Yield Characteristics of California 'Hass' Avocado Trees

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Introduction

Production characteristics of 'Hass' avocado trees in California were determined using yield data from ~3,000 trees in commercial coastal and inland valley orchards from 1992 to 2012. The data set included total yield, fruit size distribution (pack out) and fruit quality for 'Hass' avocado trees on different but known clonal and seedling rootstocks in more than 15 commercially-producing orchards representing the major avocado-growing areas of California. The orchards were managed according to each grower's standard cultural practices. Fruit was harvested between March and October at ≥ 20.8% dry matter content. Climate data (maximum and minimum temperatures, relative humidity, precipitation and wind speed) and information on soil type and depth were included in the data set.

The objective was to identify relationships among yield parameters, including total yield, fruit size, fruit quality and alternate bearing, that were independent of rootstock and cultural practices and prevailed across the climate conditions and soil types of California's avocado-growing areas or *conversely*, to identify those climatic conditions and/or soil types that promoted or limited productivity in specific microclimates or edaphic (soil-related) zones.

To our knowledge, this is the first large-scale, in-depth analysis of the California avocado industry of this type. The results of the first phase of our analysis are reported below.

Yield as Fruit Weight per Tree

Total yield. The mean yield for all trees in the data set was 112 lb/tree (12,320 lb/110 trees/acre). However, the median yield was only 62 lb/tree (6,820 lb/acre). Thus, half of the trees yielded less than 62 lb/tree and half of the trees yielded more than 62 lb/tree. Based on the frequency of individual tree yields (i.e., the number of trees having a specific yield), 50 percent of the trees in the data set yielded from 22 to 154 lb/tree (2,420 lb/acre to 16,940 lb/acre).

The greater number of trees (y-axis) yielding less than 22 lb/tree (x-axis) relative to the number of trees yielding more than 154 lb/tree is clearly seen in Figure 1.

It is of interest that the data set included trees yielding more than 350 lb/tree. However, these trees were considered outliers since they represented less than 2.5 percent of the trees in the data set.

Yield of commercially valuable large fruit. Yields of both commercially

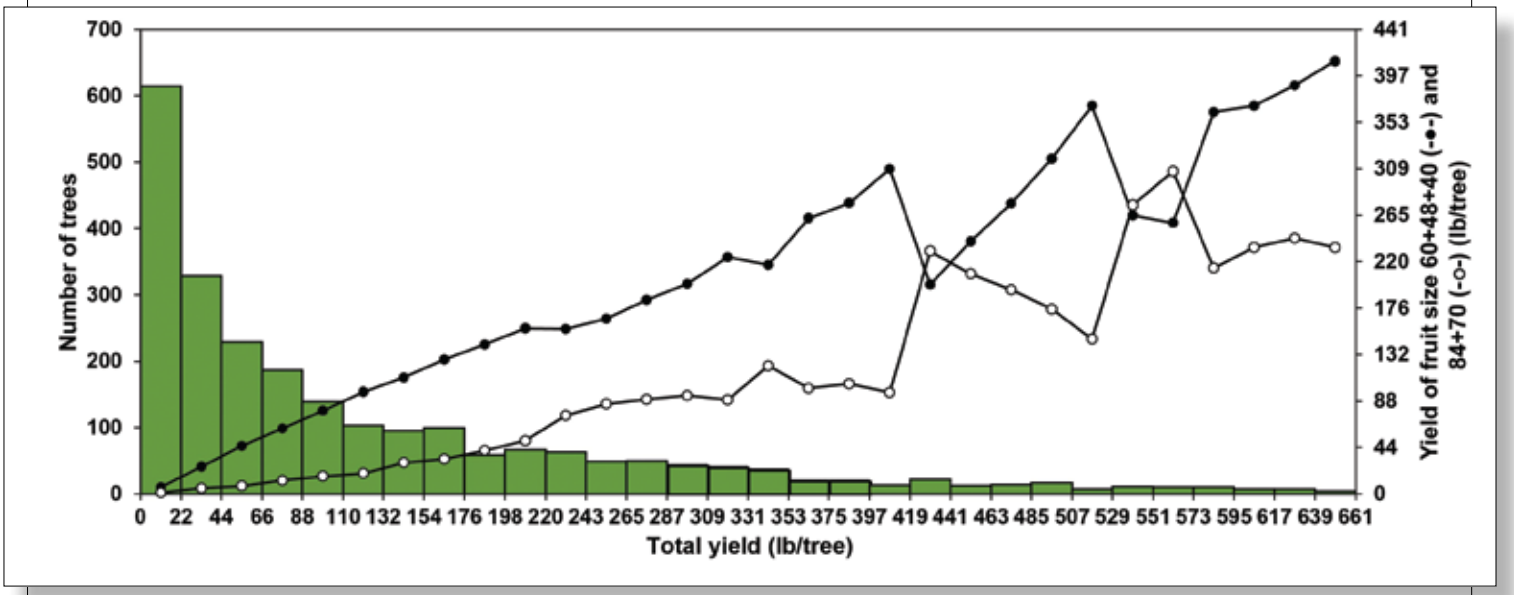

Figure 1. *The green bars are the number of trees (left y-axis) in the data set having total yields of 0-21.99 lb/tree, 22-43.99 lb/tree, 44-65.99 lb/tree etc., (lower x-axis). Black circles indicate the average pounds of commercially valuable large (CVL) fruit (packing carton sizes 60+48+40) per tree and white circles indicate the average pounds of small fruit (SF) (packing carton size 84+70) per tree (right y-axis) for trees in each total yield category on the x-axis, respectively.*

valuable large (CVL) fruit (packing carton sizes 60+48+40; 178-325 g/fruit) and small fruit (SF) (packing carton sizes 84+70; 99-177 g/fruit) increased as total yield increased (Figure 1).

To correct for prejudice caused by having significantly more trees at one site than other sites, an unbiased mean yield was determined. The unbiased mean yield was a respectable 95 lb/tree (10,450 lb/acre) with an unbiased yield of CVL fruit of 68 lb/tree (72 percent of the total yield).

It is noteworthy that CVL fruit were consistently a greater proportion of the total yield up to 419 lb/tree. On average, up to 419 lb/tree, 72 percent of the total yield was CVL fruit, with larger fruit (326-397 g/fruit) only 2 percent of the crop, and smaller fruit (SF) making up approximately 25 percent of the total yield.

Thus, even with a dramatic increase in total yield (as lb/tree or number of fruit/tree) above the current production levels, California 'Hass' avocado growers are unlikely to experience a decline in the yield of CVL fruit.

Alternate Bearing

It should be noted that the majority of low yielding trees (< 22 lb/tree) in the data set produced low yields in response to adverse climatic conditions, including multiple years with freezing temperatures and one year of excessively high temperatures during fruit set. The fact that only 2 percent of the trees in the entire data set produced back-to-back yields of less than 22 lb/tree provides strong evidence that low yields, in the majority of cases, were not the result of poor cultural management practices or disease, nematode or insect pest damage. The adverse climate events resulting in low yields (off crops) initiated alternate bearing.

Alternate bearing was a characteristic of the majority of the orchards in the data set. The severity of alternate bearing is estimated by calculating the alternate bearing index (ABI) for each data tree for each pair of consecutive harvests using the following equation: ABI = (the absolute value of year 1 yield minus year 2 yield)/(sum of year 1 yield and year 2 yield) in which yield was defined as total lbs of fruit per tree. ABI ranges from 0 (no alternate bearing) to 1 (complete alternate bearing; crop one year, no crop the other year).

Only 17 percent of the trees in the data set had an ABI less than or equal to 0.25, 17 percent had an ABI greater than 0.25 up to 0.50, with 19 percent of the trees having an ABI greater than 0.50 to 0.75 and 47 percent of the trees having an ABI greater than 0.75 up to 1.0. Thus, over the period from 1992-

2012, 66 percent of the 'Hass' avocado trees in the data set were severely alternate bearing with 50 percent to 100 percent differences in yield from one year to the next.

The severity of alternate bearing was independent of orchard location and no avocado-producing area in California was more or less prone to alternate bearing over the 20 years the data were collected. For trees having an ABI from 0 to 0.75, the occurrence and severity of alternate bearing was not related to crop load. In contrast, trees having the most extreme ABI (0.75 to 0.99) tended to produce yields greater than the unbiased mean or median yields reported above in both the on- and off-crop years and thus had significantly greater two-year cumulative yields than trees with an ABI less than 0.75. These greater yielding trees did not suffer a reduction in two-year cumulative yield of CVL fruit, but produced significantly more small fruit than trees in all other ABI categories.

It is interesting that for trees producing on-crops of less than 110 lb/tree, the following off-crop yields were less than 33 lb/tree, becoming dramatically lower with progressively lower on-crop yields. In contrast, on-crop trees producing more than 110 lb/tree produced more than 33 lb/tree and up to 77 lb/tree in the following off-crop year. No off-crop yield following an on-crop year exceeded 77 lb/tree.

Fruit Quality

Stem end rot, discoloration of the mesocarp (edible portion of the fruit), vascularization of the mesocarp, and seed germination within the fruit were each rated 0 (absent) to 4 (high incidence of the problem) for two fruit per tree collected at harvest for each tree in our data set (~6,000 fruit). The fruit were ripened at 18 to 21 °C to "eating soft" and then evaluated. Statistical analysis of the fruit quality data provided strong evidence that the quality of 'Hass' avocado fruit produced in California is excellent. The majority of trees in the majority of orchards across the majority of years produced fruit that were rated 0 or 1 for these disorders.

- For stem end rot, 83 percent of all fruit were rated 0, 14 percent as 1, with less than 1 percent rated a 3 or 4.
- For mesocarp discoloration, 80 percent of all fruit were rated 0, with another 15 percent rated 1; only 1.9 percent were rated a 3 and 0.3 percent were rated a 4.
- For vascularization of the mesocarp, 86 percent of all fruit were rated 0 or 1; only 1.4 percent of all trees produced fruit that were rated a 3 and only 0.2 percent of the trees produced fruit that were rated a 4.
- For seed germination, 72 percent of all fruit were rated 0, with 11 percent rated 1; 6 percent rated 2; 9 percent rated 3 and 2 percent rated 4.
- Whereas the incidence of seed germination within the fruit was very low, this disorder was more prevalent, but no factors were identified that influenced its occurrence.
- Across all orchards and years, vascularization of the mesocarp was weakly but significantly related to progressively later harvest dates and weakly, negatively related to leaf calcium concentrations — a finding that needs to be investigated further.
- The number of days after harvest required for fruit to ripen to "eating soft" was weakly, positively related with total yield (lb/tree) and weakly, negatively correlated with harvest date.

Effect of Climate on Yield

Extreme climatic events in any given year became the main factor controlling yield and fruit size. Freezes in 1990-91, 1998-99 (only parts of the California avocado industry), and 2006-07 (only 5 percent crop loss in Ventura, but 50-75 percent crop loss in San Diego, Santa Paula, Carpinteria, Santa Barbara and San Luis Obispo) impacted the yields of trees in the data set. Excessively-high temperatures for several days during fruit set in 2008-09 had a devastating effect on yield from San Diego to Santa Paula, impacting the yields of trees in the data set.

Effect of Soil Factors on Yield

Statistical analysis obtained by calculating the correlation coefficients for the relationships among yield parameters (maximum total yield or yield of CVL fruit or SF and fruit quality) and soil composition identified a positive relationship between the maximum total yield attained in an orchard and the percent sand in the orchard soil, with a concomitant negative relationship between total yield and percent clay in the soil; the relationship between total yield and percent silt in the soil was weak but also negative and significant. These results are consistent with the fact that the sand, clay and silt content of an orchard soil would have a critical effect on drainage and aeration and soil microflora in the orchard and therefore on root health and tree productivity. Research by David Crowley has shown that soil composition can become a factor that overrides the optimal nutrient status of trees in an orchard if not managed properly. These results emphasize the importance of soil type as one of the criteria for selecting a site for a new orchard. Soil depth was greater than 200 cm in 60 percent of the orchards and was not related to yield. Orchards having soils with a greater percent sand or a

greater soil depth were not clustered in one particular avocado-growing area.

Discussion

Despite problems of low yield, small fruit size and alternate bearing, the 'Hass' avocado dominates the global avocado industry. The average (unbiased) yield in California avocado orchards included in this research was at a production level acceptable to the industry, 95 lb/tree (10,450 lb/acre), with 73 percent of the yield CVL fruit (packing carton sizes 60+48+40). The problem is that 50 percent of the trees in the data set produced at a level well below the average at less than 62 lb/tree, the median yield (< 6,820 lb/acre). Further, the yield of CVL fruit remained at 72 percent of these lower total yields, reducing grower income. Although the frequency was low, there were trees within 'Hass' avocado orchards included in this research that produced very high yields and trees with the capacity to produce back-to-back yields greater than 154 lb/tree, which would translate to yields of greater than 16,940 lb/110 trees/acre. Each tree in the data set has a unique number that identifies the year, the site and any special treatment the tree might have received. The next step is to identify these high-yielding trees and orchards within the data set — as well their low-yielding counterparts — to retrieve detailed information that was collected as part of the original research on tree age, rootstock, aspects of cultural management, irrigation water quality, climate, soil characteristics and tree nutrient status (leaf nutrient analyses were determined according to the standard protocol in California for all trees in the data set). This information should prove valuable in identifying key determinates of yield that can be translated into useful strategies for increasing the median yield of 'Hass' avocado orchards in California and possibly elsewhere.

The results of the first phase of this research provided evidence that the proportion of sand versus clay in the composition of the orchard soil was a factor influencing total yield, with a high percentage of sand having a positive effect on yield and conversely a high percentage of clay having a negative impact. An orchard soil with a greater proportion of sand to clay would have better drainage and aeration, which would contribute to improved root health with consequent benefits on-tree productivity.

Whereas California 'Hass' avocado trees suffer from low yield, the industry has not experienced the 'Hass' "small fruit" problem reported elsewhere. Based on the results of this research, 'Hass' avocado yields can increase dramatically to approximately 419 lb/tree with no negative effect on the yield of CVL fruit preferred by the California industry. Whereas the yield of small fruit also will increase at the higher yields, the absolute yield of large size fruit does not decrease, only its relative proportion decreases. Further, California's warm, dry Mediterranean climate and industry-wide high standard of cultural management result in fruit of excellent quality.

Alternate bearing was demonstrated to be a major problem for California 'Hass' avocado growers, with 66 percent of the trees in the data set exhibiting severe alternate bearing during the period from 1992 to 2012; ABI was greater than 0.5 to 1.0 indicating 50 percent to 100 percent differences in yield from one year to the next. Moreover, nearly half of all trees in the data set (47 percent) had an ABI greater than 0.75 to 1.0 over the 20-year period. The effect of alternate bearing on yield was dramatic — following an on crop, trees in all yield categories produced less than 77 lb/tree. Despite the severity of alternate bearing in 'Hass' avocado orchards in California, the results of this research identified trees with the capacity to produce consecutive yields greater than 154 lb/tree. A subsequent more detailed investigation of these trees may provide new insights for maintaining high yields annually.

Conclusions

To sustain the California 'Hass' avocado industry in an era of increasing production costs (land, water, labor, fertilizer, etc.) and greater competition within the U.S. avocado fresh fruit market, avocado growers must increase their yields of high quality CVL fruit per unit land. Taken together, the results of this research provide strong evidence that the yield of CVL fruit of excellent quality, and hence grower income, can be increased annually by increasing total yield per tree annually. The results demonstrated that yield of CVL fruit was positively and significantly correlated with total yield (lb/tree) over a very broad range of yields. However, with the severity of alternate bearing that characterizes 'Hass' avocado orchards in California, increasing total yield annually will require mitigating alternate bearing to reduce the occurrence of off-crop years, which had average yields of less than 77 lb/tree. It is anticipated that further investigation of 'Hass' avocado trees (orchards) having the capacity to produce consecutive yields greater than 154 lb/tree identified in this research will provide important insight into sustaining high yields annually despite alternate bearing. Understanding the yield characteristics of 'Hass' avocado trees under California growing conditions was the first phase in our research to increase yield of CVL fruit, improve grower annual revenue and sustain the avocado industry of California.