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A CONVERSATION WITH TONY WHILEY

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Dr. Anthony Whiley, who visited us from Australia under the prestigious U.C. Regents fellowship program, is acknowledged to be a world class avocado and other subtropical fruit plants physiologist. His knowledge goes beyond the complex physiological processes of the avocado tree and into most issues concerning avocado culture. It was a great honor to be able to spend the afternoon of March 25, 1996, conversing with him. This essay is an attempt to put in writing the insightful responses Whiley gave to my endless questions.

Limited pollination opportunity for the avocado is one of two major limiting factors in our environment. The need for cross-pollination in California is not experienced in the subtropics. Pollination in the subtropics is enhanced due to asynchrony in the floral cycle. There is significant overlapping of the male and female stages and hence, improved intra-cultivar pollination. Overlapping increases even more when days with substantial increases in temperature, 6-10°C (10.8-18°F), follow cooler days. This explains in part how large single variety groves in Australia and Mexico can produce heavy crops. Higher mean temperatures in the subtropics enhance pollen tube growth and ovule viability, and thus higher productivity. [In our situation, during the bloom period warm days are often followed by cool nights. Pollen tubes grow too slowly; and by the time they reach the ovule, the ovule is often not viable.] Boron and low biuret urea foliar spray applications are not practiced in Australia. This practice, however, has the potential for enhancement of pollen tube growth and fertilization opportunities, as has been demonstrated by other researchers. Honey bees are introduced to the Australian groves at a density of 8-10 hives per hectare (3.2-4 hives per acre) in addition to a local feral social bee that is a pollination vector.

Avocado leaves have a life span of 10 to 12 months, and as long as they remain photosynthetically active, opportunities for greater productivity increase. In the warm and humid subtropical zones of Australia, well—managed groves produce maximum sustained Hass crops of 20 metric tonnes per hectare (17,600 pounds per acre). These production levels are substantially greater than sustained average crops in California. Carbohydrate levels in the avocado tree are at their highest at the end of winter just before anthesis (bloom state). Spring brings a period of high demand for assimilates (products of photosynthesis) and rapid depletion of stored carbohydrates (starch). In terms of sink (demand for nutrients) strength, seeds are the strongest sink followed by fruit, new shoots and leaves, cambium, roots, and storage. The depletion of carbohydrates lasts approximately 40 days till the new leaves' growth reaches the sink:source transition period (this is when the leaves are about 80% expanded and are able to create more carbohydrates than they use). Once the sink:source transition is reached, fruit drop is greatly reduced. A retained canopy of mature leaves that is healthy and efficiently photosynthesizing is crucial to supplying photoassimilates during this critical time. Although these mature leaves are not as efficient as younger mature leaves, due to the effects of over-wintering and other external and internal damage to them, they are nevertheless very important. Cold damage reduces the quantum efficiency of over-wintered leaves by 40%, but a good portion of the lost efficiency is restored as the season progresses. When leaves of 4 year-old Hass trees were removed from the canopy prior to anthesis, the shoots ended up with 1.2 fruit per defoliated shoot. Shoots with a full leaf complement had 4 fruit per shoot. Average per tree production was 6 Kg (13.2 pounds) for the defoliated trees and 30 Kg (66 pounds) for the full-canopied trees. *The tendency of over-wintered leaves in semi-arid environment to abscise prior to and during anthesis is an important contributor to limiting productivity.* Fruit size is established during the first 10-12 weeks of growth when most of the cell division takes place. Factors limiting cell division will ultimately reduce final fruit size at harvest. Leaf health and retention during this period are critically important. Whiley claims that tip burn, for example, reduces the photo-efficiency of the leaf; and that prior to showing any external symptoms of tip burn, the capacity of the "photo-assimilation factory" has already been damaged. Leaves surrounding the inflorescence tend to yellow during anthesis because of the translocation of N; and as a result, their assimilation efficiency is reduced. Whiley is not surprised that there appears to be a perceived reduction in fruit size resulting from Persea mite infestation and the associated leaf damage caused by the mite.

Carbohydrate availability is influenced by internal and external factors, some of which could be manipulated for better fruit production. On-tree fruit storage is detrimental and contributes to alternate cropping. When Hass fruit was totally removed, when dry weight reached 24%, there was little alternating, and the following production was of 21 tonnes per hectare (18,500 pounds per acre). When the fruit was harvested at 30%, or when half was harvested at 24% and the other half at 30%, some alternate bearing followed with production of 18.5 tonnes per hectare (16,280 pounds per acre). When all the fruit was harvested at 35% dry matter, or when half was harvested at 30% and the other half at 35%, heavy alternate cropping followed, with production down by 20% relative to the trees that were harvested early. *This off and on pattern, once established, is very difficult to change; and only drastic actions such as induced stress, severe tree pruning, a weather related catastrophe, and to a lesser extent total fruit removal could bring about a reversal.* Whiley visualizes a controlled atmosphere environment for fruit storage as a substitute for a prolonged on-tree storage. Strictly as a carbohydrate management tool, he recommends early harvesting of *30%* to 50% of the crop in a normal year, and a proportionally even larger percentage in a bumper crop year. The best cultural strategy in such a year is to strip harvest when maturity is reached, but to do what is culturally right is not often commercially feasible. (Australia has a minimum maturity standard for Hass set at 24%, as compared to California's 21.2%). [In my opinion, we help create alternate crops by failing to pick the trees that are most in need of fruit removal. Economically, we are encouraged to size pick our orchards; but early season large fruit, unless the grove is young, are normally found on trees that are carrying low volumes of fruit. The opposite is much more important: the trees that are loaded need to be stripped, or a substantial portion of the crop must be harvested very early to reduce the load and avoid the likely specter of alternate bearing]. In Australia, fruit volume, historical production data, and canopy size are taken into consideration for fertilization and irrigation recommendations. *Higher levels of N and additional water are recommended when a large crop is on the trees, and a reduced dosage of N and irrigation during low crop years. This practice helps reduce excessive vegetative growth in off years and can aid heavily loaded trees produce critically needed new shoots.*

Leafy inflorescences are a strong sink for nutrients. In Australia, a product called Cultar (paclobutrazol, or PBZ, which is a growth-regulating compound) is now registered for application in producing avocado orchards. It is applied on the foliage during mid-flowering, and among its effects is the inhibition of the biosynthesis of gibberellins, which are believed to delay the onset of bloom in many fruit trees. PBZ is also responsible for the suppression of the leafy part of the inflorescence. PBZ is only effective on young tissue, and its influence is transitory; by the time summer growth takes place, PBZ is gone. PBZ has a negative effect on root growth, particularly in the spring when root volume is already reduced. A combination of a pre-anthesis N application (30% of summer N) followed by PBZ at a rate ranging from 0.62 to 1.25 grams/liter helped produce larger fruit size and the highest sustainable yields in a three year study. *The ability to load up on N, which is known to enhance fruit retention, and at the same time reduce the competing vegetative expression during bloom, is an important tool in the hands of the Australian farmer.*

The phenology (growth cycles) model for the particular genotype (variety) must be kept in mind at all time. Dr. Whiley mentioned, as an example, their success with trunk injection of phosphonates for the control of Phytophthora Root Rot (PRR) in highly infected trees. Sink strength was found to be similar to the demand for assimilates, for example, after phosphonate injection into the tree, measurements show 150 ppm phosphonates in young fruit, a very strong sink for assimilates, and 3-5 ppm in mature fruit. In Australia, two injections were made annually: the first application at the end of the spring shoot flush and before the first root flush (early May in California), and the second injection prior to the summer shoot and leaf flush (around August). *When the injection took place in the spring, an importing period, only low levels of phosphonates, maximum 5 ppm, were measured in the roots. When shoots passed the sink:source transition, an exporting period, and after the summer injection, the root phosphonate level increased to 30 ppm, a desirable level for the control of PRR.* Here again one can see how important, effective, and cost saving following the phenology model can be.

The following data were presented by Tony Whiley at a UCR seminar. Carbon partitioning in the different phases of the phenology model is an example of the insights we can gain from such a model in making cultural decisions such as phosphonate injection, N- fertilization, tree pruning, etc.

	Leaves	Branches	Roots
FLUSH PHASE	43.0%	42.5%	14.5%
QUIESCENT	29.9%	38.5%	31 .8%

[Mary Lu Arpaia and her associates have been researching many aspects of the phenology of the Hass cultivar in California.]

It is universal in Australia to use the youngest fully expanded summer leaves for leaf analysis. This is different from the practice in California, where mature *spring* leaves are used. Whiley feels that the information gathered from such leaves is more relevant to the status of the tree as it goes into dormancy. These are the leaves which are in closest proximity to the flowers and setting fruit. They are found on the outer extremes of the canopy and are responsible for supplying energy during the critical fruit setting period. The samples are taken later in the autumn as compared to the sampling period in California. Some growers in Australia complain that since the results come so late in the season they cannot do much about changing the condition of their trees. Leaf analyses indicate a trend, and if a grower follows earlier recommendations, only minor adjustments are likely to be required. Dr. Whiley does not like sampling of sap or petiole extract as an alternative to leaf analysis because of lack of standards and a demonstration that such a test is necessary. He also feels that traditional soil analysis includes results of available nutrients, and he finds no need for soil solution extract analysis.

In Australia, fertilizer mixes are customized depending on what is required. Whiley recommends loading up with N in late summer in order that this important nutrient will be available during anthesis. Potassium is applied only when leaf analysis shows a decline. Among micronutrients, boron is the most deficient. A leaf boron level of 40-60 ppm is recommended, with a maximum tolerable level around 100 ppm. Whiley does not recognize boron deficiency in California, but he suggests that low leaf boron levels need to be addressed. The recommendations for zinc leaf levels are similar to those adhered to in California, but he has no evidence that such levels are optimally required. The phosphonate-zinc injectable, popular through the '80s, is no longer recommended in Australia. Soil pH of 5.5 is preferred, and high organic matter, as mulch, is encouraged, particularly in areas susceptible to PER. In instances where the pH drops to about 4.5, they encounter problems with excessive manganese and low availability of zinc and boron. High leaf levels of aluminum do not occur in subtropical Australia as they do in California when soils become acidic.

In Australia there are many insects, including a variety of exotic fruit flies. Dr. Whiley says that for many years they used insecticides for pest control, but a high ecological price was associated with such a practice. He suggests that *it is essential that we should seek biological control for the Persea mite infestation in California.* He feels that in the long haul insecticides are not a viable solution.

Our conversation drifted to subjects such as irradiance, light management, canopy size and spacing, carbohydrate production, water stress, water management, humidity, temperature, and other factors that influence productivity. It would have taken days to answer completely all my questions. I took the liberty of augmenting his responses by paraphrasing and quoting directly from the Avocado Chapter of the CRC Handbook of Environmental Physiology of Fruit Crops, Volume 2, Subtropical and Tropical Crops, written by Anthony Whiley and Bruce Schaffer. [In my attempt to make technical terminology and concepts understandable, I may have oversimplified things; if so, my apologies].

Irradiance, water stress, humidity, and temperature are the most influential limiting factors for photosynthetic efficiency. Tony Whiley's research with fruiting Hass trees, including current measurements at our South Coast Field Station, indicates that light saturation for photosynthesis of mature avocado leaves is much higher than previously thought. Unlike work done by Scholefield and others that pegged light saturation for assimilation rate at 20-33% of full sunlight, Whiley's results, using more sophisticated *field* equipment, indicate efficient assimilation rates at light saturation exceeding 50% of full sunlight. Assimilation rate increases to an optimum efficiency when it reaches light saturation. Dr. Whiley is adamant that his findings are accurate and that there is a direct correlation between the fruiting efficiency of sides of tree canopies and the amount and intensity of light they receive. He observed that fruiting efficiency declines as the photosynthetic photon flux declines. He intends to embark on a research project where trees will be spaced at distances where no interference to light will take place. Such research will help define critical light thresholds for fruiting. This information is necessary for deciding the type and timing of canopy management, canopy shape and optimum tree spacing. Since 95% of dry matter is derived from photo—assimilation of CO_2, well lit leaves with close proximity to fruit are a must for consistent fruit production. Many studies that are being conducted internationally show that high density planting produces higher yields in the first five years when compared to conventional tree spacing. However, *it is imperative to commence canopy management in a timely fashion in order to maintain acceptable productivity.*

Avocado trees, and the Hass cultivar in particular, are highly stress sensitive. During anthesis, the flowering segment of the canopy constitutes almost half the surface area that can contribute to water loss. There are several physiological processes which are involved in the reduction of assimilation as a response to atmospheric water deficit. Stomates are found on the lower surface of leaves, on flowers, and on young fruit. Although stomatal conductance is reduced in response to reduced light, independent of external and internal water deficit, it is critical to fruit production and retention by its response to water stress. As the absolute humidity difference between leaves and air increases, the stomates, which are highly sensitive to deficit in atmospheric moisture, respond by reduced conductance (Stern *et al.}. When conductance was decreased by half, there was a proportional reduction in the assimilation rate of carbon dioxide.* In the subtropics, photoassimilation remains at a high rate by maintaining high level of stomatal conductance due to elevated ambient humidity. [I asked Dr. Whiley for his opinion about a canopy spray that will go on automatically during stress sensitive periods when a preset drop in canopy humidity or an increase in external temperature is detected. He felt that it could be an expensive enterprise, and cautioned against using water that may contain dissolved salts in quantities that can damage the leaves. I believe he said that it will reduce stress and emulate, to some extent, subtropical humid conditions.]

Irrigation management is extremely important for sustained productivity. The soil must be monitored in the *active root zone,* and irrigation scheduling should be influenced by soil type, soil moisture, irradiance, air temperature, stage in the phenology of the tree, and crop size. Lahav and Kalmar found that in Israel a 21 day interval between irrigation gave the most efficient use of water resources. Southwest Australia is semi-arid and windy and avocados are grown in sea sand, almost hydroponically. A grower who was disappointed with his yields is now irrigating three times per day to achieve acceptable production. Work done by Bower showed that when soil water potential was kept below -40 kPa (practically the same as 40 centibars) and no other stressful conditions were involved, there was little change in stomatal conductance. As the soil water potential declined from -40 to -70 kPa, stomatal conductance was exponentially reduced to the point of stomatal closure. Even when water is reintroduced to the soil and leaf water potential returns to normal and leaves appear unstressed, the damage is not over yet. *When stomates close as a result of water stress it takes stomatal conductance 4 to 6 days to return to normalcy.* It is thought to be the increased accumulation of ABA (abscisic acid) in the leaves, resulting from water stress, that reduces stomatal opening. Obviously, as was mentioned above, such a decline in stomatal conductance can only help reduce photoassimilation and productivity, as well as encourage fruit drop and the development of "ring neck" symptoms. Additionally, as water stress occurs and the leaves enter into a stage of wilt, there is a migration of moisture from the fruit, which is a water reservoir, to the leaves. Fruit dehydration can severely reduce the capability of the fruit to remain viable if the condition continues.

Temperature can be a major limiting factor in the productivity of the avocado tree. Extremes in temperature influence root growth, shoot growth, flower initiation, pollen tube growth, fruit set, fruit growth and retention, stomatal conductance, and many other processes. Obviously, freezing temperatures can affect the tree from minor stem damage to fruit drop, to severe leaf burn and defoliation, and even to the death of the tree. As was mentioned earlier, overwintered leaves which are exposed to low temperatures lose their photosynthetic efficiency due to photo-inhibition, photo-oxidation of the chlorophyll, and translocation of nutrients during anthesis. High temperatures hurt productivity, particularly when they are coupled with low humidity. When air temperature is between 20 and 30°C (68-86°F), photosynthesis is likely to be optimal. Soil temperature obviously affects root growth and appears to be optimal between 18 and 28°C (64- 82°F). Warm soil temperatures increase bacterial activity, early nutrient absorption, and the production of cytokinins which are thought to take part in a variety of flowering processes. *It is thought that cool temperatures, rather than photoperiod, induce floral initiation.* West Indian cultivars need to be exposed to higher temperatures than Mexican and Guatemalan cultivars for flower initiation. High temperatures appear to be correlated to small fruit size in late maturing varieties. Hass in warm coastal Australia is 30% smaller than fruit grown in the cooler highlands. [This is also true for the vicinity of the sea of Galilee in Israel where summer temperatures often exceed 40°C (104°F). Hass fruit is so small to the point that the variety is not cultivated at all. Other varieties such as Fuerte, Ettinger, Reed, and Pinkerton are very productive there and produce large fruit]. There are several theories to explain this, but the phenomenon is not well understood. One theory observes that late maturing cultivars appear to have a higher respiration rate (the process, which greatly influenced by temperature, by which cells obtain energy from organic material) than early maturing varieties.

The Australian avocado industry, like other avocado groups around the globe, is faced with problems of sustained productivity, fruit size, accessibility to information, and technology transfer. Australia's problem is compounded by the fact that avocados are grown on both sides of a continent the size of the continental United States where diverse climatic zones range from tropical to sub-tropical to semi-arid. Using the most current computer technology, the Australians embarked upon a project to create a software package to address these and other concerns. What they have come up with is a tripartite program called AVOMAN, written in MS Windows 95, which is composed of AVOINFO, AVOREC, and AVOGRO. There are some 130 participants in the experimental version of AVOMAN which is currently being tested in Australia.

AVOINFO is a stand alone, user-friendly, reference database of literature titles and related abstracts, diagnostic information, and quality related facts useful to avocado growers, merchandisers, and researchers. There are currently some 4,000 articles, and many more will be added when royalties and abstracts concerns are resolved. AVOINFO will be available to Australian growers on a compact disc, or possibly on the Internet.

AVOREC is a database structure where growers can input a variety of information, in response to very detailed questions, about their individual farm blocks. Each database table in AVOREC represents a production unit. Updated records are kept, ranging from soil information, age of the trees, varieties, rootstocks, tree spacing, canopy size, irrigation information, and productivity data.

AVOGRO utilizes AVOREC data to produce cultural recommendations to the user. Depending on the completeness of the information that is available to AVOGRO through the growers' input into AVOREC, recommendations are generated with a confidence level ranging from 20% to 95%. The recommendation algorithm for irrigation and fertilization utilizes the phenology of a particular variety in a particular environment. Knowledge of the phenology is crucial to making the most accurate cultural decisions. Growers throughout Australia meet in regional productivity groups to discuss and record information about their trees, their growth cycles, and their tree habits. These growers collect data, which are compiled by a program team, and thus increase the size and quality of the database underlying AVOGRO decision making. Because of current technology limitations, this is as close as one can get to an expert system.

I asked Dr. Whiley whether his industry would consider going on line with AVOINFO, where subscribers can gain access for a fee. He said that it is the intention to make this software internationally available. *[The California avocado industry can ill afford to be without such a tool. Additionally, for us to develop our own AVOINFO will be very costly and redundant].* AVOREC and AVOGRO, customized and updated periodically, could be purchased as a management program by growers anywhere. Obviously, local phenology modeling must be more complete than what is currently available before AVOMAN could become a universal program. Dr. Whiley promised to look into the various options, particularly since funding in Australia may run out in two years.

This report represents trends in research coming out of Australia, New Zealand South Africa, and to some extent California and Israel. Dr. Whiley is on the right track to identify the limiting factors for avocado productivity and finding ways to minimize their negative effects. His research and his participation in the dissemination of information are an important link in bridging the products of research with the practicing avocado farmers around the globe.