Re-evaluating Crop Nutrient Management In Light Of Spatial Variability in Orchard Crops

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ABSTRACT:

Ninety % of growers and consultants participating in the recent grower and consultant focus groups on nutrient management in tree crops, and the majority of respondents to an industry wide survey, felt that the University of California 'Critical Values (CV's)' for nutrient management in Almond and Pistachio, were invalid. Two explanations for this observation were suggested, 1) the current CV's are limited in application and are possibly incorrect, or 2) that there are systematic errors in the manner in which critical values are used. Review of current and historic data, however, indicated that the CV's for Almond and Pistachio production were reasonable and unlikely to be sufficiently incorrect to warrant the largely negative industry perceptions. It was apparent therefore, that there has been a systematic misuse of sampling methodology and an industry (and university) wide misinterpretation of results. In orchards and other high value crops, standardized leaf samples from plants scattered through the orchard are collected, analyzed for nutrients and compared with established CV's. If the resultant mean field nutrient concentration is equal or greater than the CV then the field is deemed to be sufficient. In high value crops, however, this is an invalid approach since it does not account for within field or between year variability and does not recognize that maximum profitability in these crops often requires that all individuals in a field meet or exceed minimal nutrient concentrations at all times. Discussions with plant nutritionists working in high value crops in the US and in the international community suggest that this 'simple' misinterpretation of the use and interpretation of tissue samples is widespread.

INTRODUCTION AND BACKGROUND

In tree crop production in California, leaf sampling and critical value analysis represents the primary tool for fertilizer decision making (Brown and Uriu, 1996). A recent focus group activity among leading growers, consultants and a subsequent survey of almond growers, however, demonstrated that > 90% of all respondents felt that UC Critical Values (CV's), especially for N and K, were not appropriate for current yield levels. A vast majority of growers also noted that CV's are of no use early in the season when in-season adjustments could still be made, and many noted that even if a sound leaf sample is taken that the analysis cannot be used to determine a specific fertilization response.

Ideally, critical values are established by carefully controlled experiments in which the relationship between yield and nutrient concentration is closely followed. The majority of critical values relating to almond and pistachio, however, have been determined on the basis of visual symptoms, not from yield reduction. Yield based determination of critical values in Almond, for example, are only available for N, K and B and to our knowledge there are no yield based CV's established for the essential elements P, Mg, Ca, S, Cu, Zn, Fe, Mn, Mo, Ni, or Cl.

The poor validation of current almond and pistachio CV's is further exacerbated by the very significant constraints to tissue sampling in a perennial species. The difficulties in obtaining a meaningful leaf sample have long been known. Many factors contribute to the variability among tissue samples even within a single tree. In Olive, the largest single influence on N concentration was light exposure. In 'Comice' pear fruits in west and south quadrants had more N than those from north and east locations. Fruits from the top and middle canopy levels had more N than fruit from the bottom level and peripheral leaves always had significantly higher leaf N than that of mid-stem or interior leaves. Crop load also influences nutrient variability. Leaves in bearing trees have significantly lower K than non-bearing trees in the growing season. In almond, both light exposure and crop load have important implications at least in leaf N.

The very great deal of variability in leaf nutrient concentrations seen in tree crops has resulted in the development of standardized sampling techniques that strive to limit variability from sample to sample. While it is true that the use of a standardized sampling protocol is essential if you are to contrast results with a pre-determined standard, this does not necessarily imply that such leaf samples are either the most sensitive or the most relevant indicators of tree nutrient status or potential for response. The choice of a July, non-fruiting, exposed spur leaf for nutrient analysis in Almond is clearly a compromise selected to ensure low variability, there has been no study (to our knowledge) that specifically attempts to determine the relative sensitivity of this standard leaf with any other leaf type, or time of sampling.

In addition to within-tree variability in leaf nutrient status, there is also a great deal of within orchard and between orchard variability that occurs as a consequence of variability between trees, changes in soil conditions and local micro-climate. Typically, this within field variability is not considered in sampling and as a consequence can lead to incorrect interpretation.

This principle is illustrated in the following graph of 50 independent single tree nutrient samples taken, one per row, across a mature Almond orchard (Figure 1). In this example leaf K concentrations vary greatly in the 50 sampled trees in this highly productive orchard. The average leaf K of this orchard in 2.0%, which is significantly greater than the UC recommended 1.4% K. Current UC recommendations would suggest this field, is over fertilized. The grower, however, is convinced, and has good yield records to verify it, that he obtains his highest yields when he targets a field average K concentration of 2.0%. The reason for this apparent disagreement is clear, by targeting a field mean of 2.0% the grower is ensuring that all trees in the orchard are above the critical required K concentration of 1.4%. Maintenance of the field at the UC recommended 1.4% mean value would result in 50% of all trees being deficient of K. In this instance the growers perception of the critical value was more sophisticated than the researchers.

These results highlight a pint that has been overlooked: For an individual plant the CV represents the minimum nutrient concentration in that individual that is required to attain 95% full yield. In a population of plants, however, the CV is the nutrient concentration of the population that results in 95% of all individuals attaining full yield. This population CV will always be greater than the CV of the individual by an amount determined by the variability in the population. Estimating field variability, is therefore essential if the true field CV is to be determined. None of the current texts or guidelines on nutrient management in tree species recognizes this issue and as a consequence we have been misusing the single most ‘trusted’ tool for nutrient management in tree crops .

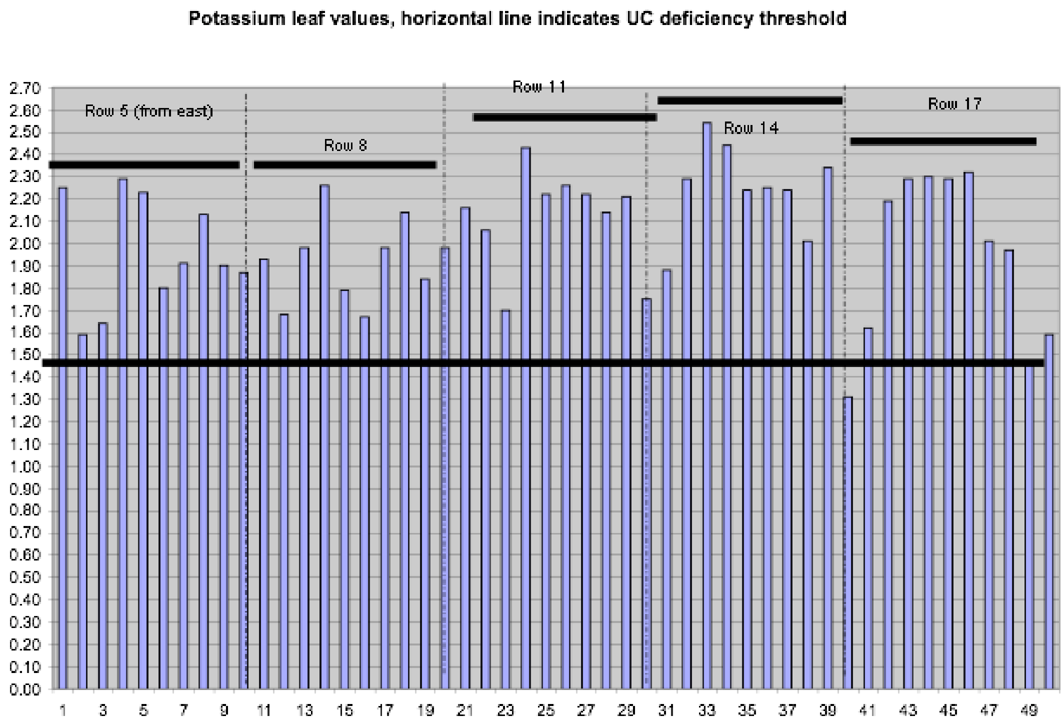

Figure 1: Leaf K values were determined in 50 individuals (1 per row) across a 50 acre orchard. The current CV for K in Almond is 1.5%. Here the grower has targeted a field CV of 1.9% with the resultant effect that yield response to K has been maximized and 95% of all individuals have a tissue K value exceeding 1.5%.

To further examine and illustrate the extent and nature of this ‘misuse’ of tissue sampling we have initiated a series of experiments in which the yields and nutrient use in large numbers of individual trees has been examined. Estimates of spatial, temporal, environmental and genetic components of nutrient variability are underway and will be used to develop new approaches to sampling methodology and nutrient management in high value crops.

PRELIMINARY EXPERIMENTATION AND RESULTS

Estimating Field Variability: In agronomic crops derived from genetically uniform material, field variability in yields and nutrient status is largely the result changes in local environmental (soil, water, micro-climate). In perennial crops field variability is not only a result of this local environmental effect but is also a consequence of significant variability in genetics of the rootstock, the life history of the plant (grafting, pruning, harvesting effects) as well as prior yield and growth of neighboring trees. The resulting complexity is therefore far greater. To address this an extensive Grid-Sampling protocol has been established at each of 5 separate sites across a transect across Californian Almond production regions, using techniques developed for GIS. In each orchard at 54 grid points uniformly distributed across a 10-15 acre block of trees, May and July leaf nutrient status, light interception, trunk diameter and tree yield will be determined in each tree (Figure 2) . At 30 of these grid points, the nutrient status and yield of 2 neighboring NP trees will also be collected as independent data points. Initially, non-fruiting spur leaves in exposed positions will be selected for these samples, however, depending on the early results, sampling protocols may be adjusted. Two statistical techniques ‘nugget sampling’ and ‘modified Mantel’ statistics will be used, this approach allows for partitioning of variance in nutrient status due to environment, due to genetic variability and 'random' variability and allows for determination of the interactions and dependencies between nutrition and yield and the nature of spatial variability within an orchard.

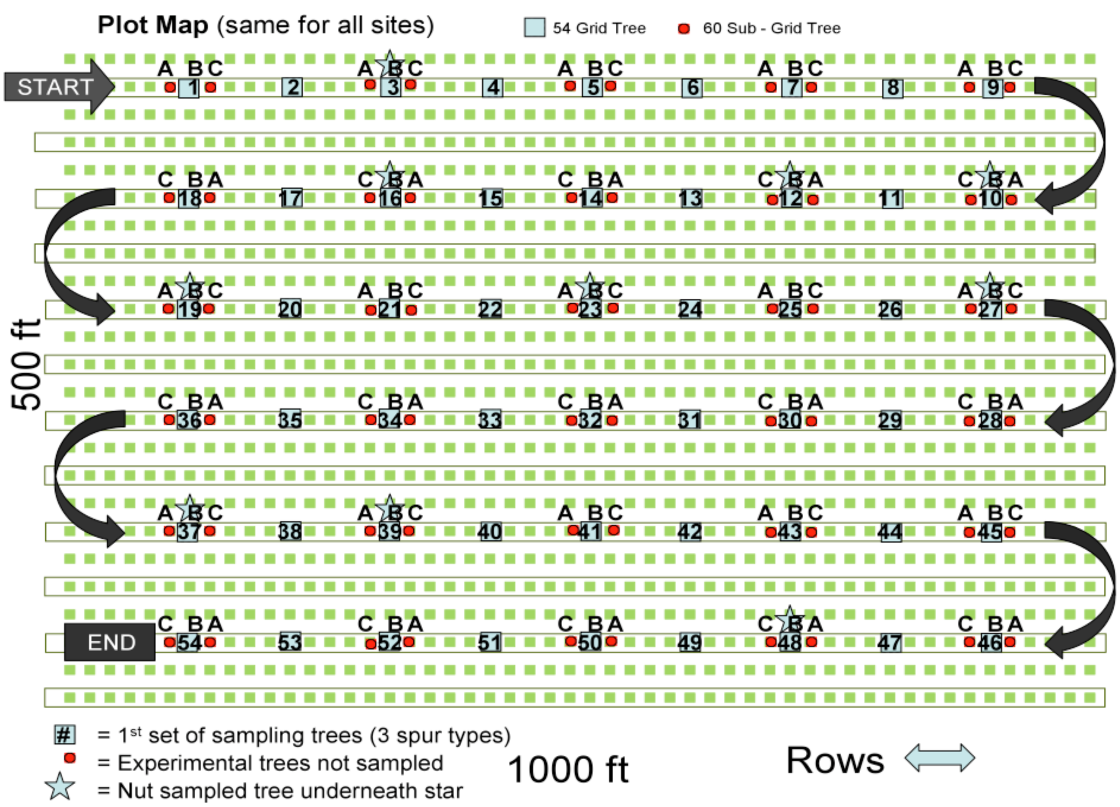

Figure 2: Field sampling strategy to partition components of yield and nutrient variability in Almond. This experiment I repeated at 5 sites spanning the Almond production areas of California.

Large Scale Yield Collection. Individual tree yields were determined on 4,288 trees for six years in a single, highly productive orchard. Tree yields were gathered by a precision harvester, The Pistachio Yield Monitor (Brown et al., 2007; Rosa et al., 2008) developed by UC Davis in collaboration with Paramount Farming Company. Briefly, a standard commercial pistachio harvester was retrofitted with a weighing system that allowed tree yields to be discretely determined. Tree location in the field was simultaneously determined with a number of redundant mechanisms including differential GPS for row identification, physical markings, and an odometric encoder wheel.

Nutrient Analysis and Determination of Nutrient Use Efficiency. Leaf and nut samples have been collected across all experimental sites at 5 stages of crop growth. Sampling intensity averaged 20 discrete samples from each acre across each 50 acre at each of the 5 experimental sites at five dates. Data will be presented as histograms to illustrate field variability and surface maps. Overall this experiment will collect far more samples (2,672 samples from 456 individual trees), analyzed for more nutrients (N, K, P, S, Ca, Mg, B, Zn, Mn, Fe) than ever performed before and will collect the individual tree yields associated with each of these samples. This detailed approach is designed to provide the foundation statistical information needed to guide fertilizer practice for the foreseeable future.

Nutrient use efficiency is calculated as nitrogen removed in crop / nitrogen input annually over a 8 year period. In these orchards no significant N is present in the irrigation water and all prunings and leaves remain in the orchard.

Results: we would predict that the adoption by growers of fertilization regimes aimed to ensure that >95% of all individual trees in an orchard are above the established critical value, would result in a field mean nutrient concentration would be at least two standard deviations above the established CV. Figure three illustrates that this is indeed the case and highlights that the grower in this example has quite precisely targeted the optimal economic fertilization rate.

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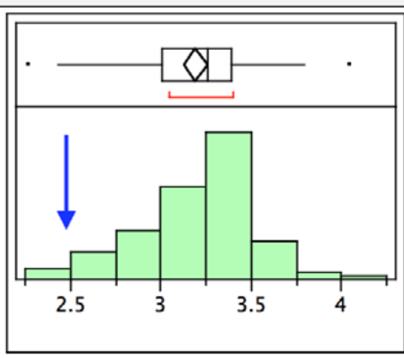

Quantiles

100.0%	maximum	4.0500
99.5%		4.0500
97.5%		3.7952
90.0%		3.5710
75.0%	quartile	3.3925
50.0%	median	3.2600
25.0%	quartile	3.0075
10.0%		2.7090
2.5%		2.4300
0.5%		2.2700
0.0%	minimum	2.2700

Moments

Mean	3.189898
Std Dev	0.3273338
Std Err Mean	0.0330657
upper 95% Mean	3.2555242
lower 95% Mean	3.1242717
N	98

Figure 3: Leaf samples were collected using standard practice (10 pairs of leaves pooled from each tree) from 100 individual pistachio trees across a 10 acre orchard containing 1,250 individuals. Leaf tissue N was analyzed. Established critical values for Pistachio are marked with a blue arrow and the corresponding blue box outlines the percentages of trees that are below this value.

While the results illustrated in figure three verify that growers are fertilizing the majority of their orchard to ensure every individual is satisfied, this approach is only economically viable since fertilizer costs are only a small part of operating expenses. This approach to fertilization is also a consequence of the lack of technology available for variable rate fertilization in orchards that are managed as a single uniform fertigated unit.

The impact of this approach to fertilization is further exacerbated in crops that vary unpredictably in their yield. Pistachio undergoes strong yield fluctuations and growers currently have neither the means to predict current years yield, nor monitor in-season nutrient status, nor apply variable rate fertilization within a single management unit (typically an orchard 40-100 acres in size). As a consequence there is a tendency over time to select a fertilization regime that ensures that every individual tree receives adequate fertilization in every year. The outcome of this approach is highlighted in Figure 4 below.

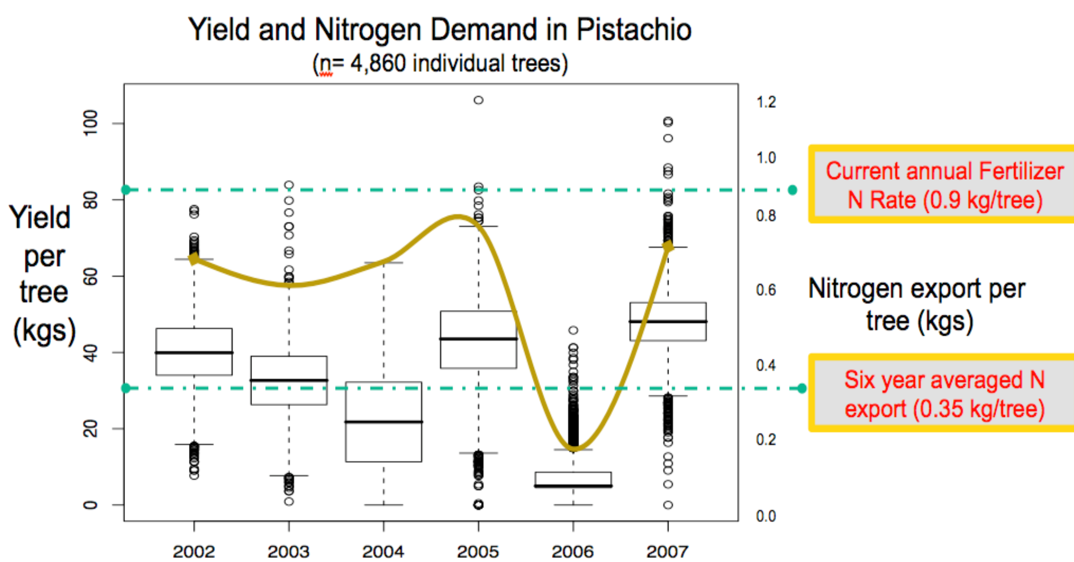

Figure 4: Nutrient demand was calculated as the product of yield x nutrient content of the exported crop. Yield was measured in every individual tree over the 6 year experimental period. Box and whisker plots show mean (25th, 75th and 95th percentiles) of yield and N removal in each year. Dashed lines represent current n fertilization rate and calculated N removal in each year. The solid line represents a theoretical annual fertilization regime that would maintain fertilization of 95% of individuals based upon real yield in that year.

In this example the grower established fertilization rate of 0.9 kg/tree ensures that >95% of all trees receive adequate N in all years. This level of fertilization takes into account the variability within and between years, and has been developed as a means of removing uncertainty. This rate of application, however, represents 2.5 times the six-year average tree N export (0.35 kg/tree), and an overall nutrient use efficiency (NUE) of less than 33% across 6 years. This apparent gross inefficiency can be traced to 1) the marginal cost of additional N, 2) the inability to predict or measure field variability and 3) lack of adequate tools to measure and monitor nutrient status. In the absence of any alternative approach, the logic behind grower decisions to fertilize in this manner is both clear and reasonable. However, if a grower were provided with the tools to predict and fertilize to meet actual demand (solid line), NUE could immediately be increased from 33% to 45%. However, even this simple tool does not currently exist.

DISCUSSION

An industry wide survey of almond and pistachio growers and crop consultants demonstrated a high level of dissatisfaction of with current CV's established for orchard crops. These results in turn led to the conclusion that that there are systematic errors in the manner in which critical values are used in high value crops. Discussions with university personnel in the US and internationally suggest that the systematic misuses of tissue sampling protocols and CV's observed in California, is indeed a global issue.

In high value crops, it is concluded, that tissue sampling strategies that only provide knowledge of 'mean' field nutrient status are of limited value unless they also provides an estimate of field variability. The constraints of tissue sampling are further exacerbated by the perennial nature of tree crops and the inability to effectively predict yield or to conduct early season tissue sampling and fertilizer adjustment for which standards of practice have not been established. The limitations of current sampling strategy is further exacerbated by the constraints to nutrient management (which is now largely applied through fertigation) which limits the ability of growers to manage within field variability. This, coupled with the relatively low cost of fertilizers as a component of overall production costs, has resulted in the adoption of fertilizer regimes that are inefficient.

To address these issues several new initiatives are:

1) Tissue sampling strategies must provide information of in-field variability. This will require:
    a. Development of new sampling strategies
    b. Development of low cost handheld, remote or in situ probes to monitor plant and or soil nutrient status.
    c. Research into modeling approaches to nutrient demand and nutrient status determination.

2) Yield prediction models are required. For most high value crops, extractive yield represents the primary determinant of nutrient application. Yield prediction models that allow for early season adjustment of fertilization strategies are required. This will require:
    a. Development of yield monitors and predictive technologies.
    b. Research into yield determinants and model development.

3) Variable rate application technologies are required for high value species. It is counterintuitive that precision agricultural technologies have not been applied to high value crops and that the adoption of fertigation as the primary source of nutrition has reduced the ability to conduct variable rate fertilization.

a. Development of engineering approaches to provide differential within field fertilizer deliver
b. Research into the effects of timing and product form on crop response.

Research and extension efforts to address these needs in tree crop industries are currently underway in the laboratory of Dr Patrick Brown and collaborators at UC Davis, NMSU and TAMU.