Fertilization of Perennial Tree Crops: *Timing is everything!*

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Introduction

There are key stages in the phenology of every plant that have a greater demand for nutrients than others. For perennial tree crops, flowering, fruit set (with its associated period of early fruit drop) and June drop [the period of fruit drop (approx. June through July) that occurs when exponential fruit growth and vegetative shoot and root growth are simultaneous (Hamid et al., 1988)], are phenological stages of high nutrient demand. It is during these stages that the greatest gains in fruit number and retention, determinants of final yield, can be made. Moreover, events or treatments during these stages of phenology also impact fruit size, quality and storage life. The uptake of adequate amounts of nutrients during the period of flowering and fruit set can be compromised by cold, wet soil (Hamid et al., 1988), creating nutrient deficiencies that persist until the soil warms. A deficiency identified by visual symptoms or leaf analysis, even a transient or incipient deficiency, should be corrected quickly. The longer the tree's nutrient status remains at the low end or below the optimal range, especially during stages critical to yield, the greater the negative effects on yield, fruit size, quality and next year's bloom. Foliar fertilization can successfully supply essential nutrients more rapidly and more efficiently than soil fertilization. Application of zinc (Zn), manganese (Mn), boron (B) and molybdenum (Mo) to foliage was four to 30 times more efficient than soil application (PureGro, n.d.). Foliar fertilization has several additional advantages over traditional soil-applied fertilizer. Foliar fertilization can meet the tree's demand for a nutrient at times when soil conditions (low temperature, low soil moisture, poor drainage, pH, salinity) would render soil-applied fertilizers ineffective. Thus, foliar fertilization is an effective method for correcting soil deficiencies and overcoming the soil's inability to transfer nutrients to the plant. Nutrients, especially phosphate, potassium and trace elements can become fixed in the soil and unavailable to plants. Applying nutrients directly to leaves, the major organ for photosynthesis, ensures that the plant's metabolic machinery is not compromised by low availability of an essential nutrient. It is important to note that foliar-applied fertilizers of phloem mobile nutrients are translocated to all parts of the tree, including the smallest feeder roots. Moreover, foliar fertilizers reduce the potential for accumulation of nutrients in soil, run-off water, surface water (streams, lakes and oceans), and groundwater (drinking water supply), where they can contribute to salinity, eutrophication and nitrate contamination, all of which have serious consequences for the environment and humans. Replacing soil-applied fertilizer, at least in part, with foliar-applied fertilizer contributes to fertilizer best management practices (BMPs).

However, it must be noted that not all nutrients are taken up through the foliage of all plants and, even if taken up, some nutrients are not phloem mobile. *A priori* knowledge (research) is necessary to develop a foliar fertilization program for a crop. Whereas rates of foliar fertilizer are typically lower than soil-applied fertilizer, application of foliar fertilizer can be, in some instances, more expensive due to the need to use spray equipment. Thus, a goal of the author's research program has been to identify the role that the essential nutrient elements play in the physiology of a tree crop and then to apply the nutrient as a fertilizer to the foliage at the appropriate time in the phenology of the tree, i.e., a time when the demand for the nutrient is likely to be high, in order to stimulate a specific physiological process that increases yield, fruit (or nut) size or fruit (or nut) quality, such that the foliar application of the fertilizer results in a net increase in grower return even when the tree is not deficient in the nutrient by standard leaf (or petiole) analyses (Lovatt, 1999). The goal of the author's research is to obtain a plant growth regulator effect, yield benefit and net increase in grower income from a foliar-applied fertilizer by properly timing its application.

Due to the varying influences of edaphic and climatic factors, exactly when and how much soil-applied fertilizer the plant takes up remains largely speculative. Still timing is important. For example, to protect the groundwater from potential nitrate pollution, growers of the ‘Hass’ avocado (*Persea americana* Mill.) in California divide the total annual amount of nitrogen (N) into six small soil applications made from late January to early November. The lack of research data raised the question of whether ‘Hass’ avocado yield was being compromised by this fertilization practice. The author (Lovatt, 2001) addressed the question of whether yield of ‘Hass’ avocado could be increased by doubling the amount of N applied in one of the six applications if it was timed to meet the nutrient demands of a specific key stage of avocado tree phenology. The results of this research provided clear evidence that time of N fertilizer application to the soil was an important factor in determining final yield and fruit size, as well as yield the following year (Lovatt, 2001).

With the price of fertilizer continuing to increase, timing the application of foliar, and even soil-applied, fertilizers to stages of crop phenology with high nutrient demand makes sense. Not only will the crop utilize a greater amount of the nutrient applied, but also meeting the crop's nutrient demand will result in a yield benefit and an increase in net income to the grower. Use of foliar-applied fertilizers at key stages of crop phenology when soil conditions impede the uptake of soil-applied fertilizers is a judicious approach for enhancing yield and grower income.

Examples of Properly Timed Foliar-applied Fertilizers that Prove the Concept

Winter prebloom foliar applications of low-biuret urea or potassium phosphite (a form of P [HPO_3^{-2}] readily taken up by leaves and translocated through trees to the roots [Lovatt and Mikkelsen, 2006]) have been shown to increase total yield, yield of commercially valuable large size fruit and total soluble solids (TSS) of sweet oranges (*Citrus sinensis*) (Albrigo, 1999; Ali and Lovatt, 1992, 1994; Lovatt, 1999); when low-biuret urea and potassium phosphite were combined, the yield benefits were additive (Albrigo, 1999). When used as a winter prebloom foliar spray on navel oranges in California, low-biuret urea (46-0-0, ≤ 0.25% biuret) applied at 50 lb low-biuret urea (23 lb N) in 200 gallons water per acre (25.8 kg N in 1869 L/ha) resulted in an average net increase in yield of 3 US tons per acre (7 metric tons per ha) annually for the 3 years of the experiment (Ali and Lovatt, 1992, 1994; Lovatt, 1999). Furthermore, as total yield increased per tree, the yield of commercially valuable large size fruit (transverse diameter 2.7-3.5 inches; 6.9-8.8 cm; packing carton sizes 88+72+56) also increased (Ali and Lovatt, 1994; Lovatt 1999). NOTE: Lower spray volumes can be used as long as tree coverage is good, but volumes of 500 to 700 gallons per acre (4,673-6,542 L/ha) showed greater incidence of tip burn due to pooling of the solution at the leaf tip.

The potassium phosphite formulation that has been used on perennial tree crops in all US research trials reported in the literature thus far is Nutri-Phite (Biagro Western Sales, Inc., Visalia, Calif.). Nutri-Phite (0-28-26) applied as a winter prebloom spray at 2.6 quarts (0.64 gallons) in 200 gallons water per acre (6 L Nutri-Phite in 1869 L/ha) to Valencia oranges in Florida resulted in an annual net increase in total yield of 3 US tons per acre (7 metric tons per ha), whereas the winter prebloom urea treatment resulted in a net increase of only 1.8 US tons per acre (4 metric tons per ha) (Albrigo, 1999). Both treatments significantly increased the total soluble solids concentration of the fruit. Use of urea and potassium phosphite in Clementine mandarin (*C. reticulata*) production in Morocco produced similar beneficial yield results (El-Otmani et al., 2003a, b).

To increase fruit size of navel oranges, potassium phosphite is applied to the foliage in May (during the cell division stage of fruit development) and again in July (at maximum peel thickness, which marks the end of the cell division stage of citrus fruit development) or a single application of low-biuret urea is made at maximum peel thickness in July. Potassium phosphite [Nutri-Phite, 0-28-26] is applied in two sprays at 2 quarts (0.49 gallons) in 200 gallons water per acre for each application (4.6 L Nutri-Phite in 1869 L/ha). The first application targets May 15 ± 7 days and the second targets July 15 ± 7 days. This treatment resulted in a 3-year cumulative net increase of commercially valuable large size fruit (transverse diameters 2.7-3.5 inches; 6.9-8.8 cm) of 4 US tons per acre (9 metric tons per ha) (Lovatt, 1999). When applied in the summer at maximum peel thickness, low biuret urea (46-0-0, $\leq 0.25\%$ biuret) is applied as a single spray targeting July 15 ± 7 days at 50 lb low-biuret urea (23 lb N) in 200 gallons water per acre (25.8 kg N in 1869 L/ha). This treatment resulted in a 3-year cumulative net increase of commercially valuable large size fruit (transverse diameters 2.7-3.5 inches; 6.9-8.8 cm) of 6.25 US tons per acre (14 metric tons per ha) (Lovatt, 1999). Additionally, the yield of commercially valuable large size 'Sunburst' tangerine (*C. reticulata* x *C. paradisi*) fruit was increased with three foliar applications of potassium nitrate (KNO_3) (25 lb KNO_3 in 250 gallons of water per acre per application (11 kg KNO_3 in 2336 L/ha) at dormancy (February), post-bloom (~April) and exponential fruit growth (July-August) (Boman, 2002). The treatment increased the number of commercially valuable large size fruit at the first pick by 30% and resulted in a 23% increase in commercially valuable large size fruit harvested over the season and an average annual net increase in grower return of $2,626 per acre.

Foliar application of potassium sulfate (K_2SO_4) at the post-shooting stage of banana (*Musa* spp.) increased yield, fruit quality and post-harvest shelf-life (Kumar and Kumar, 2007). Foliar-applied potassium during cantaloupe (*Cucumis melo*) fruit development and maturation improved fruit market quality by increasing firmness, sugar content, and nutritional value through increased beta-carotene, ascorbic acid and K concentrations in the edible flesh (Lester et al., 2007).

For avocado, canopy applications of B at 1.45 lb in 200 gallons of water per 110 trees per acre (1.63 kg B in 1869 L/ha) or urea-N at 50 lb (46-0-0, $\leq 0.25\%$ biuret; 23 lb N) in 200 gallons water per acre (25.8 kg N in 1869 L/ha) just prior to avocado inflorescence expansion (cauliflower stage of inflorescence development), significantly increased the number of viable ovules and increased the number of pollen tubes that reached the ovules (Jaganath and Lovatt, 1998). These treatments resulted in a 3-year cumulative net increase of 5.4 and 5.0 US tons per acre (12.2 and 11 metric tons/ha) for boron and urea, respectively (Lovatt, 1999). Earlier (bud break) applications were not effective; later (full bloom) applications were intermediate in effect. B is also known to stimulate cell division and increase fruit set and fruit size of many crops, even seedless fruit, and even when leaf analyses indicate B is adequate. NOTE: B and urea-N should not be applied as a single spray to avocado as double pistils result. The effect of the combined treatment on other crops is not known.

Foliar-applied potassium phosphite [Nutri-Phite, 0-28-26; 2.6 quarts in 200 gallons water per acre (6 L Nutri-Phite in 1869 L/ha)] increased 'Hass' avocado total yield ($P = 0.0640$) and yield of fruit of packing carton sizes 60 (fruit weighing 6.3-7.5 oz; 178-212 g) ($P = 0.0534$) and 48 (fruit weighing 7.51-9.5 oz; 213-269 g) ($P = 0.0644$) and the combined pool of fruit of packing cartons sizes 60+48+40 (fruit weighing 6.3-11.5 oz; 178-325 g) ($P = 0.0595$) as both kg and number of fruit per tree in the off-crop year but had no significant effect in the on-crop years. As a result foliar-applied potassium phosphite significantly increased the 3-year cumulative yield of commercially valuable large size fruit in the combined pool of fruit of packing carton sizes 60+48+40 compared to trees receiving potassium phosphate to the canopy or to the roots. Based on a standard 240 trees per ha, foliar-applied potassium phosphite produced a 3-year cumulative net increase in commercially valuable large size fruit (packing carton sizes 60+48+40) of 3,769 or 3,364 lb per acre (4,224 or 3,770 kg/ha) compared to trees receiving foliar-applied potassium phosphate or control trees receiving soil-applied potassium phosphate, respectively. The net increase in yield of commercially valuable fruit produced a net increase in grower income, making the treatment cost-effective (Gonzalez et al., in press).

In the cases cited above, proper timing of the foliar fertilizer application was a factor in increasing commercial yield or improving fruit quality parameters, including increased fruit size. Moreover, these results were attained even though the crops were not nutrient deficient based on standard nutrient analysis for the crop.

An Example of Properly Timed Soil-applied Fertilizer that Supports the Concept

To protect the groundwater from potential nitrate pollution, growers of the ‘Hass’ avocado in California divide the total annual amount of N fertilizer into six small soil applications made during the period from late January to early November. This grower practice of annually applying N as NH_4NO_3 at 150 lb per acre (168 kg/ha; 168 trees/ha) in six small doses of N at 25 lb per acre (28 kg/ha) in January, February, April, June, July, and November served as the control in the following experiment, in which additional N as NH_4NO_3 at 25 lb per acre (28 kg/ha) was applied at one key stage of avocado tree phenology for a total annual N of 175 lb per acre) (196 kg/ha) (Lovatt, 2001). Two phenological stages were identified for which N application at 50 lb per acre (56 kg/ha) in a single application (double dose of N) significantly increased the 4-year cumulative yield (kilograms fruit per tree) 30% and 39%, respectively, compared to control trees ($P \leq 0.01$). In each case, more than 70% of the net increase in yield was commercially valuable large size fruit (fruit weighing 178-325 g). The two phenological stages were: (1) when shoot apical buds have four or more secondary axis inflorescence meristems present (mid-November) and (2) anthesis-early fruit set and initiation of the vegetative shoot flush at the apex of indeterminate floral shoots (approx. mid-April). Application of the double dose of N at flower initiation (January), during early gynoecium development (February), or during June drop had no significant effect on yield or fruit size compared to control trees.

Application of the double dose of N in April significantly reduced the severity of alternate bearing ($P \leq 0.05$). Yield was not significantly correlated with leaf N concentration. When the amounts of N applied were equal (175 lb/acre; 196 kg/ha), time of application was an important factor, affecting yield, fruit size and the severity of alternate bearing.

Conclusion

Time and rate of fertilizer application are factors that can be optimized to increase yield, fruit (or nut) size, and fruit (or nut) quality of perennial tree crops. Applying fertilizers to the soil, or foliage, at key stages of crop phenology when nutrient demand is high is fundamental to fertilizer best management practices because it improves fertilizer-use efficiency, is cost-effective and protects the environment. Moreover, incipient or transient nutrient deficiencies at phenological stages critical to yield, fruit (or nut) size or quality, reduce annual production and grower income in accordance with "Leibig's law of the minimum", i.e., crops can only yield to the level supported by the most limiting factor. The key to achieving a yield benefit and net increase in grower income is (1) to properly time soil-applied fertilizers when it is known that a specific essential nutrient is ineffective as a foliar fertilizer with a given crop and (2) to properly time foliar-applied fertilizer to specific stages of crop phenology when nutrient demand is likely to be high or when soil conditions are known to restrict nutrient uptake. For citrus and avocado tree crops, this approach is in contrast to the earlier standard application of foliar fertilizers at 2/3-leaf expansion to target foliage with a thin cuticle and large surface area to achieve yields equal to those attained with soil-applied fertilizer (Embleton and Jones, 1974; Labanauskas et al., 1969). With demonstration that properly timed foliar fertilization strategies can be used reliably to increase yield parameters of citrus, avocado and other crops and grower net income (Ali and Lovatt, 1992, 1994; Lovatt 1999), growers will increasingly replace soil-applied fertilizer, at least in part, with foliar-applied fertilizer, improving fertilizer efficiency and protecting the environment. As the cost of fertilizers continues to increase, the benefit of shifting from soil-applied fertilizer to properly timed foliar-applied fertilizers will also increase.

It is clear that the use of foliar fertilizers when uptake of nutrients from the soil is compromised and/or when nutrient demand is too high to quickly correct nutrient deficiencies—even ones that are transient or incipient—is a cost-effective means to reduce overall fertilizer use and obtain a yield benefit that results in a net increase in grower income even when trees are not deficient by standard analyses for the crop. Results presented herein provide strong evidence that when it comes to foliar fertilization, and even soil fertilization, timing is everything.

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