CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)

Project Final Report (2003)

a) Project Title Precision Horticulture: Technology Development and Research and Management Applications

CDFA contract number: 00-0497

Project Leader: Patrick H. Brown, Professor, Department of Pomology, University of California, Davis, CA 95616.

Cooperators Uriel A. Rosa, Assistant Professor, Biological and Agricultural Engineering, University of California, Davis, CA 95616.

b) Objectives:

The goal of this project was to develop the harvesting machinery, and initiate statistical and mapping methodologies to allow growers to view and interpret the annual productivity of each tree in their orchards. The overall goal of this activity is to provide the information needed to optimize fertilization strategies and to improve on-farm research capability.

c) Executive Summary:

In a preceding CDFA funded study by the principle investigator of this grant, it was clearly demonstrated that yield is the primary determinant of nutrient demand and uptake efficiency and therefore, fertilizer needs. In tree crops it is recognized, however, that yields vary dramatically from tree to tree within an orchard and between orchards therefore making accurate fertilizer recommendations impossible. Given this fundamental limitation it has been impossible to develop truly efficient orchard fertilizer management systems or to conduct nutritional research experiments properly.

Based upon this earlier work, it was theorized that the ability to map yield of each tree in an orchard and to use that information to optimize inputs and directly contribute to improved resource use efficiency. The benefits to in-field experimentation would be equally significant. The most direct benefit of this information would be the ability to optimize fertilization strategies on a site-specific basis. To achieve this goal this project aimed to develop the means to rapidly harvest and map Pistachio tree yields in commercial orchards on a tree by tree basis by integrating tree location protocols and yield monitors into the harvesting machinery and to develop the statistical and visual computational methodology to analyze and map results. To help determine the cause of yield variability soil and plant tissue samples were collected and remote sensed data was collected and contrasted with yield data.

A majority of the originally designed tasks and objectives have been achieved. In 2002 we successfully tested a new instrument that allowed us to attain the yields of every tree in a 6040 tree orchard accurately and without substantially slowing normal harvest times. In 2003, the experiment was extended to cover the original 6,040 trees harvested in 2002 and an additional 6,200 for a total of 12,240 individual yield data points. Yield maps, plant nutrient maps, soil maps and remote sensed spectral analysis, were generated and contrasted with yield maps to provide an initial determination of the causes of yield variability and propose changes in management practice. Several critical observations can be drawn from this data. Three years of results demonstrate a great deal of variability across the orchard and from tree to tree within each orchard row. This unexpectedly large variation (in an orchard which was thought to be relatively uniform), indicates how greatly tree variability has been underestimated. This has several consequences, firstly it suggests that management practices should not be applied uniformly across large areas of orchards as they are now, but rather must be optimized at a far more local scale. Secondly, it demonstrates that the full yield potential of Pistachio is as high as 9,000 lbs in-shell split (acre equivalent/year) which is almost twice as high as previously accepted.

In an attempt to determine the cause of yield variability in this orchard, a series of 10,000 individual soil and plant samples were collected and analyzed for nutrients (soil and plant) and physical characteristics (soil). This data was supplemented with remote sensed analysis of leaf temperature, vegetation index, multi- spectral analysis and chlorophyll index. While clear trends and correlations between yield and several variables it has not been possible to clearly associate yield variability with any single variable.

Engineering and statistical challenges remain and this project will be continued for 2 additional years with private funding.

d) Work description (2003):

General: Continue re-engineering and developing the harvesting equipment to resolve outstanding issues, including improving the speed of harvest, ensuring full separation of nuts from every tree, installation of back-up systems to avoid missing data, improving in-field location and mapping to allow single tree recognition.

Task 1: Engineer Harvesting Equipment

Main machine design completed. Ongoing engineering design and refinement, improved data collection technology, development of improved geographic postitional data.

Major Engineering Completed 12/03

Task 2: Conduct site identification and Pre-harvest Ground Truthing

Identify and Mark 80 Acre block.

Completed 8/01

Task 3: Harvest Crop with Newly Engineered Harvest Machine

Completed 10/01, 10/02, 10/03

Task 4: Initiate statistical analysis of ground and machine attained data. Develop statistical methodology to separate environmental and genetic components. Identify causes of yield variability.

Analysis completed 12/02, 12/03

Task 5: Examine data to reconcile machine yield data and yield patterns with local environmental conditions.

In 2001 there was sufficient uncertainty in the data collected that it was not deemed worthwhile conducting a close analysis of in-field tree size to contrast with yield data. Data for 2002 and 2003, analyzed and reported.

Intitial analysis completed 12/02
Addtitional analysis underway.

Task 6: Re-engineer as needed. (Ongoing)

Task 7: Initiate field based experimentation to identify basis for observed yield variability and to demonstrate utility of equipment as a research tool. Impose treatments.

Delayed due to ongoing machine optimization

e) Results and Discussion:

In 2002 we successfully determined the yield of more than 6000 individual trees. This yield was collected using a standard Pistachio harvester with bank-out wagon fitted with newly designed yield monitor and positional instruments. The prototype machine operated at >75% of full commercial harvest speed and provided very accurate determination of tree yield when compared to hand weighed trees (Figure 1). In 2003 this pattern of accuracy was repeated with and increase in harvest speed to 83% was achieved.

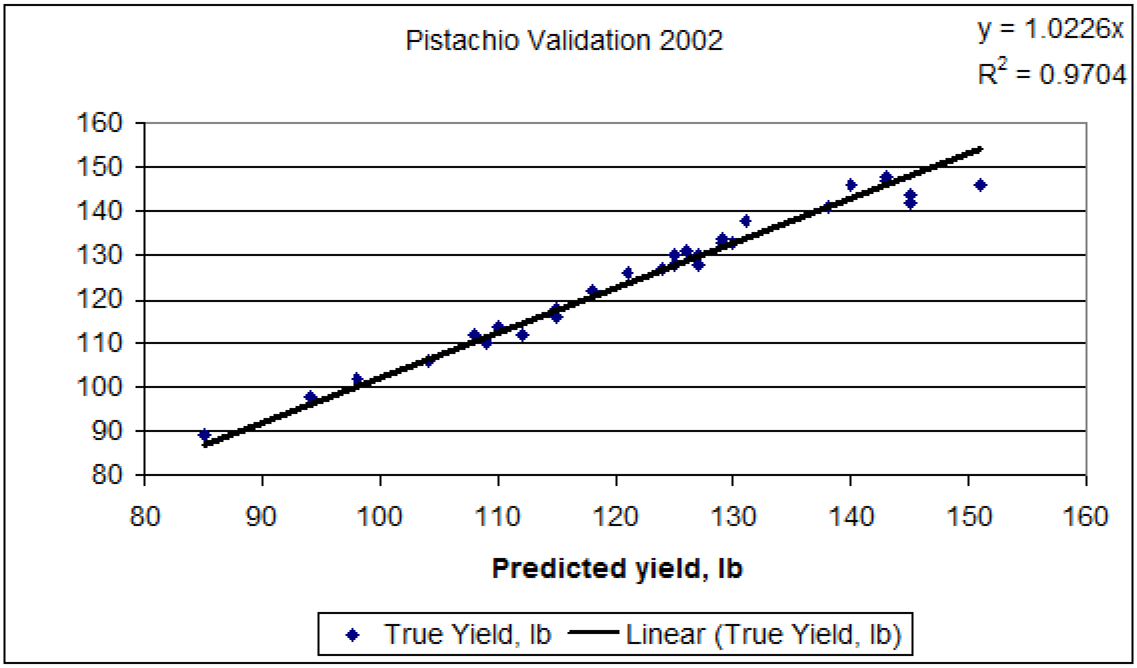

Figure 1: Comparison of yield determined by harvester (predicted) and yield determined by hand (true yield). This is an excellent correlation.

The results of the 2002 and 2003 harvest have undergone initial analysis and the data have had an immediate benefit to the grower. The results also highlight the great deal of information that can be obtained using this methodology. The significance of the results are illustrated in the following two sample graphs (from 2002) which I have included to highlight the potential uses of this project. These two graphs represent less than 5% of the data collected in the first year.

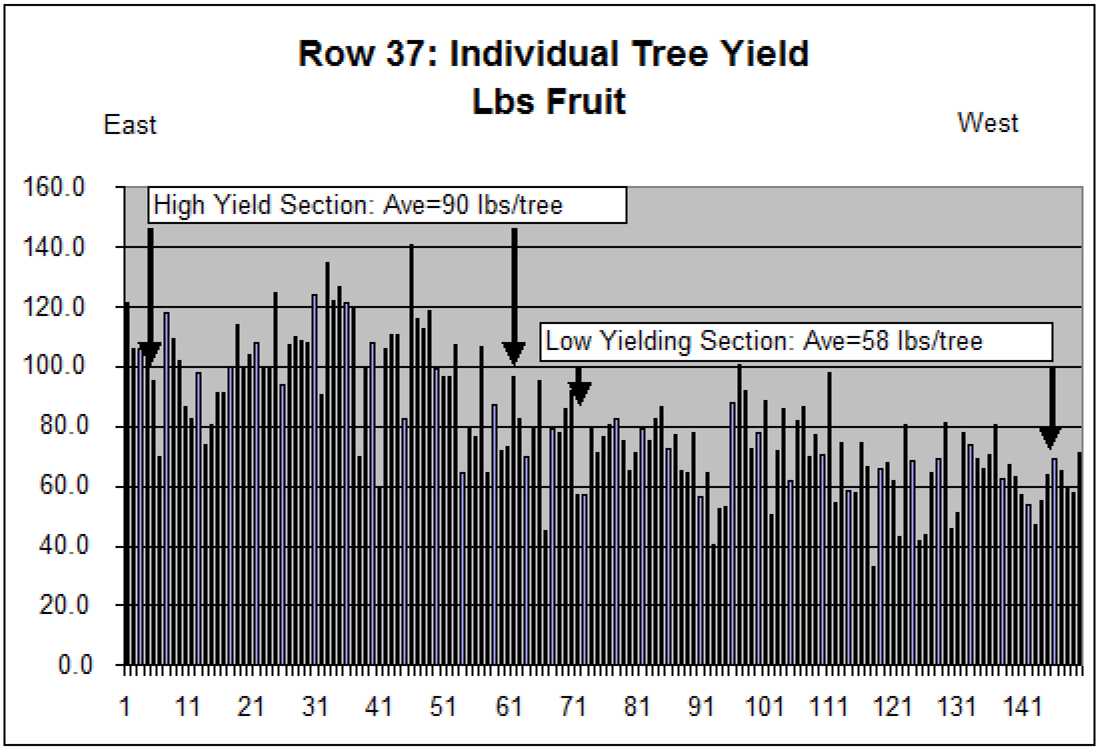

Figure2: Individual tree yield from east to west in row 37 of a 17 year old pistachio orchard.

In figure 2 we can see a very distinct yield trend from east to west with a division roughly in the center of field. Yield of the eastern section is reduced by 35% (equivalent to approximately 4200 lbs acre versus 2688 lbs acre). This is a very significant yield loss that was not recognized by the grower who previously harvested the block as a whole and had not observed this trend. The cause of this yield difference is likely due to a soil type change that may be negatively impacting water use, which might be corrected by a change in emitter pattern (number, flow rate etc) or a new system design.

The grower can now investigate the cause of the yield loss by observation, soil test, alteration of irrigation patterns etc. If irrigation changes can correct the problem the return on investment can also be calculated by estimating average yield loss, number of
acres impacted and cost of remediation.

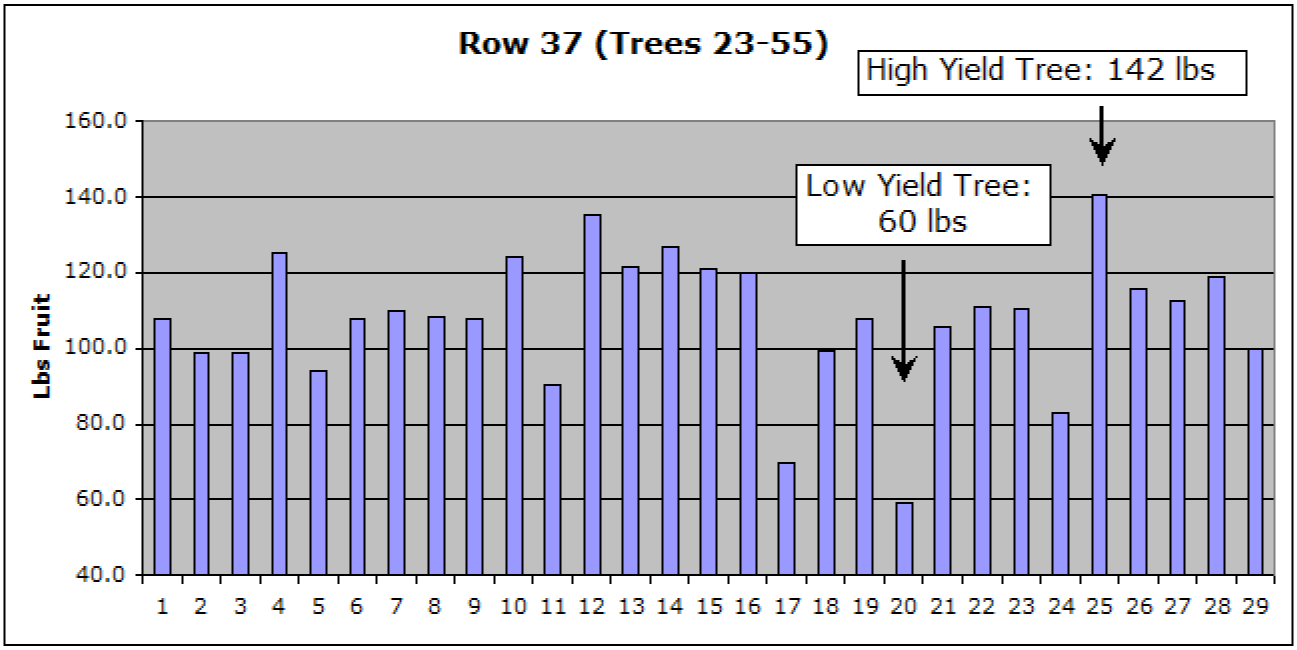

Figure 3: Detailed graph showing trees 23-55 in row 37. This is a subset of trees shown in figure 2. (Note Tree 1 in fig. 3 is the same as tree 23 in fig.2 above etc)

In addition to the clear gross effects seen in figure 1 a good deal more information on the performance of individual trees can also be seen in figure 2. For example there are individual trees with yields of 60 lbs which is less than 50% of the best performing trees, and only 60% of the average tree yield (90 lbs). This provides two pieces of immediately intriguing and potentially valuable information. Firstly, the grower can now address the issue of whether tree 20 should be removed. To make this decision the grower would predict the expected life of the orchard, the average yield of each tree and determine how much money is being lost.

Yield Analysis: The results of the 2002 and the 2003 harvest are presented in figure 4. Of importance is the observation that the pattern of yield variability is essentially identical over both years thus illustrating that trees with maximal relative yield in one year can also have maximum relative yield in year two. This suggests that locally favorable environmental conditions can maximize yield without resulting in excessive alternate bearing. The results also highlight the great deal of information that can be obtained using this methodology.

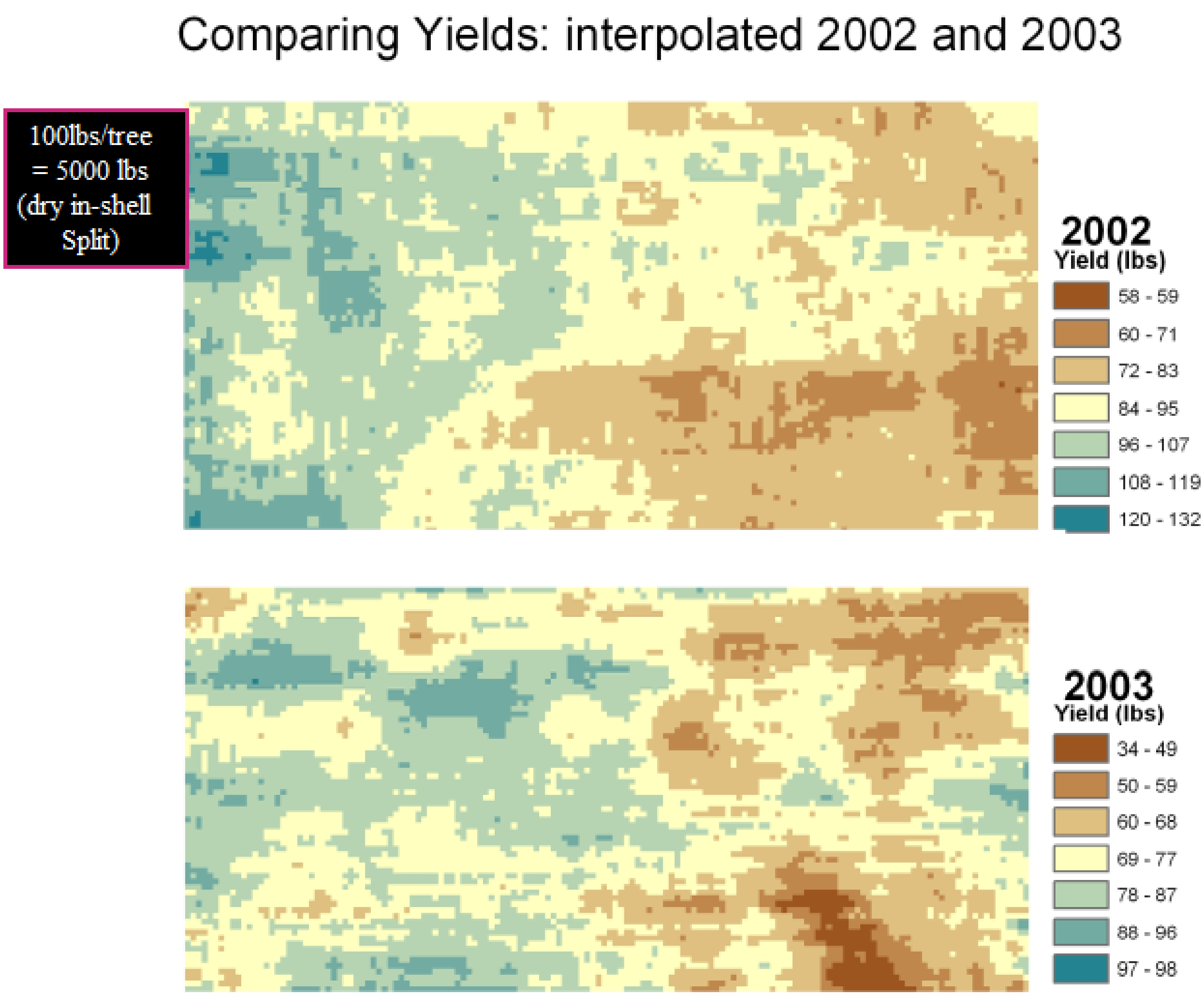

Figure 4: Yields of 80 acre orchard in 2002 and 2003. Note that high yielding regions of the orchard in 2002 are also the high yielding portions in 2003.

To help determine the cause of the yield variability across the field soil samples wee collected at 235 positions to a depth of 5-25 cm. Soil sample were analyzed for N, P, K, Mg, Ca, S, Mn, Fe, Cu, Zn, B, Cl, Na, SAR, CEC, and a full Soil Particle Analysis was conducted. In addition, 280 plant tissue samples were collected and analyzed for N, P, K, Mg, S, Ca, B, Mn, Fe, Zn, Cu. A full representation of all data (over 10,000 data points) is not presented here for space reasons, initial results suggest a correlation between yield patterns, leaf Mg levels (fig 5) and plant tissue B levels (not shown).

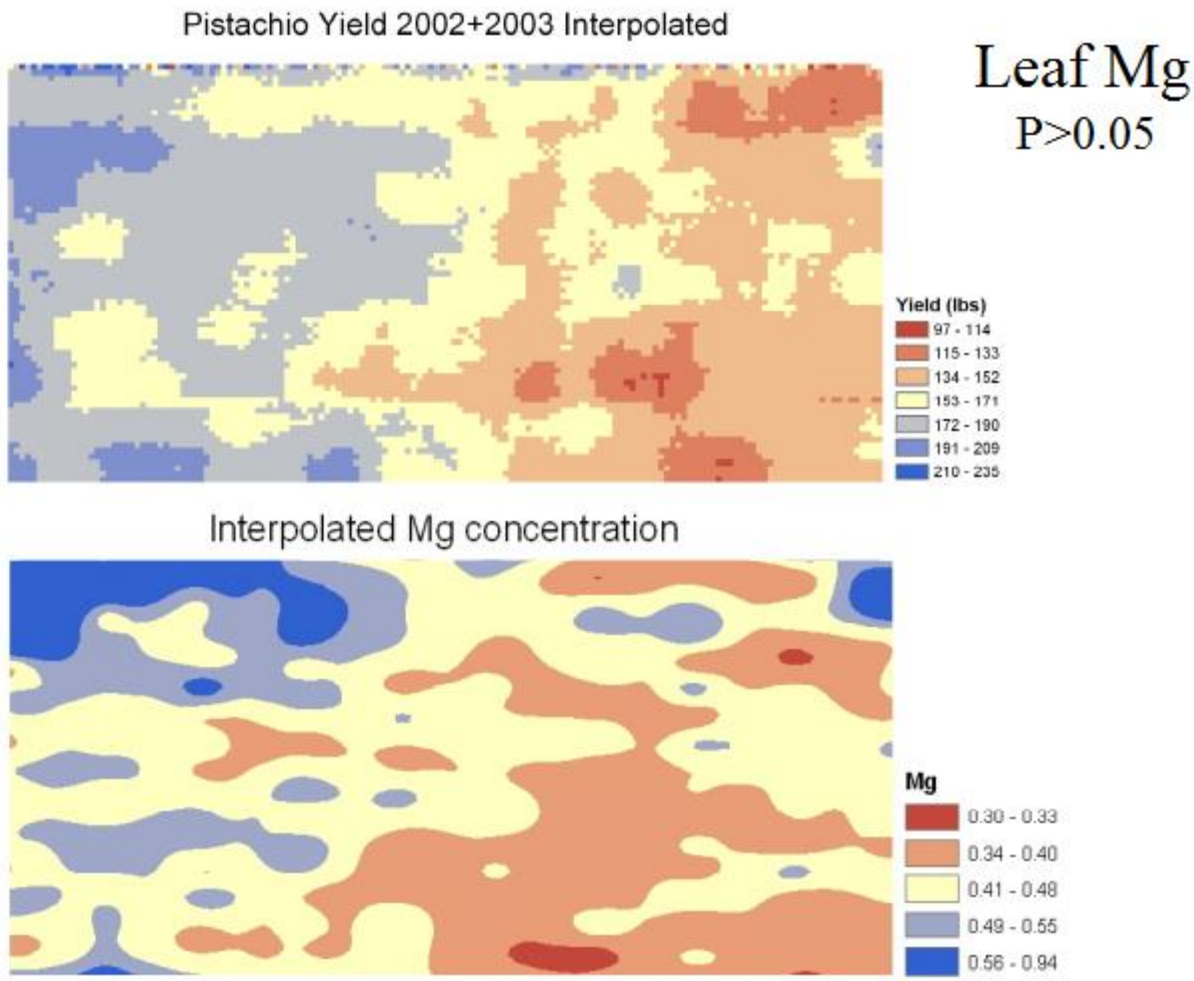

Figure 5: Visual relationship between tissue Mg levels and combined plant yield 2002 and 2003.

In figure 4 we can see a very distinct yield trend from east to west with a division roughly in the center of field. Yield of the eastern section is reduced by 35% (equivalent to approximately 4200 lbs acre versus 2688 lbs acre). This is a very significant yield loss that was not recognized by the grower who previously harvested the block as a whole and had not observed this trend. While a correlation between tissue Mg and yield is apparent we feel there is an underlying soil property that is defining this yield variability. Such a soil change may be negatively impacting water use, which might be corrected by a change in emitter pattern (number, flow rate etc) or a new system design.

While determining the yield of every tree has great practical significance, this degree of detail is difficult for an average grower to manage. To aid in the use of this information it is possible to decrease the resolution of the data and present information in 16 acre blocks to help focus management changes. This is represented in figure 6 in which the yield over each 16 acre block is represented. Ultimately data such as this can be used to help focus management resources.

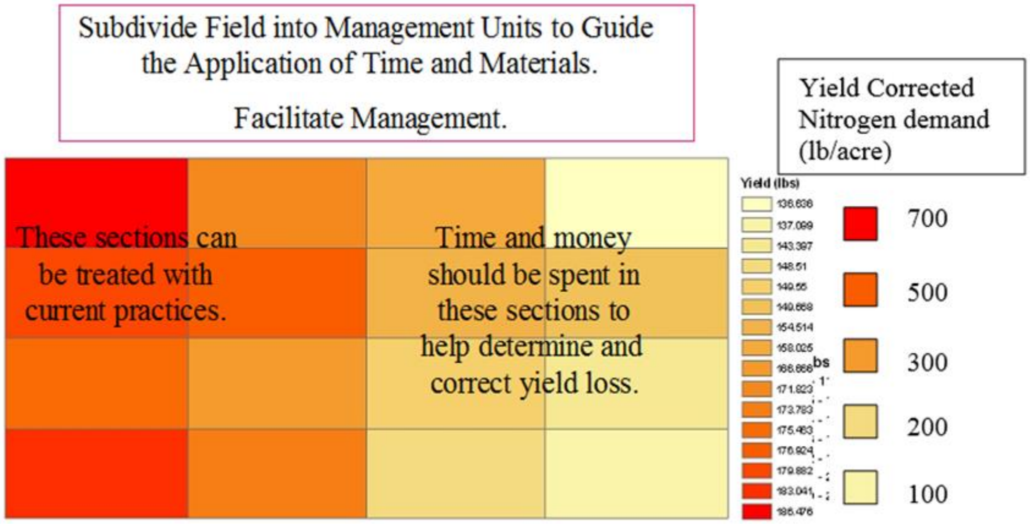

Figure 6: Yield representation in 16 acre management subunits.

With this information the grower can now investigate the cause of the yield loss by observation, soil test, alteration of irrigation patterns etc. If irrigation changes can correct the problem the return on investment can also be calculated by estimating average yield loss, number of acres impacted and cost of remediation. In this example N fertilization can be matched to the real local demand which will avoid over fertilizing poor producing trees and hence minimize sub-soil N losses.

While we have focused here on the gross trend data much more value exists for breeders since this data provides information on a large number of individual trees and hence greatly enhances the capacity to identify superior trees. As an example there has not been a single breeding trial ever conducted in which the comparative yield of 12,000 individuals has been examined. The potential to use this approach to find the best individual trees is very significant.

It is clear to us from this very first experiment that we are entering a period of significant discovery, enhanced research capability and crop improvement.

The potential uses of this technology are many-fold and include:

- Improved research capability
- Improved design of water systems
- Identification of ‘super’ trees and trees that should be removed
- Grower or industry testing of new chemicals
- Improved fertilizer management

- Discovery of the determinants of yield in pistachio

Conclusions and Practical Application:

Successful growers make management decisions based on the best available information. Currently most growers use orchard or block yield information to determine management decisions (fertilization, pruning, pest control etc) since that is all they have. The ability to know what the yield is at a scale smaller than a whole orchard provides growers with more information and allows improved management. Further, the capacity to easily determine yield will provide researchers, growers and extension agents a greatly improved ability to conduct research and test new management strategies. The ability for growers to easily test new technologies on their own fields is essential for the adoption of best management practices.

The equipment developed here operates at 75% of full commercial speed and costs approximately $8000 to add to a harvester. Additional engineering and computer development is needed before this product becomes commercial. In 2005 we will be working closely with the major harvester producers to optimize the methodology. The results we have obtained to date represent the most detailed study of pistachio yield ever conducted. With new research capability we will usher in a new era in Pistachio management, breeding and research.

F) Project Evaluation

We are in close contact and discussions with all involved parties including machine manufacturers, the Pistachio Commission and the grower. We have proposed a project of this kind to the Almond Board for consideration and will discuss this technology at the annual Pomology Continuing Conference in April 2003. We believe the data we present here (see full yield analysis) is the first of its kind ever collected and represents a new era in precision orchard management.

G) Outreach Activities

This information has been resented at CDFA annual meeting, will be discussed at the California Agronomy Society (Jan 2003), the Pomology Continuing Conference (April 2003), the Pistachio Conference (Jan 2002, 2003, 2004), Biological and Agricultural Engineering (2003, 4), the Nickels Field Day 2004. As the techniques are further refined additional presentations and publications can be expected.