<tr>
<td>22</td>
<td>28.67</td>
</tr>
<tr>
<td>24</td>
<td>15.67</td>
</tr>
<tr>
<td>20</td>
<td>26.56</td>
</tr>
<tr>
<td>13</td>
<td>13.45</td>
</tr>
<tr>
<td>12</td>
<td>31.79</td>
</tr>
<tr>
<td>21</td>
<td>21.27</td>
</tr>
<tr>
<td>22</td>
<td>22.91</td>
</tr>
<tr>
<td>15</td>
<td>20.63</td>
</tr>
</tbody>
</table>

*Partial net returns evaluated at $1.00/ha per mm of water.

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

<table>
<thead>
<tr>
<th>Treatment no.</th>
<th>Year of harvest</th>
<th>Total return (kg treatment)</th>
<th>Weighted price for highest dominant size ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1989/1990</td>
<td>161</td>
<td>93.4</td>
</tr>
<tr>
<td>7</td>
<td>1990</td>
<td>444</td>
<td>238</td>
</tr>
<tr>
<td>15</td>
<td>1991</td>
<td>758</td>
<td>395.2</td>
</tr>
</tbody>
</table>

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


