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Final Report Issued Giving Tools for Fertilization and Salinity Management

During the past five years, a team of researchers led by Dr. David Crowley, professor of plant soil relations, emeritus, have gathered data from hundreds of avocado trees across a transect of major avocado production areas in Southern California in order to model the relationships between leaf nutrient concentrations and the yields of avocado trees.

The project, funded by the California Avocado Commission, was initiated to develop Decision Support Tools (DST) that can be used by California avocado growers to improve fertilization and nutrient management and minimize the effects of soil salinity in a cost-effective manner. A variety of scientists, graduate students, undergraduate student volunteers, postdoctoral research associates, CAC staff and visiting foreign researchers from Chile, Mexico and Pakistan contributed to the project and the final report issued by Dr. Crowley and Salvatore Campisi, postdoctoral research associate.

Following is a synopsis of the final report, the research groups' major findings and nutrient interaction models, as well as a look at a possible prototype for an online version of the DST.

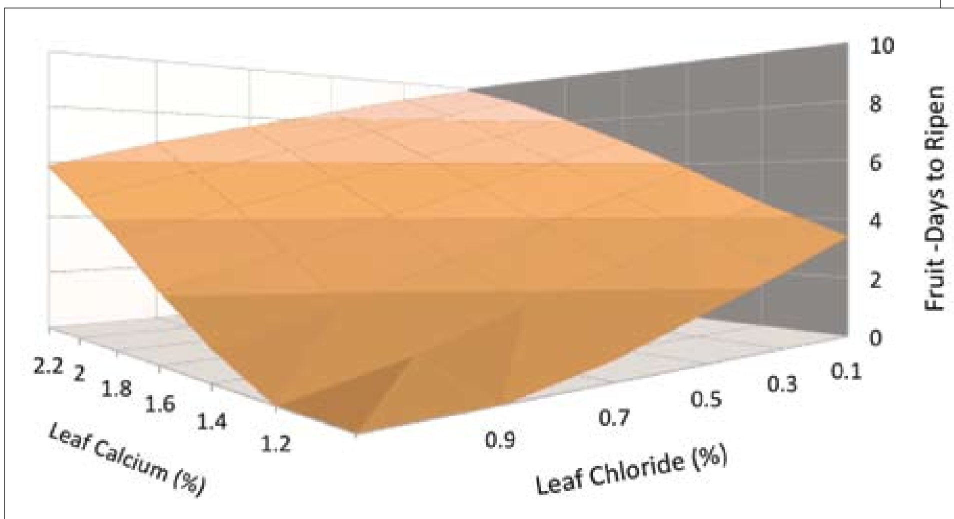

Figure 1. When fruit is removed from cold storage to ripen, high leaf chloride levels greatly reduce ripening time, thereby reducing time for transport and sale.

Final Phase

In the final phase of the DST project, researchers focused on translating all of the results into concise models that could be used in the development of an online DST for California avocado growers. During the earlier phases of the research, the team reported findings for nutrient-yield response relationships for each of the 11 individual elements monitored by leaf analysis and identified target ranges for each leaf nutrient element.

To develop the models that predict the nutrient-yield relationships of all possible combinations for the 11 elements, the researchers had to develop filters and mathematical models that could extract the relationships between yields and factors, such as chloride toxicity and alternate bearing. For example, modeling errors caused by alternate bearing trees are generated when heavy-yielding trees exhibit large nutrient removal in an on-cycle year, but accumulate nutrients during an off-cycle year. Similarly, low-yielding trees may be affected by other variables such as drought, summer heat fruit drop or poor pollination. The team thus developed filters to model trees with high yields that were not in an alternate bearing mode and whose nutrient profile should be duplicated across the orchard.

The team also refined Liebig's Law of the Minimum. This law states that "for any specific combination of elements, the *single element* that is most limiting must be corrected before any progress can be achieved by managing another element that is less limiting." For example, under Liebig's Law, chloride toxicity (the most limiting factor) would have to be alleviated before adjusting potassium, otherwise adjusting the potassium would have no affect on the yield. Because Liebig's Law does not take into account the effects of nutrient excesses or chloride toxicity, the Law was refined to measure not only how nutrient limitations affected potential yields, but also how nutrient excesses and interactions between nutrients affect fruit production.

The team then developed yield-response relationships for each individual nutrient and each nutrient pair, noting when nutrient interactions and imbalances would increase or decrease production and the resulting potential effect on yield. Having completed 482 hierarchical modeling analyses, the team developed a series of lookup tables for each element that help to identify the greatest constraint and illustrate how nutrient interactions affect avocado yield potential.

A summary of the earlier stages of the DST project can be found in the Fall 2015 issue of *From the Grove.*

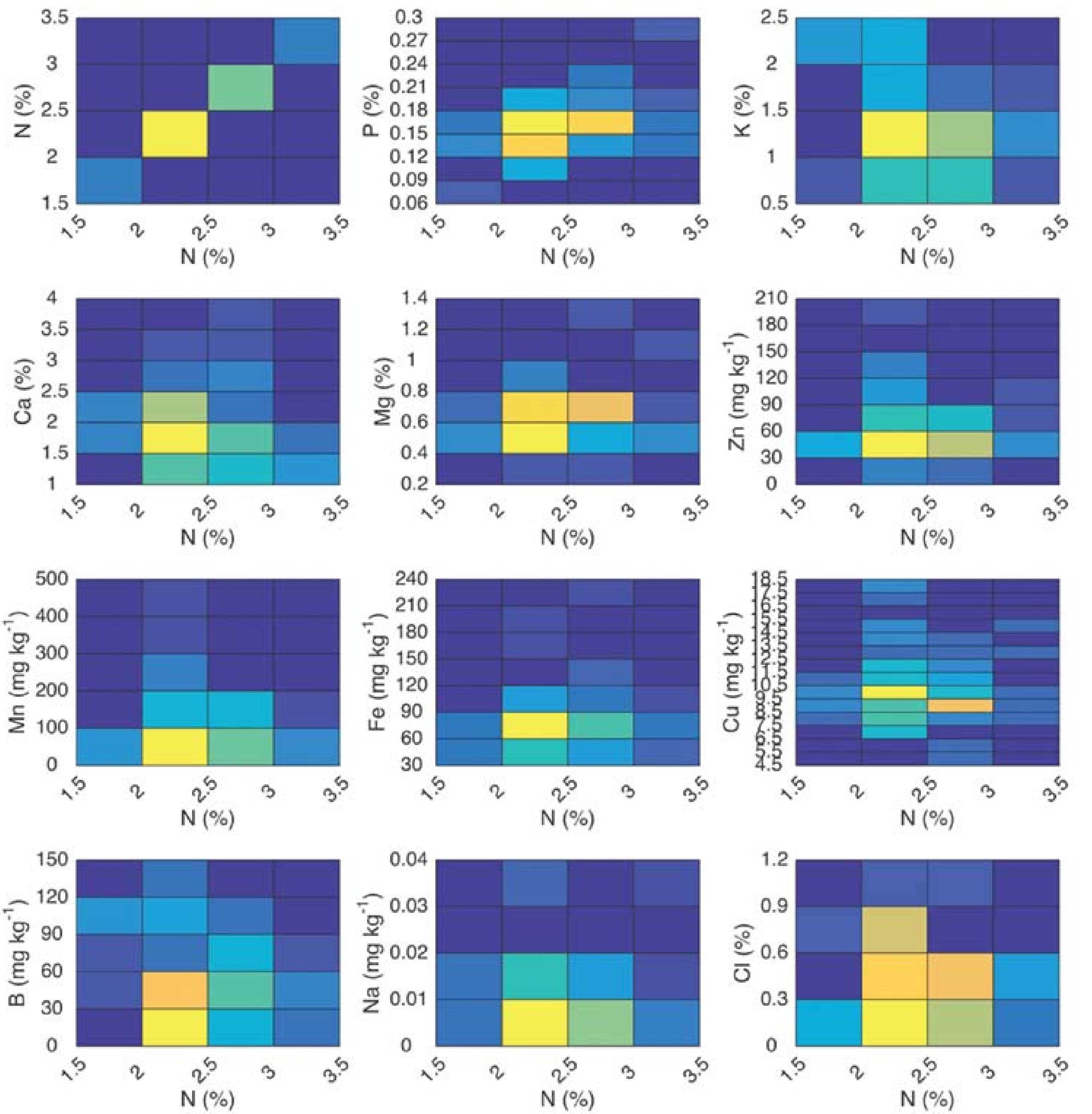

Figure 2. Production functional relationships for nitrogen and the other essential elements monitored by leaf analysis. Yellow indicates the ideal nutrient range for fruit production and dark blue indicates complete suppression of productivity.

Hass Plant Tissue Analysis

Sample Area	% Nitrogen	% Phosphorus	% Potassium	% Calcium	% Magnesium	ppm Zinc	ppm Manganese	ppm Iron	ppm Copper	ppm Boron	% Sodium	% Chloride
Tree # 01	2.98	0.193	1.07	1.19	0.540	28.9	41	73	6	60.8	0.006	0.233
Tree # 02	2.88	0.144	0.983	1.36	0.628	29.3	97	161	5	25.2	0.006	0.488
Tree # 03	2.93	0.147	1.20	1.25	0.610	27.3	96	83	6	15.1	0.005	0.421
Tree # 04	3.13	0.153	0.794	1.40	0.683	22.4	67	78	3	43.2	0.006	0.416
Tree # 05	2.85	0.162	1.87	1.38	0.557	31.6	77	63	4	31.8	0.006	0.549
Tree # 06	3.02	0.158	1.52	1.20	0.513	35.3	53	71	4	19.1	0.006	0.527
Tree # 07	2.93	0.142	0.960	1.47	0.664	26.3	63	76	4	27.6	0.007	0.568
Tree # 09	2.72	0.149	0.854	1.95	0.710	29.4	54	54	4	29.8	0.006	0.245
Tree # 10	3.11	0.165	1.52	0.954	0.414	39.7	65	71	3	24.4	0.007	0.314
Tree # 11	2.54	0.138	1.15	1.25	0.617	18.8	45	63	5	27.0	0.007	0.535
Tree # 12	2.83	0.156	1.30	1.10	0.483	23.2	47	72	4	26.7	0.006	0.463
Tree # 13	2.87	0.164	0.894	1.79	0.735	31.0	54	70	5	31.1	0.005	0.543
Tree # 14	2.91	0.158	1.66	1.12	0.514	31.4	44	61	4	28.6	0.009	0.498
Tree # 15	3.07	0.149	1.09	1.23	0.463	24.5	51	75	4	25.8	0.005	0.328
Optimum Range - Average	2.2 - 2.4	0.080 - 0.44	1.0 - 3.0	1.0 - 4.5	0.25 - 1.0	30 - 250	30 - 700	50 - 300	5 - 65	12 - 100	0.0 - 0.25	0.0 - 0.25

Good Problem Low High

Note: Color coded bar graphs have been used to provide you with 'AT-A-GLANCE' interpretations.

Figure 3. Sample of typical results for avocado leaf analysis, with existent optimal nutrient ranges listed in the bottom row.

Major Findings

Based on the data collected, it is evident that many of the California avocado growers are applying too much nitrogen and potassium and not applying enough sulfur and calcium (gypsum). This is critical because the researchers' models indicate that excesses of Nitrogen (N), Potassium (K) or over-fertilization of any element, can lead to "huge losses" in production.

In addition, data indicates that an avocado tree's nutritional status is linked to the alternate bearing cycle and may be a leading driver of placing the tree into such a cycle. Large nutrient imbalances between nitrogen and potassium were highly associated with alternate bearing trees.

During the study, researchers also examined the relationship between leaf nutrient values and avocado ripening time. Results indicate that chloride toxicity leads to greatly reduced shelf life, while increasing calcium can offset the shortened shelf life. The research team reports that more research is necessary to better understand this relationship.

Interactions of Pairwise Nutrient Combinations

The lookup tables that indicate how nutrient interactions affect the yield potential of avocado reveal a variety of interesting findings. Below are highlights from the final report. To review functional relationships for all 11 elements, California avocado growers can download a copy of the *Decision Support Tools for Management of Avocado Nutrition and Chloride Toxicity: Final Report* from the California avocado grower website.

Figure 2 (on page 27) is based on the lookup table for nutrient interactions with nitrogen. By examining these charts, we can make note of the following relationships between nitrogen and other nutrients:

- Nitrogen is optimal between 2 – 2.5 percent (indicated by the yellow box in the upper left hand chart on page 27)
- When nitrogen levels are high, growers must increase phosphorous (P) and K to maintain optimal productivity
- Calcium must be maintained between 1.5 – 2 percent in order to garner maximum yields
- If nitrogen is higher than 2.5 percent, excess calcium can seriously suppress yield
- If nitrogen is outside the ideal range, high amounts of iron have severe effects on production; the ideal range for iron is 60-90 parts per million (ppm)
- Optimal nitrogen levels are best paired with low levels of boron
- Excessive nitrogen and high chloride eliminate fruit production

The final report summarizes a number of nutrient interactions that will be of interest to growers. Some of the findings include:

- Yield losses associated with high leaf chloride levels caused by soil salinity can be partially alleviated with 30 ppm boron levels, 1.5 – 2 percent calcium levels and 1 – 1.5 percent potassium levels
- High leaf potassium is associated with greatly reduced yields
- A balance between iron and potassium is critical; low iron paired with high potassium or low potassium paired with high iron can significantly decrease yields
- Yield losses associated with high levels of boron can be alleviated by maintaining zinc concentrations between 30 – 60 ppm

Current avocado nutrient recommendations are based on those that were generated for citrus trees and adapted to avocado. Figure 3 is a sample of typical leaf analysis results for an avocado tree, with current optimal nutrient ranges listed in the final row. The research conducted by the DST team indicates that all of the optimal ranges listed in the bot-

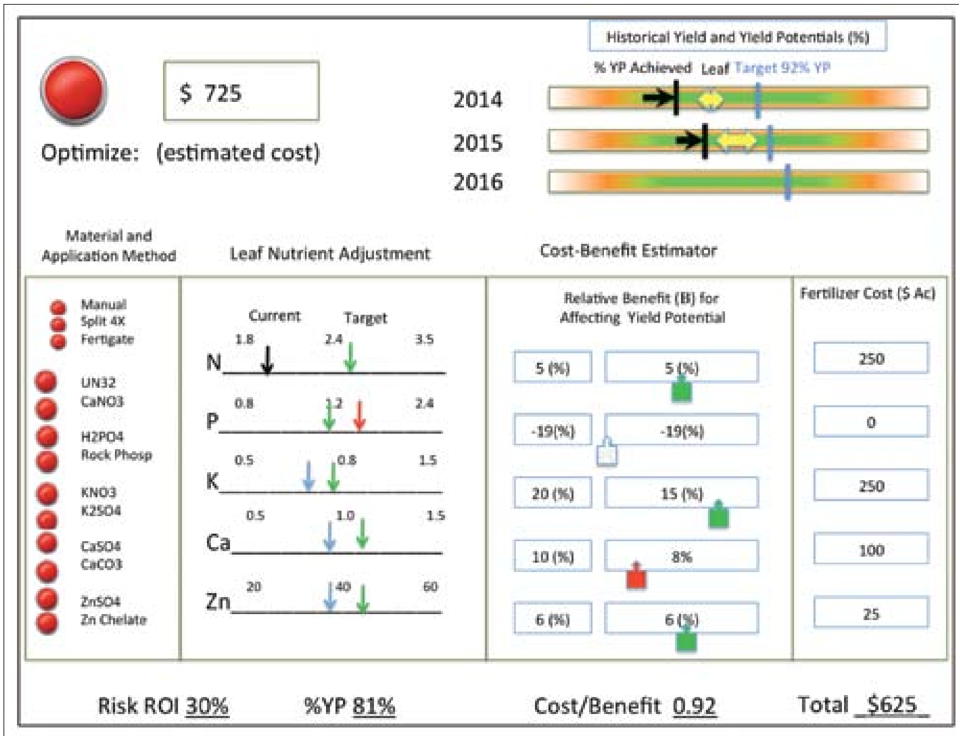

Figure 4. Draft concept for an online decision support tool that will help growers adjust nutrients and calculate the cost and cost-benefit ratio of adjusting fertilization methods.

tom row, except for nitrogen, will need "considerable revision" based on their findings.

The data sequence approach developed by the researchers involved in the DST project is a novel method for plant nutrition and as such the UC Office of Research has filed a patent application for this new intellectual property.

Online Decision Support Tool

Having completed the research and data analysis, the research team will now work to develop an online DST program that can be used by California avocado growers to optimize nutrient and salinity management in a cost-effective manner. Negotiations are underway with a software company to license the hierarchical data analysis and resulting predictive models for use by California avocado growers.

Figure 4 represents a draft concept of a DST webpage. Ideally, growers would enter leaf nutrient analysis data and the program would generate nutrient ratio calculations and specific recommendations concerning salinity and nutrient management. The recommendations would identify the most limiting constraint (the factor that would need to be addressed first, per Leibig's Law) and subsequent actions. The tool also would calculate cost and the cost-benefit ratio, as well as fertilizer schedules and grower reports.

While the research phase of the DST project has been completed, the researchers have identified new nutrient interaction factors worthy of further discussion (such as the calcium/chloride interaction relative to shelf-life) that could impact the avocado industry. The California Avocado Commission will keep growers abreast of the latest developments concerning the development of an online DST program, and will continue to partner with the research team as it completes the patent application and software development phases.