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Title: EVALUATION OF THE DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS) ON HAZELNUTS (CORYLUS AVELLANA) IN OREGON

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This study evaluates Beufil's Diagnosis and Recommendation Integrated System (DRIS) on hazelnuts. Although sufficiency ranges are currently the main approach for fertilizer recommendations in Oregon, DRIS enhanced nutritional interpretations, and might alter recommendations. Reference values (DRIS norms) were developed using 15 years of published and unpublished field data. DRIS indices and Nutritional Imbalance Indices (NII) were then calculated for a previously published experiment. NII was a good indicator of nutrition limitations to maximizing yield. Obtaining high yield was only possible with low NII trees. There was a

good agreement between DRIS and sufficiency ranges, especially if the relative deficiency or excess associated with corresponding relative excesses or deficiencies are evaluated. DRIS indices and NII more clearly present both beneficial and harmful effects of altered plant mineral composition. The data indicate that using these two parameters will help in better evaluations and more valuable recommendations.

AN EVALUATION OF THE DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS) ON HAZELNUTS (<u>CORYLUS AVELLANA</u>) IN OREGON

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I. REVIEW OF LITERATURE

Introduction

Yield is the result of many interacting factors, and most of these factors are difficult to control. Environmental and biological factors often limit yield even though nutritional problems have been corrected. However, plant nutrition is to a large extent controllable. It is important to optimize the nutritional status of the crop, because optimum yields can be achieved only if plants are properly fed. Plant tissue analysis for nutrient concentration provides an indication of the nutrient status of a crop and can help to guide fertilizer recommendations.

The standard approach to interpreting the results of foliar analysis is usually on the basis of the critical nutrient concentration (CNC). A critical value is defined as that concentration of nutrient below which a reduction of yield results. Unfortunately, relationships of this type are usually obtained under conditions where only a single growth factor is varied (60). The order of importance of the various limiting nutrients on yield is difficult to establish (53). Since values vary with timing, critical value approaches require sampling of a particular stage of growth (53).

The Diagnosis and Recommendation Integrated System (DRIS) developed by Beufils (1,2,3) and later by Sumner (50) is an alternate approach that minimizes difficulties in interpreting mineral analyses. This system uses nutrient concentration ratios, rather than concentrations themselves, to interpret plant analysis. High yield and low yield subpopulations are selected from a large number of independent observations. DRIS norms are defined as the average values of important nutrient ratios from the high yield subpopulation. DRIS indices for each individual nutrient can be calculated using these reference norms, their standard deviations, and the observed ratios from the sample being evaluated (27). The degree of nutrient imbalance in the plant is expressed in terms of a DRIS index which measures the extent to which a particular nutrient deviates from the established norms (4, 5). These indices will have a negative or positive value depending on the deficiency or surplus of the particular element. Recommendations are based on the relative value of the indices.

DRIS reflects nutritional balance and indicates not only the nutrient most likely to be limiting, but also the order in which other nutrients are likely to become limiting. Standards for DRIS can be developed quickly, because simple surveys can produce independent observations. DRIS has been successful on several annual and perrenial crops (1,3,4,18,14,34,50,53). The present study was conducted to evaluate the effectiveness of using DRIS as a guide for hazelnut fertilization.

Hazelnut Fertilization

Hazelnuts are produced commercially in only limited regions of the world. About 70% of the world production comes from Turkey (43). The United States only produces about 3% of the world production (44). Most of this is produced in the Coastal Valley of Oregon. In general, hazelnuts grow best in areas with mild winters, warm springs and cool summers (32,33). They also thrive under cultivation in areas whose climates are influenced by large bodies of water (33).

As in most other tree crops, optimum fertilization is necessary for optimum yield in hazelnuts. Fertilizers, however, are too expensive to waste. Correct amounts and good timing are very important, especially in the application of nitrogen. It is known that nitrogen is highly soluble in water and must be applied at a time when uptake by the plant is taking place. It is also important to consider that nitrogen applied late in the year is stored (primarily in the root system) for use in the following year (13).

Critical Nutrient Concentration (CNC) based on leaf tissue analysis is the main approach for fertilizer recommendations in Oregon's hazelnut crops. Soil testing is used mainly for liming recommendations. Soil test values often correlate poorly with plant uptake. Painter (39) demonstrated the advantage of leaf tissue analysis over soil tests for hazelnuts. He observed that soil tests showed a very high level of potassium in a hazelnut orchard while leaf tissue analysis indicated a potassium deficiency. Potassium fertilizer led to increased growth and yield. Painter concluded that potassium was present in the soil, but it was in an unavailable form for the plant. It could also be concluded there was a missampling of the soil as a result of banded application of potassium. Banded application of most fertilizers on hazelnut orchards contributes further difficulties in using soil tests for fertilizer recommendations. Soil analysis, however, is useful in predicting the need for potassium, magnesium and lime applications before planting new orchards (49).

Based on mineral content, the main deficiencies found in hazelnut orchards in Oregon are N, K, and B (49). A study done by Kowaleko (29) in British Columbia examined the current elemental status of orchards there. He oberved that K was the main deficiency according to leaf analysis, and instances of N, P, Ca, Mg and B deficiency were also found. However, these may not be applicable in Oregon since, according to Kowaleko (29), Oregon management practices are often not suitable for British Columbia conditions. Furthermore, weather and soil conditions in hazelnut growing areas of British Columbia are not always comparable to those of Oregon (29).

The normal fertilizer requirements for a mature hazelnut tree, as published by Nut Growers Handbook (39), are 1 1/2 - 2 lbs. N per tree annually; up to 10 lbs. of potash per tree banded when needed; and boron when needed as a soil application. These recommendations agree to a great extent with the Oregon State University Fertilizer Guide (49) for hazelnut trees, which advocates using tissue analyses to determine need.

Disadvantages of the CNC approach are discussed in more detail elsewhere in this paper. This study was conducted to evaluate if DRIS could alleviate some of these disadvantages in hazelnuts.

Factors Affecting Interpretation

Fifteen elements are generally recognized as essential for the normal growth and reproduction of plants (45). It is well known that an application of one element will cause an increase or decrease in others. These mineral interactions complicate the intepretation of plant analysis. Shear (44) reported that the absorption and accumulation of each nutrient ion is dependent on the absorption and accumulation of other available ions. In order to maximize yield, leaf elements should be present in the proper proportion to other essential elements. Defining a single critical value without regard to the concentrations of other elements is overly simplistic.

Antagonism and synergism effects are general terms used to describe interrelationships between nutrients in plants (48). Antagonism may occur by one of three processes: a) interference or competition in absorption, b) interference in translocation, or c) interference in utilization at the point of destination.

Nitrogen and phosphorus antagonism has been reported by Weeks (61) and others. Chaplin and Dixon (11), while working on developing N standards for hazelnuts, found a significant decrease in P following N treatments. Another well known reciprocal relationship is between potassium and magnesium content of the foliage (5,6,7). Boynton (5,7) reported that magnesium deficiency symptoms in McIntosh apples increase in severity with the use of potash fertilizer. Nitrogen fertilizers also were found to decrease leaf K (9,11,19). Cain (9) suggested that this effect is likely to be related to the metabolic function of potassium rather than antagonism in the tissue. Chaplin (11) found that N treatment causes a slight decrease in leaf K. However the effect was not always consistent. Increasing N content initially increased but at higher N levels decreased leaf K in the fifth year of the study. Increase in growth and vigor may complicate simple interpretation. Dilutions and concentrations may result in concentration differences that are unrelated to uptake. It is not suprising that literature reports are inconsistent.

Chapman and Brown (12) reported that citrus trees which have potassium deficiency accumulate more Ca, Mg and Na. Another example of antagonism is between Fe and P where a high level of P may result in Fe deficiency. In addition to these examples, there are other antagnonisms between other different elements, for example Fe and Mn (46), and Fe and Mo (21).

Synergism, on the other hand, is an opposite effect to antagonism, wherein an increase in one element results in a simultaneous increase in another. Cain (9), Sheer (44) and Walter (59) report a synergistic effect between N and Mg, with an increase in N resulting in an increase in leaf Mg. However Goode and Higgs (20) found that nitrogen fertilizer had no effect on leaf Mg. Another synergistic effect is between K and Na, where increasing K causes a simultaneous increase in tissue Na. Smith (48) reported that this effect disappears at high levels of K and that Na will decrease with further continuous increase in K. A similar synergism occurs between Ca and Mg, where increased Ca application may result in increases in both

Ca and Mg, though further increases in Ca may not be accompanied by corresponding increases in Mg.

It is important to keep in mind that the occurrence of antagonism or synergism in a given cultivar, specie or genera under certain environmental conditions may not generally apply to other situations. However, these effects will have an important bearing on the interpretation of tissue analysis. Low tissue concentration of one element may be the result of excessive application of another. For example, magnesium deficiency may be alleviated by increasing N or reducing K rather than increasing Mg.

Age of the plant is an important factor determining how nutrient contents differ. Mineral constituents of the plants increase or decrease with the age of the plant (30,31,45). There are also differences between different parts in the same plant, depending on the age of the tissue. In general N, P, K, Cu, and Zn were found to decrease with age (47,49), whereas Ca, Mg, Mn, Fe, Al, and B increase with age of the tissue (30,35,40,47,49). Seasonal changes within a given year have less effect on mineral composition than do year to year variations (49).

Translocation of elements within plants is important in interpreting tissue analysis. Hosely (22) reported that new growth of apple trees is almost entirely dependent on the use of stored minerals, thus fertilizer additions may not have an immediate effect on the current season. Wallace (5) found that citrus leaves may lose 25-30% of N as the element moves directly into new growth. Partitioning between fruit and leaves also alters the interpretation of plant mobile elements. Potassium is very mobile in the plant, and loss of K from the leaves in high crop years may result in an apparent K deficiency that is not observed in low crop years. Phosphorus also moves up and down in the plant; however, Rinne and Langston (42) showed that P doesn't move laterally in the plant. Some other elements like Ca and B are known to be relatively immobile in the plant, whereas Fe, Zn, Mn are less mobile than K, N, and P.

Diagnostic Methods

The objective of applying any diagnostic method to a crop is to obtain information that assists in making management decisions to optimize yield and quality. Visual symptoms of deficiency or excess are useful, but do not provide a diagnosis until the problem is severe. Early detection is desirable. There are many soil and plant diagnostic methods (57). It is difficult to find a chemical extractant for soil that will reproduce the extracting properties of the roots of higher plants (38). Reliable tests for N and micronutrients are not available for many soils, and changes in fertility practices make accurate evaluation of the soil nutrient status difficult. Furthermore, plants behave differently with regard to the absorption of mineral nutrients from the same soil (57). Smith (49) stated that the plant is the best indicator of nutrient availability, and plant sampling is more convenient than soil sampling. Nicholas (38) and Wallace (57) et al. reported that plant tissue tests are superior to soil tests and give a better guide to diagnosing deficiencies. Soil tests, however, can be used successfully as a complement to plant tissue tests.

Leibig in 1840 was the first to propose the principles of plant growth analysis, and he introduced the idea that plant growth may be limited by its mineral nutritional status. Tissue tests are more adapted to long term perennial crops, especially fruit trees, and are less useful for annual crops. This is because of the time necessary for diagnosis and subsequent application of corrective fertilizers. When one considers the lifetime of an orchard, long term management is possible.

Critical Nutrient Concenrtration (CNC)

Tissue analysis has been used in interpreting the nutritional status of plants for many years. It is well established that there is generally a good relationship between plant nutrient status and crop performance. Most systems of crop diagnosis utilize the critical nutrient concentration (CNC) approach for interpretation and fertilizer recommendations. The principles of this approach were developed first by Lundegardh in 1945.

Critical nutrient concentration approaches assume that the concentration of a nutrient in an indicator tissue can be deficient, normal or excessive, and the critical level is the concentration below which yield reduction due to a deficiency of that nutrient is expected when other cultural and environmental factors are not limiting (28).

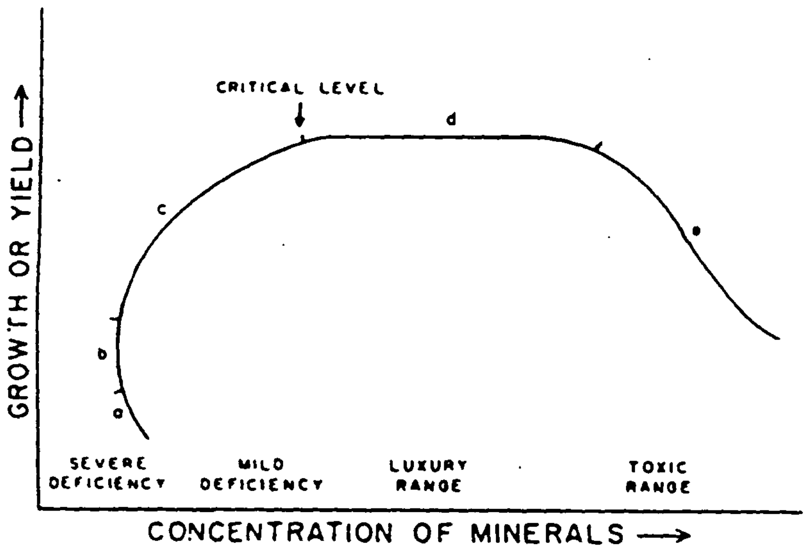

Figure 1. Relationship between mineral concentration and yield.

Figure 1 shows the general scheme of this approach. Zone a shows the Steenjberg-effect where application of a deficient element causes a decrease in leaf concentration, following an application of a deficient element due to the low increase in growth. This is usually found under the extreme deficiency of an element. Zone b illustrates a possible growth response with little or no change in leaf concentration. In zone c simultaneous increases in growth and leaf concentration occur until the critical level is reached. In zone d there is no growth response, although the leaf concentration increases. Zone c shows decrease in growth or yield accompanied by toxic qualities.

Although this system has several disadvantages it still receives general acceptance. The success and value of such plant analysis, however, depends on the accuracy with which the analytical results can be interpreted and related to field conditions (36). This is especially true since plant composition can vary widely, particularly in the range of luxuary consumptions, without having any measurable or visible influence on growth and yield.

Several investigators have pointed out that CNC may lead to indistinct and ambiguous relationships between yield and leaf nutrients. Sumner (50), working on maize, found that an increased application of a nutrient to a soil doesn't always correspond to an increase in the concentration of that nutrient in the plant. Similar results were found on hazelnuts (11) where leaf nitrogen didn't always correspond to increased levels of applied nitrogen. The supposition that if leaf concentration of a certain nutrient is below a given value, more fertilizer should be applied, is not always valid (10). Changes in the nutrient content of the foliage don't necessarily reflect corresponding changes in the shoot tissue nor can they be interpreted as changes in the uptake of nutrients from the soil (9). Without biomass estimates total uptake cannot be evaluated. Dilution and concentration effects complicate interpretation. Interactions among elements are not accounted for when CNC approaches are applied. It is possible that the optimum level of one nutrient depends on levels of another.

Since relationships between yield and nutrient concentration are usually obtained under conditions where only a single growth factor is varied, the relationships may be specific for the conditions of a specific experiment and may not hold true under different conditions (60). Nutrient concentration varies depending upon plant part, stage of growth, variety and geographic location (10,49). The way in which the critical level of an element may fluctuate if it is modified by some other factor doesn't seem to be generally understood. Unless all of the main parameters affected in plant performance can be identified and quantified, the regression approach is of limited value in extrapolating to unknown situations and will simply remain an a posteriori approach to organizing data (60).

Diagnosis and Recommendation Integrated System (DRIS)

DRIS was first proposed by Beaufils (1,2) as a means of detecting mineral imbalances in corn and rubber trees. This approach is being increasingly used as a diagnostic tool for determining fertilizer recommendations. In studies applying DRIS to sugar cane (3,16), corn (16,18), soybean (50), oranges (Valencia) (4) and sweet cherries (14), DRIS has been found reliable in diagnosing nutrient requirements. DRIS was generally more accurate than the CNC approach in most of these studies. Elwali and Gascho (16) found that fertilization according to DRIS significantly increased both cane and sugar yields compared with those obtained when fertilization was guided by foliar analysis using the CNC approach and soil tests. Jones (26) and Jones and Bowen (28) reported that DRIS often produces more accurate diagnoses than conventional systems. Sumner (52) concluded that DRIS indices have been superior to sufficiency range approaches.

Jones (26) summarized the possible advantages of using DRIS in plantation programs of tissue analysis as follows.

1. DRIS is an independent means of analyzing the nutritional status of the crop. It is often more accurate than conventional soil and plant analyses.

2. Where sufficient tissue analyses are available, plantation and variety-specific indices can be obtained.
3. DRIS provides a means of normalizing nutrient indices so that the indices of the various nutrients are directly comparable. This allows identification of the most limiting nutrient.
4. Nutritional recommendations based on DRIS are reported to be less subject to error due to variation in crop age and environmental factors than are conventional systems of tissue analysis.

Several workers are in complete agreement on the first three advantages. However, as mentioned before, the last advantage is debatable and further research is required.

Sumner (53) stated that his results on soybean show that the diagnosis can be made irrespective of variety and age at which the leaf is sampled. The same results were found on corn (50). According to Sumner (50), DRIS is able to make consistent diagnosis of the order of a plant's requirement of elements irrespective of the position of the leaf sampled. On sugar cane studies (16,52), the DRIS approach was superior to the threshold value approach in that it can be conducted over a wider range of ages of the material sampled.

In contrast, Beverly, Stark, Ojala and Embleton (4) reported that DRIS diagnoses were affected by the type and age of the tissue sampled. However, sensitivity of DRIS to the type and age of the tissue may differ from one crop to another, and is likely to be dependent on the elements being evaluated. In general it is less sensitive to type, age of tissue, or environmental conditions than is the CNC approach.

The major limitation in using DRIS is the calculation difficulties which limit its use. However, Jones (27) proposed a simplified formula for calculating DRIS norms and indices. Once norms are obtained DRIS can be verified with either historical data or newly conducted controlled experiments. It is essential that any set of diagnostic norms be tested against independent data in order to ensure that they are capable of making meaningful diagnoses. The following are the three major steps in developing DRIS indices for any particular crop.

Establishing DRIS Norms

The first step in establishing DRIS norms is to collect data where yield or other desirable parameters can be coupled with a mineral analysis. Data can be from published or unpublished sources, either derived from the literature or collected from survey work. Sumner (52) found that the best data banks for corn are those which are large, random and have a substantial number of high yield observations. DRIS norms are then developed from the collected data. Beufils (1,2,3) originally stated that norms could be established from average yielding plants. But Sumner (51) later found that it is more accurate to use high yielding plants to establish norms.

A clear example in developing DRIS norms for N, P, and K in soybeans was presented by Sumner (53). In this example, preliminary DRIS norms for soybean leaves are developed from 1,245 data points. The population of observations was divided into two subpopulations on the basis of yield. All possible ratios for each element in the plant were calculated. For each subpopulation the mean, standard deviation, coefficient of variation and variance for each ratio were computed. All forms of expression, for which a significant variance ratio existed between the two subpopulations, were considered as being important or discriminatory. Sumner found N/P, N/K and K/P as the ratios which discriminate between high and low subpopulations. These three important ratios of the high subpopulation were considered the norms and were used to calculate DRIS indices.

Calculating DRIS Indices

Details of how to calculate DRIS indices are fully described by Beaufils (1,2) and Sumner (50). The following are the formulas which Sumner (53) used to calculate N, P, K indices for soybean.

$$\text{N index} = + \left[\frac{f(N/P) + f(N/K)}{2} \right]$$

$$\text{P index} = - \left[\frac{f(N/P) + f(K/P)}{2} \right]$$

$$\text{N index} = + \left[\frac{f(K/P) - f(N/K)}{2} \right]$$

where $f(N/P) = 100 \left(\frac{N/P}{n/p} - 1\right)\frac{10}{CV}$

when the actual value of $N/P < n/p$,

or $f(N/P) = 100\left(1 - \frac{n/p}{N/P}\right)\frac{10}{CV}$

when the actual value of $N/P > n/p$;

and where N/P is the value of the sample and n/p is the norm for the parameter under consideration. These indices have positive and negative values which always sum to zero as they measure the relative balance among N, P, and K or other elements that might be included (53).

Jones (27) proposed some modification in order to simplify the calculation of DRIS indices. He suggested that Beaufils' equation overestimates f(X/A) when X/A is less than x/a, and he proposed the following equation be used to calculate the intermediate function regardless of the relative values of the parameter involved:

$f(N/P) = (N/P - n/p)\ SDi$

where SDi is the standard deviation of the norm n/p.

Elwali and Gascho (16,17) slightly modified Beaufils' formula in calculating DRIS indices for sugar cane. They consider two elements (x and y) to be in balance [f(x/y) = 0) if their ratio value falls within the range of the norm mean   the standard deviation of the norm. They believe that for each DRIS ratio a range rather than a single value should be considered optimum. According to Elwali and Gascho (17), calculation of DRIS indices using this modification minimizes the chances of erroneous determination of severe imbalances between nutrients.

Other workers follow similar procedures, but with some differences. For example, Jones (26) found that if only the variances are used to determine the important parameters, only two parameters will be used to calculate the Ca index. He concluded that using only two ratios to calculate a DRIS index would make that index highly dependent on the tissue concentrations of the other elements used. He suggested that if both variances and means are used to determine important parameters, more parameters will be used and the index will be more independent.

Davee, Righetti, Fallahi and Robbins (14) used, in addition to the mean and variance to select the discriminatory ratios, those ratios which were significantly correlated with yield (and in the same direction). In general, using both means and variances to determine important parameters will increase the number of important parameters, and this will reduce the influence of abnormal concentrations of one element on the DRIS indices of other elements.

Beaufils (1,2) and Sumner (17) claimed that once DRIS norms have been established for a particular crop, they could be universally applicable for calculating DRIS indices for that crop. Meyer (37) found that this is true for sugar cane. He collected five sets of published norms for sugar cane and found them similar, although the data which were used to establish the various norms came from different sources. However, this might not be true for all other crops. Escano (18) found that using published norms gave inaccurate diagnosis of N and P fertilizers. Locally developed norms were superior.

Diagnosis and Recommendation

It is clear that actual fertilizer recommendations should not be based on tissue analyses alone. Soil data, cultural practices, and prior experience should be considered for meaningful fertilizer recommendations (4). DRIS approaches needn't completely replace critical concentration approaches. Davee, Righetti, Fallahi and Robbins (14) also reported that supplementing a sufficiency range diagnosis with DRIS indices may assist in interpretation of tissue analyses and alter recommendations when severe nutritional imbalances occur.

There are different opinions about how to use DRIS for diagnosis and fertilizer recommendation. Beaufils (1,2) suggested that a nutrient could be considered sufficient if its index falls within 1.33 units (4 SDi/3) of zero for an indecie that contains 3 intermediate functions. However in some cases using this suggestion was less accurate (8). Jones (26) noted a positive response for N if the DRIS index of that element was less than zero and one of the most negative indices. Beverly (4) found that DRIS often identified Ca as deficient. Since citrus trees are not likely to respond, he suggested that a Ca index simply means that Ca compared to N, P, K and Mg in the sample is lower than Ca compared to N, P, K and Mg in the reference population. Although it is important to know that one element is relatively more deficient than another, many other factors must be taken into consideration before a fertilizer recommendation can be made.

The nature of the DRIS expression will always make a relative diagnosis, thus specific excesses or deficiencies are only important if the tree as a whole is severely imbalanced. A Nutritional Imbalance Index (NII) helps clarify whether severe imbalances exist and is helpful in making DRIS based fertilizer recommendations. The NII is obtained by adding the values of DRIS indices irrespective of sign (14,17,51). High values for the NII are associated with more intense imbalances among nutrients and suggest less chance for obtaining a high yield. Davee, Righetti, Fallahi and Robbins (14) found that imbalanced sweet cherry trees have no chance of obtaining high yields; on the other hand, they stated that it is also possible to obtain low yields with NII, because many other environmental and biological factors are important. They established a NII threshold of value (mean NII + 1 SD) to distinguish between trees which have severe nutritional imbalances and those that do not. Various threshold NII values could be assigned and a final value involves considerable judgement.

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II. AN EVALUATION OF THE DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS) ON HAZELNUTS IN OREGON

Abstract

The Diagnosis and Recommendation Integrated System (DRIS), which uses nutrient element concentration ratios as indicators of nutrient deficiency, was used to evaluate current sufficiency ranges for hazelnut trees. Reference values were derived from published and unpublished field data from various Oregon locations. DRIS indices were calculated for each element from a formula which included DRIS standard ratios, their standard deviations, and the observed ratios in the sample. Nutritional imbalance indices (NII) were computed as the sum of DRIS indices irrespective of sign. A threshold NII value (mean NII + 1 SD) above which severe imbalances are expected was established. DRIS diagnoses were compared with the sufficiency range approach to determine if relative deficiencies or excesses associated with severely imbalanced trees would have been routinely detected. DRIS diagnosis generally agreed with the diagnoses made by the sufficiency range method, especially if ranges for Mn and B were made more narrow. However, some elements were not identified as deficient or excessive in any of the severely imbalanced trees. Nitrogen and Mg deficiencies were not detected unless lower imbalance thresholds were used. A previously published field trial was also reevaluated to determine if

imbalances among N, P, and Mn caused by nitrogen application could have adversely affected the trees and weakened the relationship between leaf N and yield. Excessive nitrogen treatments aggravated N, P, and Mn imbalances, suggesting that the lowest level of applied N was most desirable. Since nitrogen applications both enhanced nitrogen status and aggravated imbalances it is not surprising that the relationship between leaf N and yield is weak. Although DRIS will not likely become a replacement for sufficiency range diagnoses, supplementing conventional approaches with a DRIS evaluation can enhance interpretation and more clearly present the consequences of tradeoffs between beneficial and harmful effects.

Introduction

Early work on rubber (1) and more recent studies on valencia oranges (6) and Royal Ann sweet cherries (9), suggest DRIS can successfully diagnose nutritional disorders on perennial trees. The principal advantage is that DRIS provides a measure of nutritional balance rather than evaluating only a single deficiency or excess at a time.

The Diagnosis and Recommendation Integrated System (DRIS) is a diagnostic approach that uses nutrient concentration ratios rather than concentrations themselves, to interpret tissue analyses (2). Many reports suggest that DRIS can provide a better indication of nutritional status than conventional sufficiency range approaches (1,3,4,5,6,9,13). A diagnosis is based on values of a given element relative to other important elements rather than a rigidly defined sufficiency range. This approach minimizes the results of a general dilution or concentration and can better evaluate possible nutritional interactions (9).

Details of DRIS utilization are presented elsewhere (2,3,4,5,10,13), but the following is a brief summary. Reference ratios (DRIS norms) are defined as the average values of important nutrient ratios from a desireable subpopulation (11). DRIS indices can then be calculated from a formula which includes these reference ratios, their standard deviations, and the observed ratios from the sample being evaluated (11). DRIS indices for individual elements will be more negative or positive depending on the degree of relative deficiency or surplus. Summing individual DRIS indices regardless of sign provides a measure of nutritional imbalances that consistently relates to crop performance (9,13). High yield is not possible when this sum of DRIS analyses is excessive (9,13). Therefore a DRIS evaluation can identify cases where severe nutritional imbalances limit yield (sum of indices is excessive) and describe the nature of the disorder (which individual indices are most positive or negative).

Since DRIS standards are based on an evaluation of a large number of independent observations rather than observed responses in carefully controlled experimental trials, standards can be quickly developed. These standards can then be used to reevaluate previous experiments. DRIS diagnoses can also be compared with the sufficiency range approach to determine if the relative deficiencies or excesses associated with severely imbalanced plants would have been routinely detected. The approach may be valuable in reassessing sufficiency ranges currently in use. When nutritional balances data is combined with mineral concentrations, nutritional relationships that are difficult to evaluate become more apparent.

Hazelnuts are an important crop in Oregon, but their small distribution has resulted in limited study. Leaf analysis is currently used to make fertilizer recommendations but sufficiency ranges could use more refinement. Although field trials have established an optimum sufficiency range for nitrogen (2.2% - 2.4%), there is no strong relationship between leaf nitrogen concentrations and plant response to added fertilizer. The r^2 values relating leaf N to yield varied between .12-.20 in the experiments conducted to define them (7). Furthermore, nitrogen treatments also altered the concentrations of other leaf minerals, complicating interpretation. Although values remained in the sufficiency range, nitrogen treatments elevated leaf Mn and depressed leaf P (7). It is possible that induced imbalances involving N, P, and Mn have adversely affected the trees and weakened the relationship between leaf N and yield. Our goal was to develop DRIS norms for hazelnuts, evaluate the possibility of nitrogen induced imbalances, and determine if a DRIS evaluation would suggest disorders that were not revealed with a sufficiency range approach.

Materials and Methods

Published and unpublished data consisting of leaf mineral composition and corresponding yield for hazelnuts grown at various Oregon locations were obtained for N, P, K, Ca, Mg, Fe, Zn, Mn and B for norm development. Data were collected from 1970-1985, from a collection of orchard surveys and experimental plots. Leaf samping and tissue analysis were generally similar for all sources of data. Mid-shoot August leaf samples were collected for mineral analysis. Nitrogen determinations were made with an autoanalyzer after standard microkjeldhal digestion (8). Spark emission spectroscopy was used after dry ashing samples at 500^{o} for 24 hrs to measure P, K, Ca, Mg, Mn, Fe, Cu, B, Zn and Al (11). In most cases data was collected for individual trees. Some yields were obtained on an acre basis, but these were converted to yield per tree before further evaluations.

The observations were divided into high (highest 15%) and low (lowest 15%) yield subpopulations for each year of data. Subpopulations for each year were combined. Thus desirable and undesirable groups for the entire bank of data were obtained. A total of 624 individual data entries were evaluatd with 90 assigned to either high yielding or low yielding subpopulations. For the two subpopulations the mean, variance, and standard deviation were calculated for all possible ratios between nutrient concentrations (N/K, K/N, etc.). Two different approaches were used to select those ratios that discriminate between high and low yielding subpopulations:

1) If the mean of a nutrient ratio was significantly different for high and low yielding subpopulations the ratio was considered important (11).

2) If the variance of a nutrient ratio was significantly different for high and low yielding subpopulations, the ratio was considered important (3).

When both a ratio and its inverse were important, ratios with greater statistical significance were used as the reference norms.

Reference norms were incorporated into a diagnostic computer program using a modified version (11) of DRIS general calibration formula (1,2). DRIS indices were calculated on all 624 hazelnut leaf analyses using the two sets of reference norms obtained from each ratio selection approach. DRIS indices were also calculated using all ratios selected by either criterion. Additional DRIS evaluations were made using smaller subsets of ratios. Separate evaluates were made using only ratios involving N, P, and K or ratios involving N, P, K, and Mn. The end result of these procedures was a series of varied DRIS evaluations which allowed us to investigate the consequences of using different elements and ratio selection approaches on DRIS diagnoses.

A nutritional imbalance index (NII) was calculated as a measure of balance among nutrients for each DRIS evaluation. It is obtained by adding the values of DRIS indices irrespective of sign. The larger the NII, the greater the intensity of imbalances among nutrients (9,11). Although various threshold NII values could be assigned, a value greater than the mean plus one standard deviation of all NII's was used to identify severe imbalances. This value was selected because high yields (highest 15%) were not associated with NII's above this threshold in preliminary evaluations. Trees with NII values above this threshold were classified as severely limited by mineral nutrition. Trees with an NII between the mean and one standard deviation were identified as having possible imbalances. Trees with an NII less than the mean were classified as balanced. When a severely limited, or possibly limited tree was identified, DRIS indices were placed in increasing order and limiting nutrients, both relative deficiencies and excesses were identified.

DRIS diagnoses were compared with the sufficiency range approach on the 624 hazelnut leaf analyses to reveal if the relative deficiencies or excesses associated with severe imbalances would have been routinely detected.

Sufficiency ranges were obtained from the plant analysis laboratory, Department of Horticulture, Oregon State University. Additional sufficiency ranges were derived by selecting a range that produced the best agreement with DRIS evaluations for the 624 observations we evaluated.

Data from a previously reported field trial experiment (7) were used to evaluate the usefulness of the derived sufficiency ranges and the accuracy of DRIS evaluations. Treatments consisted of 0, .68, 1.36 and 2.72 kg of N per tree, per year, supplied as urea from 1971 to 1977. Thirty-year old hazelnut trees growing on well drained silty clay loam soil were used. Only data for 1974, 1975 and 1977 had complete mineral analyses and yield measurements, thus meaningful DRIS evaluations could not be calculated for other years.

Results and Discussion

Ratios selected as important by the two different criteria are presented in Table 1. Thirty-two ratios were found to discriminate between high and low yield subpopulations (Table 1). Eleven ratios were selected by the mean and twenty by variance, whereas only two ratios were selected by both mean and variance. DRIS evaluations calculated from ratios identified as important by mean, variance, or both mean and variance generally identified the same samples as imbalanced, provided the same elements were included in the evaluation.

In order to have symmetrical DRIS indices (sum equals zero) it is necessary to use an equal number of ratios in calculating the indices for each individual element. This becomes increasingly difficult as more elements are utilized in a DRIS evaluation. Although all-element indices were slightly asymmetrical (sum either slightly less or slightly greater than zero), interpretation was generally similar when either equal or unequal numbers of ratios were used to calculate indices for elements being evaluated. Symmetrical DRIS indices (sum equals zero) were obtained in calculating NPK and NPKMn indices.

Although interpretations were similar for both ratio selection methods, using ratios selected by both mean or variance was most appropriate. An insufficient number of ratios to calculate DRIS indices for some nutrients occurred when either mean or variance selection criteria was used alone. All the important ratios for some elements were selected either by the variance only, i.e. Zn, or by the mean, i.e., Mg. Furthermore, including more ratios may be more reliable. For example, if variances alone are used to determine important parameters, only two ratios (MnP, ZnP) will be used to calculate the P index. This will make this index highly dependent on the concentrations of these two parameters. Previous studies on DRIS concluded that the more ratios used to calculate DRIS indices, the more accurate the results (10).

Interpretation of DRIS indices is sometimes difficult. The nature of the DRIS expression will always make a relative diagnosis. Some elements are relatively excessive and others relatively deficient. Every sample has relative deficiencies and relative excesses. By establishing an NII threshold specific excesses or deficiencies are only considered if the tree as a whole is severely imbalanced. A comparison of DRIS diagnosis to sufficiency range approaches on trees identified by DRIS as having severe nutritional disorders is presented in Table 2. Relative deficiencies for K, P, B, Ca, and Zn were detected in the DRIS evaluation. Relative excesses for Mn, Fe, and Cu were also apparent. Both critical concentration and DRIS approaches consistently identify K and Zn deficiencies.

DRIS was in better agreement with sufficiency ranges when there was slight narrowing in O.S.U. standards for P, B, Mn, and Fe. However B and Fe diagnoses were still inconsistent. Some of the differences between techniques may be due to the symmetry of DRIS. When a tree is diagnosed as severely imbalanced it is not always clear if a relative deficiency or the accompanying relative excess is the major problem. However, if one evaluates the elements that are relatively excessive when K, P, B, and

Zn are relatively deficient or the elements that are relatively deficient when Mn, Cu, and Fe are relatively excessive, critical concentration approaches are more consistent with DRIS evaluations (Table 2). Imbalanced trees would have been almost always detected using sufficiency ranges with regard to the elements diagnosed by DRIS as either relatively deficient or relatively excessive. For example, relative P deficiencies were rarely diagnosed unless Mn was also relatively excessive. Trees diagnosed as relatively deficient for P would almost always have been diagnosed as having Mn excesses using current sufficiency ranges.

Although DRIS and sufficiency ranges are in good agreement for severely imbalanced trees many disorders are not detected by DRIS when a high NII threshold (mean NII + 1 SD) is used. Nitrogen never was identified as the major deficiency unless smaller NII threshold levels are utilized. DRIS analyses using fewer elements (N, P, K, or M, P, K, Mn) had a similar result. Elements other than nitrogen were most deficient or most excessive in severely imbalanced trees (data not shown). A similar situation exists for Mg. DRIS will not detect all deficiencies or excesses, and not all samples with concentrations outside DRIS derived sufficiency ranges were identified as imbalanced. Therefore, DRIS is best viewed as a supplement to sufficiency range diagnoses that provides additional information on possible imbalances.

Results of the nitrogen application trial are not easy to interpret. Increased leaf nitrogen level as a result of nitrogen treatment is illustrated in Table 3. Although leaf nitrogen increases as a result of nitrogen treatment, this does not occur as one might expect. It takes five years of nitrogen application for any of the three N treatments to reach the optimum range. It is difficult to imagine that trees would still be nitrogen deficient (2.13%) after 4 years of nitrogen application at the highest rate. Surprisingly, the control reaches a similar level (2.12%) in five years and is within the normal range in the sixth year. Although the authors suggest that cross feeding by control trees could lessen treatment differences with time, this would not explain increased differences in 1977. Nitrogen content in leaf tissue never explained more than 20% of the variability of yield in any year. The relationship between leaf nitrogen and yield potential is not strong and it is difficult to justify the sufficiency range for nitrogen derived in this study.

The second treatment, .68 kg N/tree, gave the highest yield and trunk cross sectional area (Tables 5 and 7). These two parameters dropped sharply by adding more nitrogen, although leaf nitrogen level was still in the optimum range. Manganese concentrations were above normal only for the highest N treatment in 1977 and were never diagnosed as excessive. All other leaf elements also remained in current optimum ranges (Table 4) even though some concentrations were changed by the nitrogen. Current sufficiency range standards cannot explain the reduction in yield. However, the DRIS derived sufficiency ranges (Table 2) would suggest possible P deficiencies or Mn excess.

DRIS evaluations of the nitrogen experiment provide more information. In Table 5 balance status, yield, NII, and DRIS indices are presented. Only ratios involving N, K, P, and Mn were used to derive DRIS indices in this example. DRIS indices and nutrient concentrations for N, P, K, and Mn (Table 4) display similar trends, but the DRIS indices and NII more clearly present potential nutrition problems. Nitrogen was the most limiting (most negative) nutrient in control treatments for all three years. The N index became much less negative where the low level of N was applied. Although N application improved nitrogen status it worsened nutritional imbalances. Increased imbalance, though not severe, and still in the normal range, occurs as a result of the low rate of application. However, higher application levels cause a marked increase in the severity of the imbalance.

Furthemore, adding more than .68 kg N/tree did not improve N status as well as the lower amount. The P index decreased sharply, indicating that N applications depressed P and made it the first limiting factor in treatment 2. However, according to current sufficiency levels this is still in the sufficiency range. The Mn index increased in proportion to the N treatments. In treatments 3 and 4, where higher nitrogen rates were applied, negative yield responses were obtained. Nitrogen was no longer a limiting factor, although it would have been diagnosed below normal by the sufficiency range approach in 1974.

DRIS indices, balance status, and NII calculated using all nutrients present are presented in Table 6. NII is slightly higher in the second treatment than the controls although controls generally have a lower yield. This suggests that improving nitrogen status in the second treatment was more important than the slight increase in NII. Adding additional N always resulted in less favorable N indices and increased imbalances. This was most apparent in the dramatic increase in the Mn index. Mn was by far the most excessive element as diagnosed by DRIS. Results are generally similar to NPKMn evaluations with some exceptions.

Nitrogen is not the most limiting factor in control treatments when more elements were included. It is the third limiting factor after Mg and Cu in 1974, and third behind Mg and Fe in 1975 and 1977. Deficiencies are possible, but since neither element was applied this cannot be determined. Iron deficiencies would not be expected in Western Oregon, thus relative Fe deficiencies are difficult to explain. Relative deficiencies for Fe may simply indicate that the value for the sample is relatively less than values for high yielding subpopulations. The nature of DRIS expressions will identify an unusually low but not necessarily harmful level as relatively deficient. Problems in interpretation are lessened if DRIS indices are not rigidly interpreted unless NII values are outside the normal range.

DRIS is helpful in evaluating the overall consequences of both desirable and undesirable aspects of nitrogen fertilization. It is not surprising that leaf nitrogen levels were only weakly related to yield, since nitrogen affected other nutrients. Treatments with similar N concentrations have large differences in NII. Nutritional imbalance indices suggest that high nitrogen rates were especially detrimental in later years and likely explain differences in cross sectional area that occurred over the 6-year period (Table 7). Perhaps high rates were not as detrimental in early years.

Both the DRIS derived sufficiency ranges and the yield responses suggest the sufficiency range for Mn should be made more narrow. Although toxicity symptoms are not apparent at high (1500 ppm Mn) concentrations (7), harmful effects may still occur at lesser levels.

Conclusion

Nutritional imbalance indices (NII) were a good indicator of nutritional limitations to maximizing yield. Severe imbalances of trees were never associated with high yield. There was good agreement between DRIS and sufficiency ranges, especially if ranges for some elements are narrowed and the relative deficiency or excess associated with corresponding relative excesses or deficiencies are evaluated. DRIS can be used to modify current sufficiency ranges. The data implies that it is possible to develop useful DRIS standards and DRIS derived sufficiency ranges from survey data. It is important to bear in mind that rigid interpretation and recommendations should not be applied unless NII values exceed a threshold level. Supplementing sufficiency range diagnosis with DRIS indices when severe nutritional imbalances occur, may assist in interpretations of tissue analyses and alter recommendations.

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TABLE 1. Mean and standard deviations of nutrient ratios selected as important by either significant differences in variance or mean.

Ratio	Mean	Standard Deviation	Method of Selection	
			Mean	Variance
N K	2.71	1.23		* *
N P	10.72	3.5	* *	
N Fe	.01361	.0045	*	
K P	4.28	1.96	* *	
K Ca	.670	.238		* *
K B	.0184	.00771		
P B	.0049	.00195		* *
Ca P	6.29	2.28	* *	
Ca Mg	5.29	1.62	* *	
Ca Zn	.0792	.0387		* *
Mg B	.0058	.0025	* *	
Mg N	.13014	.041	* *	
Mg K	.356	.211	* *	
Mn Fe	1.922	1.17	* *	
Mn N	146.58	66.15		* *
Mn K	350.746	140.8		* *
Mn P	1304.	920		* *
Mn Ca	227.5	96.4		* *
Mn B	5.44	3.08		* *
Mn Zn	14.12	5.82		* *
Fe K	216.59	108.38	* *	* *
Fe B	3.55	1.52	* *	* *
Fe Cu	34.58	19.63		* *
Fe Zn	10.17	5.27		* *
Cu N	2.902	1.24		* *
Zn N	9.32	7.58		* *
Zn K	22.39	6.94		* *
Zn P	91.4	40.25		* *
Zn Mg	78.48001	35.99		* *
Zn Cu	3.69	1.38		* *
Zn B	.398	.168		* *
Cu B	.118	.053		* *

Macro nutrients expressed in percent; micro nutrients expressed in ppm x 100

TABLE 2. Mineral concentration of major deficiencies and excesses in the leaves of hazelnut trees diagnosed by DRIS as having severe nutritional imbalances

	Major Relative Deficiencies					Major Relative Excesses		
	K	P	B	Zn	Ca	Mn	Fe	Cu
Overall Mean	.86	.23	49.12	19.26	1.32	301.73	194.56	5.42
Mean of Imbalanced Trees								
	.38	.15	23.23	4.9	1.25	929	369.1	13
Critical Ranges								
OSU	.8-3.0	.13-.6	30-75	15-80	.6-2.50	25-800	50-400	2-50
Suggested	.8-	.18	35-	15-	1.2-	-600	-300	-15
Related Disorders								
	+Fe(75)[y]	+Mn(95)	+Fe(36)	+Fe(62)	+Cu(50)	-Zn(6)	-K(44)	-Ca(50)
	+Mn(6)	+Zn(5)	+Mn(54)	+Cu(9)	Mn(25)	-Fe(18)	-Zn(28)	-B(10)
	+Cu(6)		+Cu(9)	+Mn(9)	Mg(8)	-P(50)	-B(24)	-K(20)
	+Mg(6)			+Mg(9)	Fe(8)	-B(15)		-Zn(20)
% Agreement with Critical Values								
OSU	93	18	54	100	0	70	34	0
Suggested	93	95	68	100	41	88	58	40
% Agreement with Critical Value When Related Disorder Also Considered								
OSU	100	95	82	100	27	77	100	50
Suggested	100	100	95	100	91	95	100	90

[y]Numbers in parentheses refer to the percentage of the trees for which the proceeding element was (+) diagnosed as relatively excessive (-) or deficient (i.e. 75% of the trees having K as the major relative deficiency were relatively excessive for Fe.

Table 3. Effect of N applications on leaf nitrogen content in filbert (1971-1977).

N applied per tree as urea (kg)	Leaf N (%), dry wt basis						
	1971	1972	1973	1974	1975	1976	1977
0	1.71	1.72	1.79	1.96	2.12	2.30	2.07
.68	1.95	1.82	2.04	2.12	2.37	2.41	2.34
1.36	2.04	1.86	2.15	2.08	2.42	2.44	2.38
2.72	2.10	1.94	2.19	2.13	2.54	2.54	2.40
Linear	**	**	**	*	**	**	**
Quadratic	**	NS	**	NS	*	NS	**

*, **, NS Significant at the 5% (*) or 1% (**) level or nonsignificant (NS).

Data from Chaplin and Dixon, 1979

Table 4 Effect of N applications on leaf element content in filbert.

N applied as urea (kg)	Year	Leaf element content (dry wt basis) K (%)	P (%)	Ca (%)	Mg (%)	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)
0	1974	1.07	.28	1.45	.24	296	238	6	83	21
.68		.98	.18	1.48	.23	356	228	7	69	22
1.36		.95	.17	1.43	.22	476	241	6	72	22
2.72		.97	.17	1.44	.23	577	236	6	76	21
Linear		NS	**	NS	NS	**	NS	NS	NS	NS
Quadratic		NS	**	NS	NS	NS	NS	NS	NS	NS
0	1975	.93	.26	1.36	.22	266	131	6	68	25
.68		.87	.18	1.44	.24	346	154	7	61	25
1.36		.86	.17	1.43	.24	525	148	7	58	24
2.72		.90	.17	1.45	.23	819	144	6	61	26
Linear		NS	**	NS	NS	**	NS	NS	NS	NS
Quadratic		NS	**	NS	NS	NS	NS	NS	NS	NS
0	1976	1.36	.21	1.20	.23	240	108	7	84	20
.68		1.31	.16	1.19	.23	293	116	7	71	21
1.36		1.20	.15	1.22	.23	529	113	7	67	19
2.72		1.28	.15	1.24	.23	794	112	7	74	19
Linear		NS	**	NS	NS	**	NS	NS	NS	NS
Quadratic		*	**	NS	NS	NS	NS	NS	NS	NS
0	1977	1.08	.24	1.40	.24	259	99	6	63	26
.68		1.10	.18	1.52	.25	356	125	6	63	24
1.36		1.09	.17	1.49	.26	664	117	6	57	24
2.72		1.11	.16	1.48	.25	1053	116	6	55	25
Linear		NS	**	NS	NS	**	NS	NS	**	NS
Quadratic		NS	*	*	NS	NS	*	NS	NS	NS

*, **, NS Significant at 5% (*), 1% (**), or nonsignificant (NS).

Data from Chaplin and Dixon, 1979

TABLE 5. DRIS indices, balance status and NII for nitrogen treatments on filberts using ratios containing N, P, K, and Mn[y]

			N K P Mn Index				
Treatment KgN/tree	Balance Status[z]	NII	N	K	P	Mn	Yield
1974							
0	normal	2.14[ab]	-.61[c]	.24[a]	.35[a]	.02[a]	36.2[b]
.68	normal	2.03[a]	-.14[a]	.23[a]	-.72[b]	.63[a]	39.6[b]
1.36	possible imbalances	3.52[b]	-.35[b]	-.07[b]	-1.04[c]	1.5[b]	30.0[a]
2.37	possible imbalances	5.40[c]	-.62[d]	-.39[c]	-1.50[d]	2.50[c]	31.7[a]
1975							
0	normal	1.56[a]	-.25[a]	.01[a]	.35[a]	-.10[a]	82.1[b]
.68	normal	2.04[b]	.20[b]	-.21[b]	-.56[b]	.57[a]	80.4[b]
1.36	possible imbalances	4.23[c]	-.04[c]	-.71[c]	-1.27[c]	1.9[b]	75.5[a]
2.37	severe imbalances	8.00[d]	-.46[d]	-1.52[d]	-1.92[d]	3.90[c]	72.8[a]
1977							
0	normal	2.20[a]	-.32[a]	.38[a]	.05[a]	-.11[a]	23.70[a]
.68	normal	2.02[a]	.01[b]	.42[b]	-.86[b]	.43[a]	27.10[b]
1.36	possible imbalances	5.99[b]	-.43[c]	-.25[c]	-1.97[c]	2.66[b]	27.00[b]
2.37	severe imbalances	10.50[c]	-1.19[d]	-.99[d]	-3.05[d]	5.22[c]	20.00[a]

[y]Values in a column for an individual year followed by the same letter are not significantly different ($p < .05$).

[y]If NII is from 0-2.5 it is considered to be in the normal range; if from 2.5-5 there are possible imbalances; if 5 or over there are severe imbalances.

TABLE 6. DRIS indices, balance status and NII for nitrogen treatment on filberts using ratios containing all elements[y]

Treat-ment KgN/tree	Balance Status[z]	NII	N	K	P	Ca	Mg	Mn	Fe	Cu	B	Zn
1974												
0	Normal	4.13^{a}	-.19^{a}	.16^{a}	.16^{a}	.08^{a}	-.52^{a}	-.09^{a}	.34^{a}	-.29^{a}	.6^{a}	-.07^{a}
.68	Normal	5.40^{a}	.05^{a}	.05^{a}	-.86^{b}	.25^{b}	-.71^{b}	.37^{b}	.32^{a}	-.35^{a}	.46^{b}	.19^{a}
1.36	Normal	5.55^{a}	.00^{a}	-.09^{a}	-1.13^{b}	.08^{c}	-.80^{b}	1.09^{c}	.23^{b}	-.25^{a}	.43^{b}	.18^{a}
2.37	Possible Imbalances	7.30^{b}	-.13^{a}	-.23^{a}	-1.40^{d}	-.18^{a}	-.69^{b}	1.95^{d}	.19^{c}	-.51^{a}	.44^{c}	.14^{a}
1975												
0	Normal	4.18^{a}	-.21^{a}	.00^{a}	.14^{a}	-.09^{a}	-.75^{ab}	-.15^{a}	-.69^{a}	-.09^{a}	.52^{a}	.54^{a}
.68	Normal	4.40^{a}	.07^{b}	-.23^{b}	-.73^{b}	.11^{a}	-.63^{ab}	.38^{b}	-.52^{b}	.08^{a}	.32^{b}	.54^{a}
1.36	Normal	6.20^{b}	.01^{b}	-.37^{c}	-1.17^{c}	-.09^{a}	-.59^{a}	1.71^{c}	-.78^{c}	.10^{a}	.13^{c}	.34^{a}
2.37	Severe Imbalances	9.60^{c}	.19^{c}	-.67^{d}	-1.53^{d}	-.53^{b}	-.78^{b}	3.57^{d}	-1.17^{d}	-.13^{a}	.06^{d}	.27^{b}
1977												
0	Normal	5.52^{a}	-.48^{a}	.36^{a}	-.14^{a}	-.12^{a}	-.60^{a}	-.05^{a}	-1.20^{a}	-.10^{a}	.45^{a}	.64^{a}
.68	Normal	4.86^{a}	-.11^{b}	.37^{a}	-.93^{b}	.09^{a}	-.55^{ab}	.42^{b}	-.95^{b}	-.11^{a}	.42^{a}	.35^{ab}
1.36	Possible Imbalances	8.30^{b}	-.34^{c}	.13^{b}	-1.6^{c}	-.29^{b}	-.49^{b}	2.67^{c}	-1.40^{c}	-.06^{a}	.07^{b}	.14^{bc}
2.37	Severe Imbalances	13.09^{c}	-.66^{d}	-.12^{c}	-2.20^{d}	-.83^{c}	-.54^{a}	5.35^{d}	-1.96^{d}	-.06^{a}	-.29^{c}	-.09^{c}

[y]Values in a column for an individual year followed by the same letter are not significantly different ($p < .05$).

[z]If NII is from 0-6.5 it is considerd to be in the normal range; if from 6.5-9.5 there are possible imbalances; if 9.5 or over there are severe imbalances.

TABLE 7. Effect of N applications (1971-1977) on tree size and soil pH

Treatment (kgN/tree)	Increase in Trunk Cross-Sectional Area (%)	pH
0	32.7	5.2
.68	58.7	5.1
1.36	50.1	4.8
2.72	41.6	4.4
Linear	NS	**
Quadratic	**	NS

**Significant at 1% level
NS Nonsignificant

Data from Chaplin and Dixon, 1974.

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