Final Report for the Agricultural Research Foundation
For 2000-2002

Title:	Nitrogen Nutrition of Pears Grown Under Differing Soil and Environmental Conditions
Project leader:	Timothy L. Righetti, Dept. of Horticulture, Oregon State University
Cooperators:	Clark Seavert, Mid-Columbia Agriculture Research and Extension Center, Anita Azarenko, Dept. of Horticulture, Oregon State University.
Funding History:	Three-year study, 1st yr $28,800 pear, $20,000 apple; 2nd yr $15,000 pear; 3rd yr $15,000 pear

Introduction:

Like many research projects, this effort has changed over time. Both the original justification and objectives and a description of how the project has been broadened over time are included in this final report.

Original Justification:

Many of us believe that as we strive to become more efficient, fertility programs will become more complex. We need to know how important the tree storage, non-fertilizer soil sources, and fertilizer N pools are for trees grown under different conditions. The most appropriate strategy for an orchard in a clayey soil in Wenatchee may be quite different than in a loam soil at Hood River. We believe that management strategies can be designed to meet the economic and environmental demands that face our industry, but there is not a one-size-fits-all solution.

A first step in the pursuit of developing management approaches for different soil and environmental conditions, is determining how much variability exists among and within different locations. We proposed to evaluate fertilizer efficiency, and the relative importance of tree storage, non-fertilizer soil sources, and fertilizer N pools at multiple Northwest locations under different soil environments. Trials on pears were conducted at Hood River and Medford, Oregon.

Specific hypotheses as originally proposed are listed below:

1) The ^{15}N estimates of fertilizer recovery may overestimate the real efficiency of plant uptake especially in high-organic matter systems.

2) Some pear growing systems can be defined as N saturated (more N available from fertilizer and soil mineralization than plants require). Under these conditions, increasing the efficiency of fertilizer or reserve utilization may decrease the use of N mineralized from the soil. Even though plants respond to N, we have more than we need.

3) The source of the N that can potentially contaminate groundwater varies for different pear growing systems and climates.

4) Mineralized N that is released from soil organic matter may be less efficiently used than fertilizer N, and the use of mineralized N will vary with pear variety, soil type and environmental conditions.

Original Objectives as Proposed:

1. Determine the relative importance of tree storage, soil and fertilizer N pools in meeting the nitrogen needs for pears grown under different soil and environmental conditions.

2. Determine uptake efficiency for pears grown under different soil and environmental conditions.

3. Investigate how soil texture, site-specific weather conditions, and soil organic matter may modify the uptake storage and utilization of fertilizer applied N at different locations.

4. Develop possible management strategies that incorporate soil and environmental factors into N fertilizer recommendations.

Spatial Issues in Orchard Management:

As work proceeded, we took advantage of opportunities to broaden the scope of the original proposal. It appears that spatial variability with regard to N nutrition may be more important than an orchard's average N status. We hypothesized that N deficiencies and N excesses may occur within the same orchard and that differences in tree and canopy size could lead to large differences in the N status of different trees.

Early in the study it became apparent that large differences in tree size within an orchard were the major factor in a given tree's N uptake efficiency. We began to focus our research on how to incorporate tree size into N evaluations.

In our early studies, there was also a large amount of variability in canopy size and canopy density among different trees within our experimental orchards. Small canopies were either due to small trees or large trees with insufficient canopies. We utilized the canopy data acquired in the course of our nitrogen studies to develop procedures to quantify canopy status and determine if trees have sufficient or insufficient vigor. We explored different ways of expressing tree vigor to find ways that were not biased by differences in tree size.

We also initiated new studies to evaluate how canopy evaluations could supplement traditional N evaluations. Since our initial experiments suggested that canopy size was far more variable than N concentrations in leaf tissue, we hypothesized that without canopy information N concentration data would be misleading. Experiments were designed to determine if this was true.

As we documented the large variability in tree size, it became apparent that tree size is a dominant factor in determining yield potential in commercial orchards. Poor economic returns at specific locations within an orchard can be attributed to either small trees or large trees that are performing at a level far below their potential. With the information acquired in our N studies we are developing procedures to differentiate between size related and efficiency related constraints to maximizing yield or profit. We also hypothesized that the traditional measures of tree performance (yield/cross sectional area) or canopy efficiency (yield/canopy area) could be biased in favor of small trees. Therefore different approaches of quantifying tree or canopy performance were evaluated to determine if they were less biased than our traditional approaches.

Expanded Objectives:

The funding from the WTFRC has been pooled with other grant sources to expand the scope of the project. This has also allowed us to continue with apple research even though the WTFRC only funded pear research after the initial year. While the original proposal addressed the research topics listed below in categories 1), 7) and 8); all of the expanded areas of emphasis contribute to the overall understanding of interrelated topics. Technical publications in each of these categories are currently being prepared. A brief discussion of each of the following topics is presented with data examples where appropriate. Much of the ^{15}N analyses associated with category 1) and 8) are still underway, but sufficient data exists to comment on overall trends.

Although N research is an important part of our project, and finding more efficient ways of managing N is an ongoing process, our effort is now more broadly defined. We are convinced that there is more to be gained in managing the spatial variability within an orchard than there is in devising new and better management approaches to uniformly manage orchard blocks. This generalization applies to N management and many other aspects of tree fruit production. Developing an overall approach to spatial management has become our focus. This report discusses our findings and describes our current approach to implementing spatial management programs.

As our industry wrestles with an uncertain future, we do not believe that fine-tuning N management should be a high priority as researchers choose where to invest their time. None-the-less, since N management was the subject of the original proposal, the most important aspects of our N research program are presented in this final report.

Areas emphasized in this report are as follows:

1) Nitrogen Uptake Efficiency and Tree Size
2) Tree Size Variability and Orchard Performance
3) Yield or Profit Improvement Potential
4) Factors Limiting Tree Size
5) Canopy Variability and Canopy Improvement Potential
6) Quantifying Tree and Canopy Performance
7) Spatial Implications for Nitrogen Management
8) Replacement of Organic Nitrogen with Nitrogen Fertilizers

Materials and Methods:

Destructive Analysis of Entire Trees

For pears, data was collected at the Southern Oregon (Medford) and Mid Columbia (Hood River) Agricultural Experiment Stations. For apples, data was collected at OSU (Corvallis), the Mid Columbia Agricultural Experiment Station and at the University of Idaho Experiment Station in Parma, Idaho. At all four locations data was collected over a three-year period. Experimental designs varied slightly, but were generally similar. Labeled nitrogen was applied in the first year to a set of trees at all locations. In subsequent years trees that were previously treated with labeled N were treated with unlabeled N. At each location a new set of trees received labeled nitrogen fertilizer in the second and third years of the study. A portion of the trees was destructively harvested in each season. Fruit, leaves, and other above and belowground components were evaluated for dry weight, N concentration and isotopic N composition.

The destructive sampling allowed us to determine how much of the N in a tree comes from fertilizer and tree reserves. The amount of N not accounted for by either the fertilizer or tree reserves was assumed to come from soil sources (mineralization of N from organic matter). We could also determine how much variability exists in tree size, and canopy size (leaf weight/tree) at each location. Relationships between tree size (cross sectional area of the trunk or the dry weight of structural biomass) and yield were determined. Relationships between tree size and the amount of fertilizer N uptake and uptake efficiency were also evaluated.

Non-destructive Evaluations

At the Medford, Hood River, and Idaho locations yield and trunk cross sectional areas of a larger set of trees were evaluated over a two-year period. This larger data set was used to further evaluate the relationship between tree size and yield and better quantify the variability in tree size that occurs.

Additional data was collected for a 50-year-old pear orchard in Parkdale, Oregon. Yield and economic returns (ER) in dollars per tree collected in 1998, 1999, and 2000 Although evaluations at this site are ongoing, spatial treatments were implemented after the 2000 harvest so only the 1998-2000 time period is evaluated here. The 6.6-hectare (~16 acre) orchard was divided into 23 sampling units or cells. Each cell was approximately 2800 m^2 (0.7 acre; 0.5 acre if pollen source trees are excluded). At harvest, all bins from each cell were kept separate and tagged for tracking purposes. The cooperating commercial packinghouse tracked the bins through the processing facility and provided yield, fruit size, grade and cull information for individual cells. This information allowed us to determine the total yield, fruit value, and economic return for each cell. Economic returns (ER) were calculated as income minus total cost. The circumference of each tree trunk at a height of 30 cm above the ground was measured and used to calculate an estimate of tree trunk cross sectional area (CSA). The CSAs for individual trees were averaged to get representative values for each cell. Average canopy area and canopy density for each tree were estimated from an IR photograph. The canopy areas and densities for individual trees were averaged to get values for each cell.

Results and Discussion:

Nitrogen Uptake Efficiency and Tree Size

In Figure 1 tree size (structural biomass) is plotted against nitrogen recovery for pear trees in Medford Oregon. Although the strength of the relationship varies (r^2 values from 0.5 to 0.8) in various studies the results shown are typical of what is observed. Large trees simply take up more N than small trees. There is a limit to how much N a tree can take up. We would argue that unless differences in tree size are considered, there is little chance that efficiency can be improved. Fertilizer timing, fertilizer rate and the method of application (ground or foliar) are all important but these factors do not explain as much of the variability in uptake efficiency as tree size. We may have developed a nitrogen fertilizer program that results in the over fertilization of much of an orchard as we apply constant rates that meet the needs of our largest trees. The variability in tree size presented in this graph is typical of what is observed in our experimental plots. One hundred to 400 percent differences were observed at the Medford, Corvallis, Hood River, and Parma study sites in orchards that are considered to be relatively uniform with respect to tree size.

Tree Size Variability and Orchard Performance

If only standard regression statistics are used to evaluate these experimental results, one would conclude that there were not strong or consistent relationships between yield or profit and trunk cross sectional area (CSA) or structural biomass. The r^2 values for the 13 data sets from various orchards (three pear locations over three years; two apple locations over 2 years) varied from 0.05 to 0.80 but only one data set had an r^2 value greater than 0.45 and 9 were less than 0.15. However, in all orchards the data points were distributed in a manner similar to the distribution shown in Figures 2-5. For the sake of brevity, relative data has been pooled across years and sites for the apple orchards where the ^{15}N experiments were conducted (Figure 2) and across years at the pear site where 23 sample sites were evaluated over the three-year study (Figure 3). Figure 4 presents the same data that is presented in Figure 3 but average profit for the three-year evaluation period is presented. A single-year pear data set where a large number of individual pear trees were evaluated is presented in Figure 5. When data was pooled across years and sites for the pear orchards where the ^{15}N experiments were conducted the results are almost identical to the apple data in Figure 2 (data not shown).

In Figures 2 through 5, a boundary line approach has been utilized to define the upper limits of yield or profit for a given level of CSA or dormant biomass. Although the criteria used to define the upper boundary is beyond the scope of this summary, a visual evaluation of the boundary condition is informative. Although many factors can limit yield or profit and there are many points that are well under the upper limit, the maximum yield or profit obtainable is determined by CSA. Large trees can have low yield or profit, but small trees are never in high yield or profit categories. Points above the apparent upper boundary lines are rare. In individual years the upper boundary line will shift up or down as production and price change, but CSA defines the maximum return possible in any given year.

Since this relationship (a wedge shaped pattern) is consistently observed it suggests that it is possible to identify trees or regions within an orchard that are yielding less than their maximum potential. For example, many points in Figures 4 are on or near the upper boundary line presented. Locations represented by these points are performing at or near their maximum potential. It is unlikely that management changes would result in improved performance at these locations. Emphasizing corrective management treatments, in the areas of an orchard that are consistently represented by points below upper boundary lines, have the highest probability of short-term success.

Yield or Profit Improvement Potential

In Figure 6, a contour plot reveals areas of the orchard that were characterized in Figures 3 and 4 that are likely to respond to enhanced management in the short term. This map was created by calculating the relative distance between the three-year average ER for each cell and the CSA upper boundary line derived from the average data (Figure 4). This distance can be defined as an improvement potential with units of $/tree. The points slightly above the upper boundary line were given a value of zero. Points with greater relative distances from the upper boundary line have more potential to respond to enhanced management. Areas with a high improvement potential (light color) represent areas where low tree efficiency rather than small tree size limit profitability. Figure 6 gives a manager a visual representation of where responses are most likely to occur.

Better management for the orchard as a whole is of course well advised. However, if a manager is going to implement spatial management strategies, concentrating enhanced management efforts in areas most likely to be economically responsive would be a wise strategy. Managers and researchers may also be interested in identifying possible profit limiting factors and determining if management changes can improve economic return/tree. In this example the two areas with high improvement potential (the northwest and northeast corners of the orchard) were also lowest in soil pH.

Factors Limiting Tree Size

As previously discussed it is important to determine if small tree size or inefficient trees limit profit. The approach discussed above (Yield and Profit Potential section) can be used to identify possible limiting factors for areas of an orchard that are producing at less than their potential. Correcting factors that may limit tree size also has long-term advantages.

Attempts to correlate soil or tissue analyses with CSA were generally unsuccessful. This is to be expected since many factors can simultaneously limit CSA. Therefore, a boundary line approach that is similar to the procedures we used to define relationships between CSA and yield or profit (Tree Size Variability and Orchard Performance section) was used.

An example of this method is illustrated in Figure 7, where an upper boundary line is used to visualize the relationship between CSA and soil pH. Although other factors can limit CSA and there are points well below the boundary line, the maximum CSA obtainable for a given pH interval is defined by the upper limit boundary. Even though there is not a significant relationship between soil pH and CSA an identifiable wedge shaped pattern and upper boundary line suggest that increased soil pH is associated with an increase in CSA.

Similar wedge shaped patterns and boundary lines were apparent for soil organic matter (OM) and cation exchange capacity (CEC). A negative relationship between leaf Mn and CSA was also apparent. In an effort to determine if wedge shaped patterns and boundary lines could be randomly created, simulations were conducted to randomly assign pH, CEC, OM and leaf Mn values to the real CSA data. None of the random simulations produced the statistically significant boundary conditions that were apparent in the real data.

Canopy Variability and Canopy Improvement Potential

One of our goals was to quantify canopy status. However, without data on tree size, it is difficult to determine if small canopies are due to small trees or large trees that suffer from some form of stress that is limiting canopy development. This distinction is important if we want to improve canopy management. Without having some way to incorporate tree size into canopy evaluations, canopy data is much less meaningful.

Attempts to correlate canopy size or leaf biomass with CSA produced weak statistical relationships. This is to be expected since many factors can simultaneously limit canopy development. Once again, a boundary line approach can be used to define relationships between CSA and canopy coverage or total leaf biomass. For the sake of brevity only a single example is discussed below, but similar relationships were apparent in most of the data sets. In some cases it was difficult to capture all the senescent leaves from individual trees. Therefore the remote evaluation of canopy size in the pear orchard that was divided into 23 zones is discussed below.

In Figure 8 remotely assessed canopy areas are plotted against CSA. The data suggests that although trees with large CSA can still have small canopy area the maximum possible canopy area is determined by the CSA of the trunk. The familiar wedge shaped pattern is evident. Canopy improvement potential maps can be created in a manner that is analogous to the yield or profit improvement potential maps discussed above. It is also possible to determine if achieving maximum canopy area is desirable.

It could be that the maximum canopy area represents excessive vigor. This is not the case in the example shown. Points marked with a circle are from the most profitable cells (highest third) within the orchard. In this instance high producing trees are near the boundary line and have close to the maximum possible canopy size. This suggests that excessive canopy area (related to vigor) is not a problem in this orchard. Estimates of canopy density (data not shown) may be more important than canopy area assessments when determining if trees are overly vigorous.

Quantifying Tree and Canopy Performance

The data in Figure 8 also demonstrates the biases that are apparent when using conventional expressions to quantify canopy efficiency. If canopy efficiency is expressed as yield or profit per canopy area some of the best performing zones are identified as the least efficient (dashed lines). This occurs because small trees are more efficient on a yield or profit per canopy area basis. It is well known that dwarf trees are more efficient, but their efficiency advantage is only useable if many more trees are planted per unit area. In our example, trees that have limited growth (small size) appear more efficient but do not have the capability of producing large profits. The paradox, apparent here, is that if local soil or environmental conditions produce small trees and limit profit, these same trees will be rated the most efficient on a yield or profit per canopy area basis.

The same phenomenon occurs if tree efficiency is expressed on a yield or profit per trunk CSA basis. Since small trees are more efficient than large trees, conditions that stress trees and result in limited growth also produce trees that appear to be efficient when standard tree efficiency expressions are used (data not shown).

We have taken the approach that profit maps can be easily created and one can then determine if profit is limited by small tree size or large trees yielding less than their maximum potential. A profit improvement potential is the best way to integrate tree size into a profit assessment. Possible limiting factors associated with trees that are performing at less than their maximum potential can then be evaluated. If areas of an orchard that are performing at or near their maximum potential are significantly different than areas with a high improvement potential, this difference may warrant further exploration. It is also possible to evaluate factors that are associated with profit losses that are caused by small tree size.

A similar approach can be applied to canopy evaluations. Small canopies are often associated with small trees. Small canopies can also result from insufficient canopy development in large trees. A canopy improvement potential evaluation integrates tree size into a canopy evaluation. Possible limiting factors associated with trees that have smaller than optimum canopies can then be evaluated. It is also possible to determine if maximizing canopy area is advantages for a given orchard.

Spatial Implications for Nitrogen Management

Combining canopy assessments with N concentration data is essential to developing a nitrogen fertilizer strategy for an orchard. Our data suggests that low N concentrations can be a result of either insufficient N or the result of a healthy dilution of N in trees that have maximized the amount of leaves in their canopy. Since canopy sizes are much more variable than N concentration, the amount of leaves on a tree has more impact on the amount of total N in the canopy than the N concentration in the leaves. This generalization was observed in all of the data sets we evaluated. As an example, the relationships between canopy status and N concentration for the data points presented in Figure 8 will be discussed below.

Very low N concentrations were present at some locations within the orchard evaluated in Figure 8. Some of these locations have insufficient N in the tree canopies to optimize tree performance. Trees associated with the four points at the lower right in Figure 8 have less than optimum canopy size and are low in N. Adding more N may not solve their problem but there is clearly not enough N in the canopy to maximize production. At the same time, very productive trees with large canopies also have N concentrations that are also very low. As tree or canopy size increases the N in leaf tissue is diluted. This is apparent in the Figure 9. Large trees with large canopies have low N concentration even though the total N in the canopy is high.

Rather than attempting to interpret leaf N concentrations we would suggest calculating an N requirement based on whether or not canopy size is adequate. Canopy size and tree size can be used to estimate how much N a tree or orchard region will require. If a larger canopy is desired more N will be needed. We believe that both deficient and adequate or even excessive N conditions can be found in the same orchard.

Replacement of Organic Nitrogen with Nitrogen Fertilizers

Samples are still being analyzed but some preliminary trends are apparent. The amount of N derived from the fertilizer that is present in tree tissues after the growing season in which N is applied varies from a low of 12 to a high of 30 percent among the various sites we evaluated. The Medford site has the highest amount of N derived from the fertilizer. This site also has the coarsest texture.

We feel that these differences can be explained by differences in the amount of organic matter and potential N mineralization that occurs at the sites. There is likely more N available at our study sites than the trees need. The sandy site at Medford has more uptake from the fertilizer because there is less available from the soil.

We also now believe that ^{15}N data may overestimate the importance of fertilizer sources. For example a site that has 20% of its N derived from the fertilizer does not mean that fertilized treatments have 20% more N in the trees than unfertilized controls. Fertilizer N is readily available and quickly taken up resulting in substantial fertilizer N being present in the trees. However, the fertilized trees often have approximately the same total N content as unfertilized controls. This suggests that much of the N taken up from the fertilizer simply replaced N that would have eventually been taken up as the organic matter in the system slowly makes additional N available.

It is not as simple to quantify how the requirement for N fertilizer varies as soil and environmental characteristics differ as we expected. In very sandy, low organic matter soils the interpretation of ^{15}N data is more straightforward since replacement of mineralized N by fertilizer N is less important. However, many orchard sites have a substantial amount of N that is supplied by organic matter. Annual N applications are likely required to maintain profitable production, but the amount of fertilizer required to supplement organic sources is difficult to determine. The effect of annual N additions on the size of the organic N pool and how fertilizer N becomes available in future years is difficult to determine.

Figure 1. The relationship between tree size and N recovery in pear trees grown in Medford Oregon.

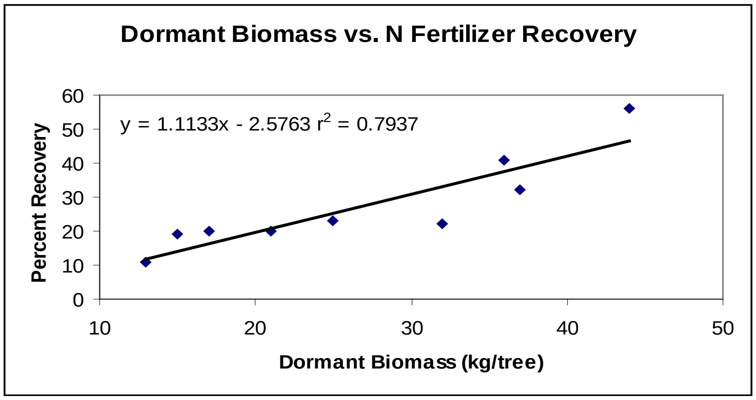

Figure 2. The relationship between relative tree size and relative yield for apple trees grown in Corvallis, OR and Parma, ID. The upper boundary line is hand drawn.

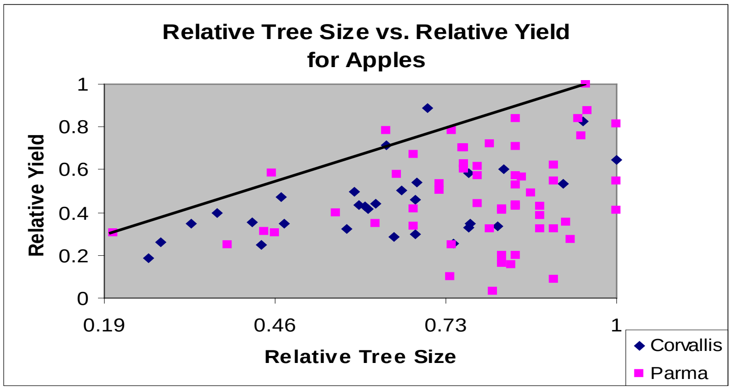

Figure 3. The relationship between relative trunk cross sectional area and relative economic return for pears grown in Hood River Oregon over a three year period. The upper boundary line is statistically derived.

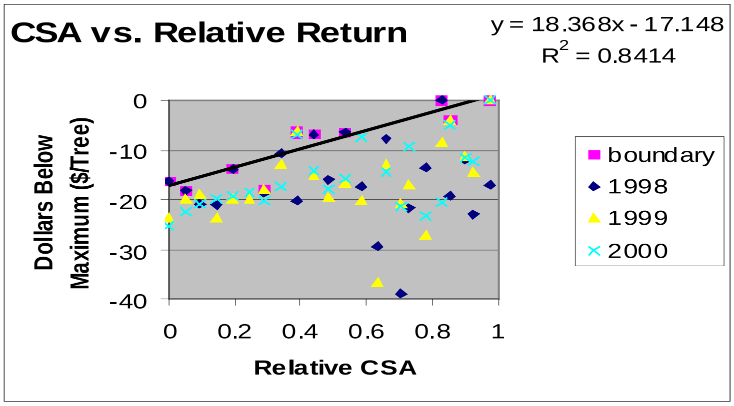

Figure 4. The relationship between trunk cross sectional area and average economic return for pears grown in Hood River Oregon over a three year period. The upper boundary line is statistically derived.

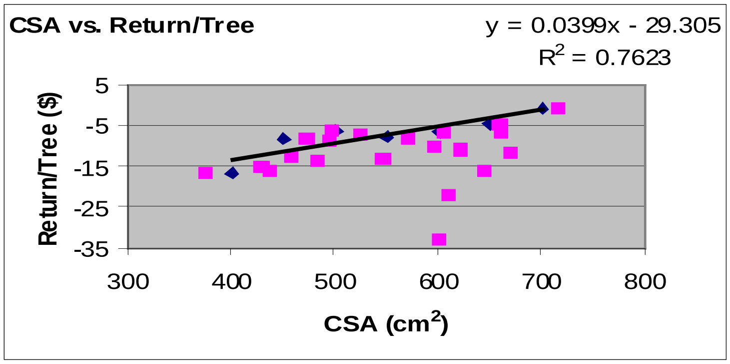

Figure 5. The relationship between trunk cross sectional area and economic return for pears grown in Hood River Oregon for a single season. An upper boundary line is not shown.

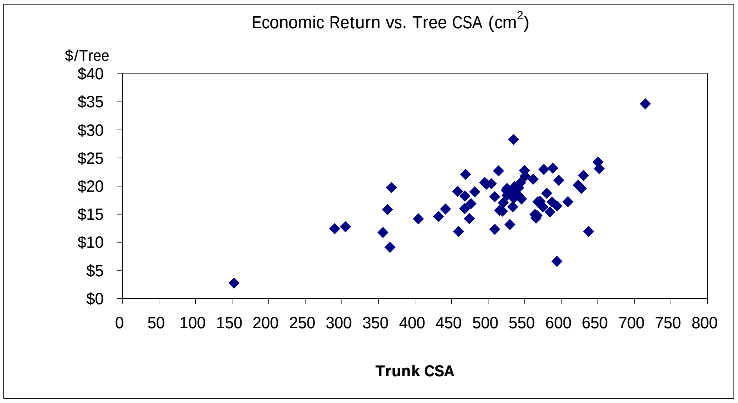

Figure 6. A contour map of a pear orchard showing regions of high, medium and low profit improvement potential. The light colored regions have high improvement potential. Dark colored areas have low improvement potential.

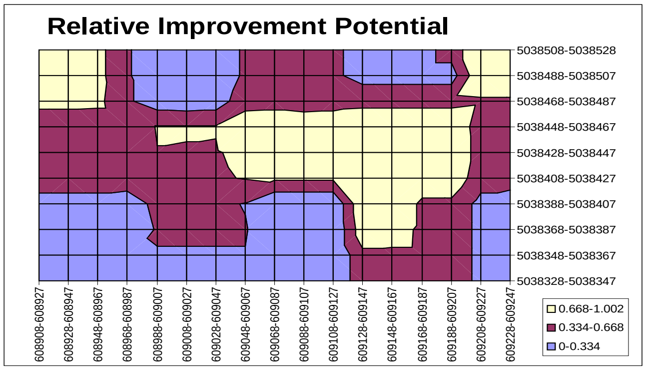

Figure 7. A scatterplot with a boundary line showing the relationship between an acidity index and trunk cross sectional area for a pear orchard. A pH or acidity index combines both soil pH and leaf Mn into a single value. A high acidity index corresponds to a high pH.

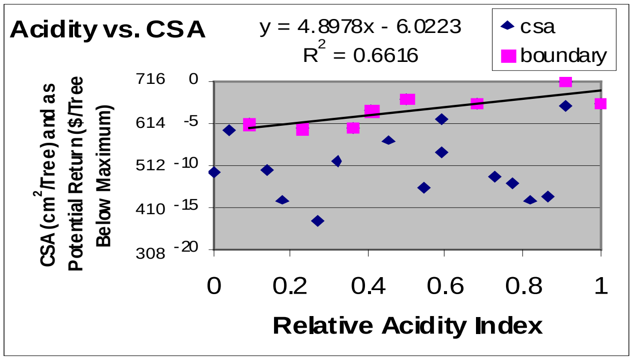

Figure 8. A scatterplot with a boundary line that demonstrates the relationship between trunk cross sectional area and canopy area for a pear orchard. The four points in the lower right of the plot represent large trees with small canopies. These trees are also low in N.

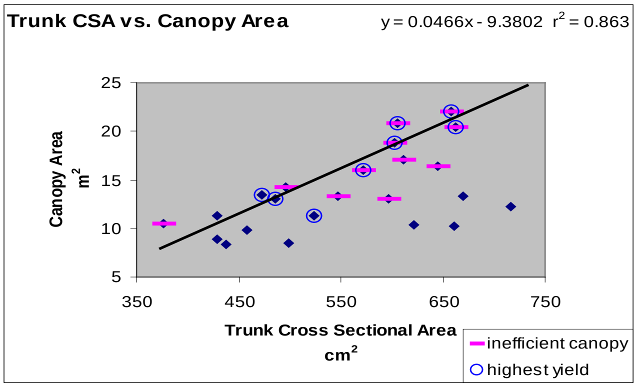

Figure 9. The relationships between canopy area and leaf N concentration for both large (right) and small (left) pear trees. The large trees with small canopies identified in Figure 8 (square points) have been excluded from the regression lines.