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Successful Use of Foliar Applications of Essential Mineral Nutrient Elements to Increase Fruit Set and Yield of Citrus and Avocado

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The importance of pollination as a factor influencing fruit set and final yield depends on the crop species, cultivar, prevailing climatic conditions, and cultural practices used in the orchard. For the navel and 'Valencia' sweet orange cultivars which dominate the citrus industry in California, pollination is inconsequential to fruit set. For the production of seedless mandarins, pollination must be prevented. In contrast, for the 'Hass' avocado, pollination is the first step in the process leading to fruit set. Pollination is defined in this review as the arrival of the pollen (the male part of the reproductive cycle) on the stigma of the pistil (the female part of the flower). Here the pollen germinates, producing a pollen tube which grows through the stigma, style and ovary tissues, to the ovule which contains the egg. This sequence of reproductive events is illustrated for the 'Hass' avocado in Fig. 1. Once the pollen tube delivers the sperm to the egg, the sperm and egg must fuse, a process called fertilization. The product of fertilization is the embryo, which will produce the young seedling tree, located within the ovule. After fertilization, the ovule develops over time into the seed within the ovary, which subsequently develops into the avocado fruit. The seed provides plant growth regulators necessary for fruit set and fruit development, a function attributed to the placenta in seedless fruit. The biological process resulting in fruit set can be influenced at many different steps by external environmental and internal plant factors, which can reduce or increase the importance of pollination to final yield.

The seasonal cycles of flowering, fruit set and fruit development for the 'Hass' avocado and 'Washington' navel orange in California are depicted chronologically in Figures 2 and 3. For citrus and avocado, as well as other tree crops, the fruit set/early fruit drop period is the most critical stage of fruit development from the grower's point of view. It is during this period that the greatest gains in fruit retention influencing final yield can be made. It is important to note that the final number of fruit set is a function of factors affecting tree physiology prior to, as well as those occurring during, this critical period.

Properly timed foliar applications of nitrogen, phosphorus, and boron have been used successfully by several researchers to increase fruit set and yield of citrus or avocado trees having optimal levels of these essential nutrient elements based on standard commercial leaf analyses. Nutrient treatments, fertilizer doses, time of application, and physiological basis for increased fruit set and yield are discussed.

For the three successive harvests from 1990 through 1992, Ali and Lovatt (1994) successfully increased fruit set and yield of the 'Wash-

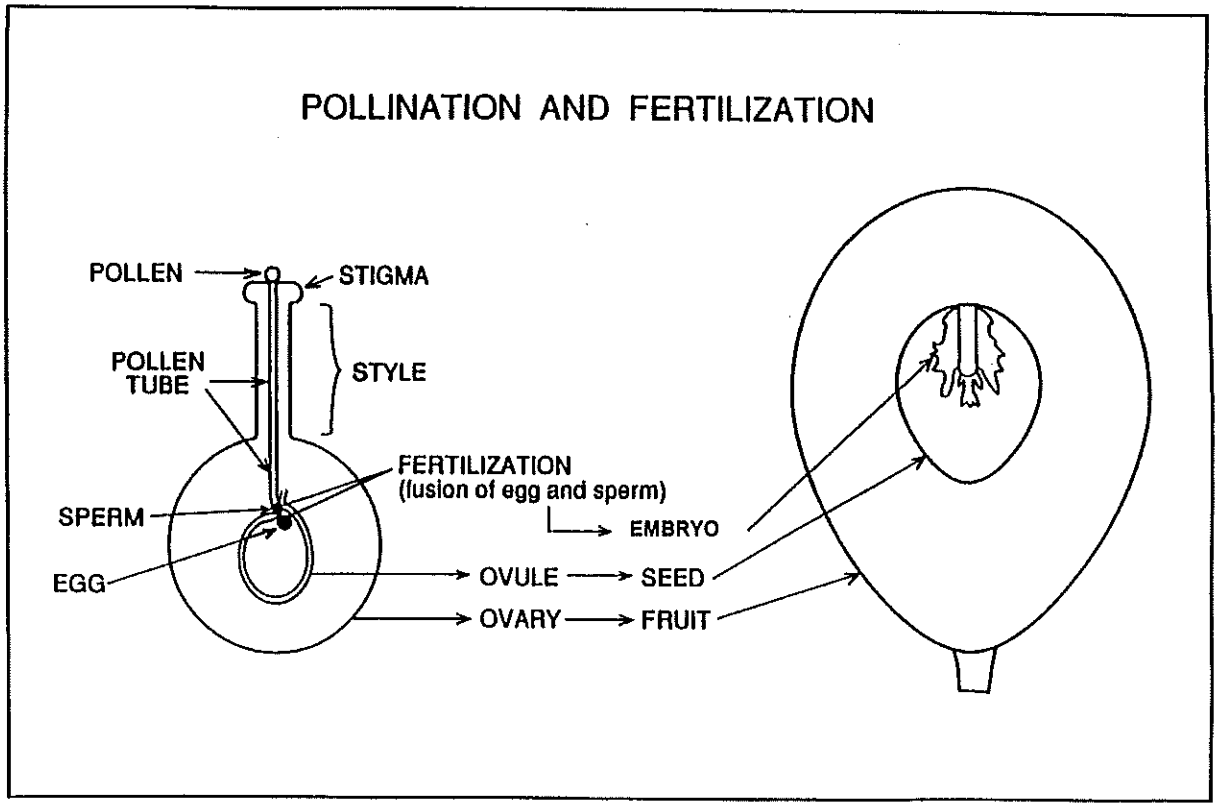

Fig. 1. An overview of the role of pollination in avocado fruit development.

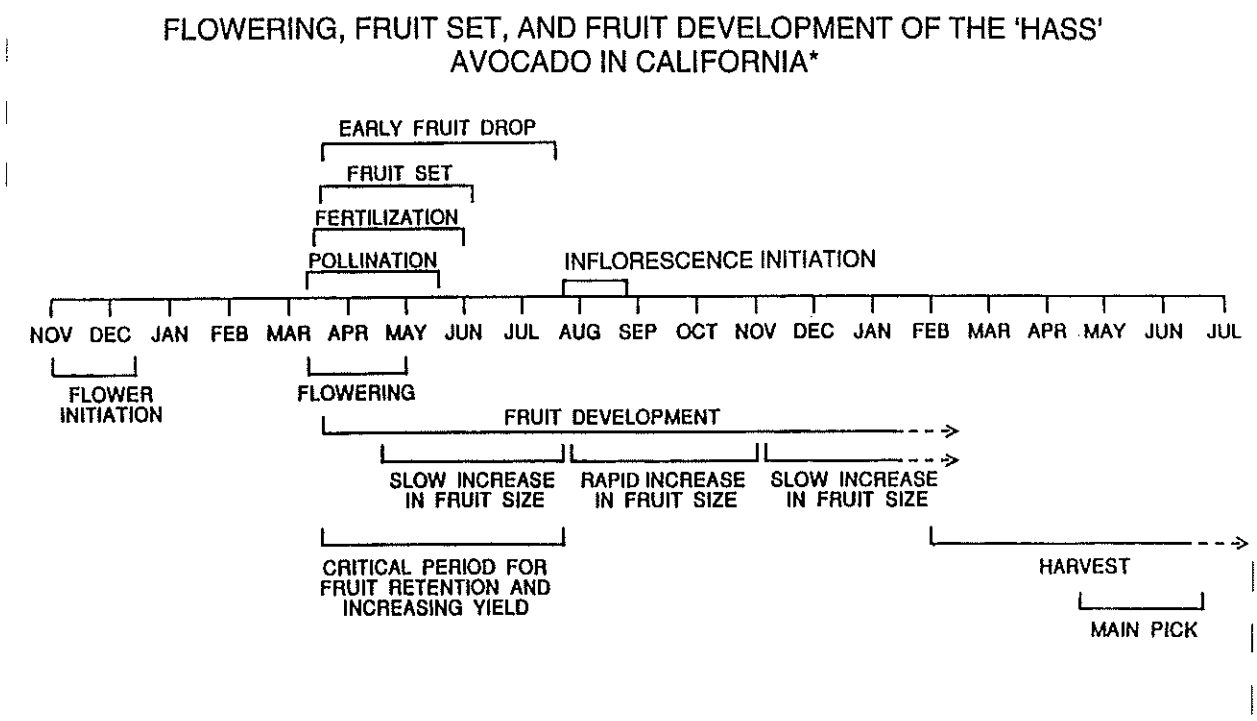

Fig. 2. Phenology model of the 'Hass' avocado based on San Diego - Riverside environmental conditions.

ington' navel orange with a winter prebloom application of low biuret urea applied to the foliage to the point of run-off at a final concentration of 0.5% N (as Unocal Plus, 20% N, 0.1% biuret), to provide 0.16 kg N per tree (approx. 28 lbs N/acre). The foliar application of urea made on January 15, the approximate time of irreversible commitment to flowering for the Southern California orchard in which the research was conducted (Lord and Eckard, 1987), significantly increased yield for all three years of the study ($P<0.05$). The December 15 and February 15 applications increased yield ($P<0.05$) in two of the three years. In addition, the winter prebloom foliar application of urea resulted in a significant increase in the number of fruit of commercially valuable sizes (packing carton sizes 88 and 72). The results of Ali and Lovatt (1994) have recently been confirmed in Florida. At the 50th Anniversary of the Indian River Citrus Seminar on March 5, 1997, Gene Albrigo reported in his presentation titled "Foliar Application of Major Elements for Flowering and Fruit Set" that a winter prebloom application of low biuret urea (0.16 kg N/tree; 28 lbs N/acre) significantly increased flower number, fruit set and yield of the 'Valencia' orange. In addition, Albrigo subsequently found that the winter prebloom foliar application of urea increased total soluble solids at harvest. In his presentation, Albrigo also reported that a winter prebloom foliar application of phosphorus as phosphite (Nutri-Phite, 0-28-26) at the rate of 2.6 quarts per acre increased flower number, fruit set and yield, and total soluble solids per acre of the 'Valencia' orange. We are currently determining the optimal time to apply the winter prebloom foliar applications of low biuret urea and phosphite to increase fruit set and yield in San Joaquin Valley orchards. In addition, we are evaluating the ability of these and later urea and phosphite treatments to increase fruit total soluble solids and to reduce acidity early in the season with goal of earlier harvest.

Research on the use of foliar applied boron to increase fruit set and yield of seeded crops has been extensive because of the well documented positive effects of this essential mineral nutrient element on pollen germination and growth of the pollen tube through the stigma, style, and ovary to the ovule, on the mitotic divisions necessary to produce the sperm and egg, and on cell division during the early stages of fruit development (Lovatt and Dugger, 1984). In South Africa, Robbertse et al. (1990, 1992) demonstrated that when pistils harvested from avocado trees receiving a foliar application of boron were pollinated with pollen from trees also sprayed with boron, pollen germination and pollen tube growth were significantly better than in flowers from untreated trees. However, statistically significant yield increases in response to foliar applied boron were only achieved in some orchards and in some years (Coetzer et al., 1993). In our experiments, boron as sodium tetraborate ($Na_2B_4O_7 \cdot 10\ H_2O$, Solubor, 20.5% B) was applied at a dose of 6 grams B per tree in sufficient water to give full canopy coverage during the cauliflower stage of inflorescence development (the stage characterized by elongation of the secondary inflorescence axes). This stage was determined to be optimal from the results of our field research, but recent research from my lab determined that during the cauliflower stage, pollen and ovule development is proceeding within the flowers (Salazar-Garcia et al., in press). This treatment significantly increased the number of pollen tubes that reached the ovule, ovule viability, and cumulative yield ($P<0.05$) (Jaganath and Lovatt, 1995). Nitrogen, as low biuret urea (Unocal Plus, 20% N, 0.1% biuret) was applied at 0.16 kg N per tree in sufficient water to give full canopy coverage to 'Hass' avocado trees during the cauliflower stage of inflorescence development. This treatment significantly increased the number of viable ovules, the number of pollen tubes that successfully reached the ovule, and cumulative yield ($P<0.05$) (Jaganath and Lovatt, 1995). The trees

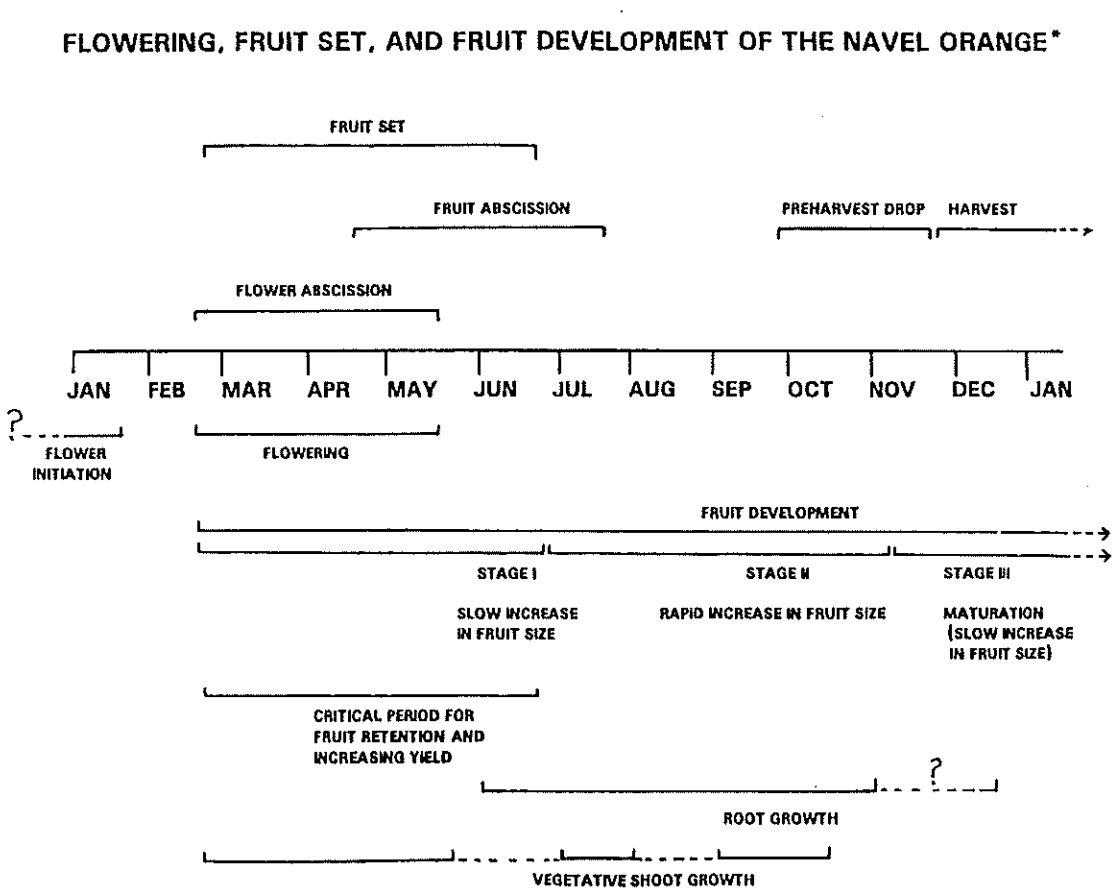

Fig. 3. Phenology model of the navel orange based on 25-year-old 'Washington' navel orange trees on Troyer citrange rootsock at Riverside, California.

had sufficient levels of boron and nitrogen throughout the study according to standard leaf analyses done annually. Statistically significant yield increases were only achieved in several and different years for boron and nitrogen over the five years of the experiment. Applying boron and nitrogen as a combined treatment reduced yield and is not recommended. Applying the foliar boron or nitrogen treatments to trees with high leaf concentrations of boron (180 ppm B by leaf analysis) reduced yield in some years (not significantly) and is not recommended due to the potential negative effect on cumulative yield. Annual applications of boron should be made in conjunction with leaf analyses to monitor boron accumulation in the orchard. We are currently testing the hypothesis that levels of boron higher than those currently cited as optimum by leaf analysis may be necessary for higher fruit set and yield for the 'Hass' avocado in California. Our results and those of Robbertse et al. (1992) strongly suggest that boron should be applied to the canopy in order to increase fruit set and yield. Robbertse et al. (1992) reported that root absorption of boron is restricted. Jaganath and Lovatt (1995) could not increase yield with trunk injections of boron even though trunk injections increased the boron status of the trees to a greater degree than the canopy sprays. Urea must be applied directly on the inflorescences because mature leaves of the 'Hass' avocado under Southern California conditions do not take up urea (Nevin et al., 1990).

An interesting observation was made in the study of Jaganath and Lovatt (1995). Open pollinated 'Hass' avocado flowers from untreated field trees had many pollen grains, which had successfully germinated, but growth of the pollen tubes had ceased mid-style. The prebloom canopy sprays of nitrogen and boron, to a significantly greater degree than nitrogen, increased the number of pollen tubes that grew completely through the style to the opening in the ovule, which is consistent with the breakdown of the barrier preventing self-fertilization (E. Lord, personal communication). Thus, in the absence of cross-pollination under adverse climatic conditions, boron or nitrogen sprays might facilitate self-pollination and increase yield, an event that would have no effect on yield if cross-pollination also occurred.

During "on" (heavy) crop years, in which the canopy application of low biuret urea at the cauliflower stage of inflorescence development had no significant effect on total kg fruit per tree, the treatment did increase the number of marketable size fruit (packing carton size #36 and 40) compared to the control ($P<0.06$). This increase in the number of marketable sized fruit was not due to any reduction in yield; trees receiving the prebloom application of low biuret urea yielded 189 kg fruit per tree (control trees, 187). While not statistically significant at the 5% level, it is worth noting that trees receiving a canopy

application of low biuret urea at the cauliflower stage of inflorescence development and a second when the spring flush leaves were 2/3 fully expanded averaged 223 kg of fruit per tree which was 36 kg (80 lbs) more fruit than the control. Consistent with the alternate bearing habit of the 'Hass' avocado in California, this treatment had a low yield the following year. Alternate bearing, alternatively or in addition to adverse climatic conditions, may be the reason that yield is not increased annually whereas cumulative yield is higher for 'Hass' avocado trees treated with foliar applications of boron or nitrogen for successive years compared to control trees.

Winter and spring foliar fertilizer applications likely increase fruit set and yield due to the fact that the availability of elements essential for flowering and fruit set is low due to reduced transpiration and/or nutrient acquisition by roots when air and/or soil temperatures are low. The key has been, however, to identify the specific nutrient elements to be applied and the role each plays in fruit set in order to determine the optimal time to apply the nutrient to stimulate a specific physiological process. A winter prebloom foliar application of nitrogen as urea or phosphorus as phosphite to citrus stimulated the flowering process to increase flower number, fruit set and yield. Our previous research provided evidence that foliar applied urea increased flowering by elevating the ammonia status of the tree, increased the polyamine content of developing citrus fruit, and that citrus fruit with a higher polyamine content have a higher potential to set (Lovatt et al., 1992). Albrigo's research was the first to demonstrate that winter prebloom foliar application of urea or phosphite increased total soluble solids in citrus fruit. If this occurs early in fruit development, improved carbohydrate status may be the basis for increased fruit set. The major effect of a foliar application of boron as sodium tetraborate or nitrogen as urea was the enhanced growth of pollen tubes past the mid-style region to increase the number of pollen tubes penetrating the ovule and a greater number of viable ovules, respectively. These results provide evidence that specific essential mineral nutrient elements can be applied as foliar fertilizers to stimulate very specific processes to successfully increase fruit set and yield of both citrus and avocado.

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Carol Lovatt's (Ph.D., Professor of Plant Physiology, Dept. of Botany and Plant Sciences, University of California, Riverside) research program includes the investigation of regulation of flowering, fruit set, and fruit development of citrus, avocado and pistachio and the effects of abiotic stresses on nitrogen metabolism.

Outcrossing in Avocado: Is There a Relationship to Fruit Yield?

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In recent years, 'Hass' has become the predominant variety grown in Southern California. This has led to trees of other varieties being removed from the grove. Along with these changes, there has been a drop in 'Hass' fruit production. Has the removal of other varieties from the grove, thus the absence of outcrossing, caused a drop in fruit production?

To address the issue of decreasing fruit numbers, our approach was to analyze the relationship between outcrossing and fruit yield. The four questions asked were: 1) What was the amount of outcrossing occurring in a 'Hass' grove when a tree of another variety served as a pollen donor?; 2) Does a correlation exist between the amount of outcrossing and the number of fruit on a 'Hass' tree?; 3) Does dis-