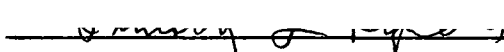


AN ABSTRACT OF THE THESIS OF

Othman Alkoshab for the degree of Doctor of Philosophy  
in the Department of Horticulture presented on  
March 28, 1989.

Title: Chilling and Nutritional Requirements  
of Fruit Trees in Yemen

Abstract approved: 

A portion of this study was initiated to provide the basis for implementing a chill unit accumulation procedure in Yemen. Most continuous or daily minimum, maximum temperature models severely underestimated chilling units, and slight modifications offered little improvement for the complex models. Only the Crossa Raynaud formula approximated generally accepted chilling requirements for the peach and apple varieties tested. Of the average temperature models, the Weinberger Sharp model is best adapted to areas in Yemen where detailed meteorological data are unavailable.

Another major goal of this study was to investigate the feasibility of using modern analytical equipment to make soil tests for arid regions cheaper, faster, and more efficient. Soil test experiments clearly indicate that a simple water DTPA extractant and Inductively Coupled Plasma

(ICP) spectroscopy can provide efficient measurements of B, K, Ca, Mg, Na, S, Cu, Fe, Zn, Mn, P, Cl, SAR, PAR, and carbonates in a one-step procedure. The sorption isotherms of K, Ca, Mg, Na, P, S, Fe, Mn, Cu, Zn and B were determined. Data from all elements except Mn and Fe generally suggest that a plot of added vs. equilibrium solution concentrations is linear when agriculturally realistic rates are utilized. The linear regression constants for P and K sorption isotherms corresponded very well to the percent recovery in a multiple spiked solution. This suggests it is possible to evaluate soil buffering for P and K in a single two-step procedure.

The final experiments were initiated to investigate the feasibility of utilizing tissue analysis to assist in prioritizing fertilizer needs for specific locations. The ratio based Diagnosis and Recommendation Integrated System (DRIS) diagnosis generally agreed with the sufficiency range method. DRIS was excellent in predicting relative nutrient responses.

CHILLING AND NUTRITIONAL REQUIREMENTS  
OF FRUIT TREES IN YEMEN

By

Othman Alkoshab

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# CHILLING AND NUTRITIONAL REQUIREMENTS OF FRUIT TREES IN YEMEN

## I. INTRODUCTION

The major portion of this research work has been conducted in a cooperative effort with U.S.A.I.D., Oregon State University, and the Ministry of Agriculture in Yemen Arab Republic. The objectives were to investigate the major problems that limit the fruit industry in Yemen, and propose possible solutions. Two of the most important limitations (inappropriate variety selection and nutritional deficiencies) were chosen for this investigation.

Varieties that require more chilling than the climate provides have been planted throughout the country. Therefore, a chilling experiment was conducted to evaluate various universal models that predict chilling requirements and adopt the most suitable for Yemen conditions. The goal was to quickly implement guidelines that the Ministry could use to make variety recommendations for specific regions of Yemen.

The lack of appropriate soil and tissue analysis procedures in Yemen contributes to widespread nutritional problems. My goal was to develop and adapt state of the art soil testing procedures, rather than implementing current techniques. U.S.A.I.D., Oregon State University and the Ministry of Agriculture are well aware that sophisticated instrumentation is not currently available in

Yemen. However, the hope was to develop tests that were usable with current instruments, but do not preclude a level of sophistication that is sure to develop.

Procedures to use plant analysis as a tool to prioritize fertilizer needs were also desired. Therefore, studies to apply ratio based diagnostic procedures were proposed. In order to verify plant analysis procedures a fertility trial was also conducted in Yemen.

## II. REVIEW OF LITERATURE

## A. Chilling Requirements

### Introduction

Growing temperate zone fruits in subtropical areas is limited by insufficient chilling periods for normal growth. Reduction in growth and yield usually results when temperate fruits are grown under subtropical conditions. Bloom and early leaf growth are delayed in deciduous fruit trees. This can also lead to poor bud break, poor fruit set, and abnormal flowering and growth, depending on the level of deficiency. However, breeding programs have provided new cultivars selected for their short chilling requirements. Proper selection of cultivars, in conjunction with modified cultural practices, has been successful in adapting several temperate zone fruits for such conditions. Chemical treatment is being used successfully in several subtropical regions as a supplement to limited chilling. Site selection can be an important factor in the success of one cultivar and not another. Consideration of all these factors has led to commercial production of some temperate zone fruits in subtropical areas provided winter temperatures allow partial breaking of the rest period.

### Dormancy and Rest

In general, dormancy can be defined as the condition in which the growth of a tree or tree part is inhibited or prevented until the tree has received sufficient chilling exposure and environmental factors are favorable for growth. Dormancy is classified into summer, winter and imposed dormancy as proposed by Doorenbos (28), or into quiescence, rest and correlative inhibition as proposed by Samish (91). The literature now has more than 50 different terms or modifications of the above terms, many with duplicate or indistinct meanings (54). A recent review by Lang et al. (54) recognized only two terms within dormancy, rest and quiescence. Rest is characterized by internal inhibition of growth resulting from physiological factors, while quiescence or imposed dormancy development is a delay brought about by unfavorable environmental conditions.

Another type of dormancy was reported by Vegis (111). He observed that toward the end of true dormancy, dormant organs can start their growth in a narrow range of low temperatures; but if temperatures exceed this range, another kind of secondary dormancy can be induced. However, Saure (90) called this a late dormancy within the true dormancy.

There has been confusion and mixed use of the terms 'dormancy' and 'rest.' For practical uses, however, Lang



et al. (54) considered 'dormancy' as a universal term for no visible growth of meristematic regions. Rest generally refers to the condition where growth will not occur regardless of environmental conditions. It is important to know the approximate dates of the beginning and end of rest for a cultivar. Rest (true dormancy) starts when bud break does not occur in the shoot even when environmental conditions are favorable. Thus, the beginning of rest in summer can be studied by removing shoot tips, exposing them to water and placing them in an ideal environment. Depending on rest intensity, the buds may grow strongly, weakly, or not at all, the latter indicating that the tree is already in rest.

The completion of rest is more complicated to determine due to variations in rest intensity and secondary dormancy. Some studies have used isolated culture buds or excised shoots that were exposed to optimum temperature. In other experiments, different concentrations of GA have been used. The greater the GA requirement to induce growth, the greater the rest intensity. Hatch and Walker (46) used detached shoots of peach and apricot with concentrations of GA from 0-1000 ppm. Rest intensity and completion of rest were determined based on the concentration of gibberellic acid necessary for the resumption of growth. Walker (115) followed a similar approach using

different concentrations of GA on intact vigorous trees, in order to estimate the state of dormancy.

During cool winters, bud growth is prevented even when true dormancy is terminated, due to the imposed dormancy that results from unfavorably cool conditions. During warm winters, on the other hand, true dormancy is extended and the symptoms of prolonged dormancy and delayed foliation are the result. Abnormal growth and irregularities of flowering and fruiting could result when dormancy is abnormally prolonged (100). Planting low and high chill cultivars will lead to simultaneous flowering in cool winter areas. However, in warm winter regions, low chill cultivars will flower before high chill cultivars, leading to lower yield in cross pollinated species.

There are several approaches for altering rest physiology and adapting some temperate-zone fruits for warm winter regions. Breeding programs have been very successful in producing low chill cultivars. Cultural practices are also a useful tool for modifying chilling requirements. Defoliation is used in the tropics to prevent true dormancy and obtain biannual crops (50). In addition, evaporative cooling and heat treatment can be used to hasten dormancy release (34).

The effect of shade on chilling requirements has been investigated. A common belief is that the primary influence of shade is to lower daytime temperatures, thus

exposing the plant to more hours of effective temperatures. Vegis (111) concluded that deep dormancy can only be overcome by chilling, not by the action of light. In contrast, Freeman and Martin (39) found that low light intensity promoted bud break in peaches even when the chilling temperatures were identical for the different light regimes. Erez et al. (33) also found that short exposure to light stimulated leaf bud break, while darkness after light preconditioning reduced leaf bud opening during dormancy.

Although most research in the subtropics deals with decreasing chilling requirements, in regions where damage from late spring frost is serious, increasing the chilling requirements to delay bud development is desirable. Chemical treatments and evaporative cooling to delay heat unit accumulation are effective means to accomplish this goal.

#### Calculation of Chilling Requirements

The standard method to determine the chilling requirements for a specific variety is to relate the number of hours below a given temperature, generally 7°C, to the time when rest completed. Weinberger (119) first proposed 7°C as the optimum temperature for chilling hour accumulation. This approach, however, is not satisfactory for all cultivars and environments. Erez and Lavee (31) found that 6°C was the optimum temperature for lateral bud

break in peach. They reported that temperatures above 21°C nullified the low temperature effect. Thompson et al. (107), working on apples, found 2°C was the best threshold temperature for bud break. In addition, Crocker and Sherman (22) stated that in low chill peach cultivars, such as Early Grand and Florida Prince, 13°C was as fully effective as 7°C in breaking dormancy. From these and other findings, the standard measurement for calculating chilling requirements is not always accurate.

The chill-unit model, based on weighted chilling hours, was developed in Utah (86). In this model one chill unit accumulation is equal to 1 hour exposure at 6°C, and the chilling contribution becomes less than 1 as temperature drops below or rises above the optimum (6°C). Gilrath and Buchanan (41) developed a chill unit model for low chill "Sungold" nectarine. This model was characterized by a broader range of effective temperatures and a higher optimum (8°C) for rest completion compared to the Utah model. They found that continuous exposure to 10°C was as effective as 7°C.

Under mild winters, Del-Real Laborde (25) concluded that the Utah chill unit model could not make accurate predictions when based on the minimum and maximum temperatures due to extreme daily fluctuations in temperatures. Although using an exponential function to describe the daily temperature curve improved predictability in this

study, the chill evaluation model generally fails to accurately estimate the completion of rest under mild winters (25).

The effect of temperatures varies at different times during chill units accumulation. The timing of chilling is important in that early chilling is less efficient than chilling in mid or late winter (53, 90). Kobayashi et al. (53) criticized all the methods of calculating chill units based on the assumption that the efficiency of each temperature in stimulating dormancy release is constant through the whole period of true dormancy. These investigations and others led to the variable chill unit (VCU) concept. The previous definition of chill unit (an hour exposure to the optimum temperature) was redefined as an hour exposure to the optimal temperature at the optimum time during the chilling process. Thus, it is not only important to know how many chill units have been accumulated, but also when they were received. Del-Real Laborde (25) suggested that we must follow the intensity of rest and know when the grand phase of rest begins and when it is completed in order to gain a real knowledge of rest. Gilrath and Buchanan (41) concluded that predictions of rest completion from chill unit models are more accurate when actual orchard temperature data are used. The collection of data over several years and/or at different

sites is required in order to obtain an accurate determination of chilling.

### Low Chill Varieties of Apples and Peaches

The most successful variety of apples in subtropical regions is "Anna." It produces good yields of high quality fruit compared to most other low chill apples. Ein Shemir and Dorset Golden are other desirable low chill varieties for subtropical areas. These two varieties are generally used as pollinators for Anna providing both production and pollen. Sherman and Sharpe (95) observed that Anna and Ein Shemir overlap in bloom at Gainesville, Florida, and high yields occur. In contrast, under Northern Florida conditions the bloom period of Anna and Ein Shemir do not overlap (56), and Ein Shemir shouldn't be the main pollinator. Dorset Golden, on the other hand, has similar chilling requirements and good overlap in bloom. Thus, Dorset Golden can be recommended as a pollinizer in almost all locations. In Yemen Arab Republic, Ein Shemir is reported to bloom early (59), but Dorset Golden and Anna both flower even earlier and have a better overlap of bloom (field observation and personal communication).

Differences in blooming time are probably due to differences in the amount of chilling in different areas. In high chill regions blooming times for most varieties

are similar and simultaneous blooming commonly occurs. In regions where chilling is low or barely sufficient, differences in bloom time are substantial. However, to achieve uniform bud break and good bloom overlap, chemical treatments by spraying with  $\text{KNO}_3$  and Thiourea are very effective (11, 32, 124). When selecting pollinizers for Anna, keep in mind that there are several clones of Dorset Golden (88). Selection of the wrong clone might result in poor pollination and low yield.

Breeding programs in different parts of the world are searching for high quality low chill apples and peaches. Anoka apple, Tropical Beauty, and Winter Banana are promising new varieties for subtropical regions (90). Breeding programs in Brazil have released six new apple cultivars with low chilling requirements (26).

More peach cultivars of good quality and productivity are well-adapted to subtropical regions than apples. This could be due to generally lower chilling requirements for peaches than for apples. Eighteen cultivars of peaches and nectarines have been released from University of Florida breeding programs (94). In Chile, Munoz et al. (73) evaluated a wide variety of low chill cultivars that collectively provide a 22 week harvested season. Most of these varieties produced an acceptable grade for that region.

Florida King is considered one of the best quality low chill peaches. It requires about 400 chilling hours. Florida Prince requires only 150 chilling hours, and is considered to be of very good quality and productivity for areas with between 200 and 400 chilling hours (73). Orion, Florida Belle, Florida Gold, Desert Gold and Early Grand are reported to be good varieties under several different subtropical conditions.

The first report on fruit variety trials at Al Irra in Yemen (59) indicated that all peach varieties with 'Florida' prefix in the name grew well, flowering and fruiting very satisfactorily. This includes Florida Prince, F. Sun, F. Gold, F. Red, F. Beauty, and F. Belle. Despite the wide variation in their chilling requirements they flower within a four week period (59). Since peaches are self fruitful, overlap in bloom is not important. In fact, a wider range of bloom times and maturity would make harvest and marketing easier.

#### Rest Breaking Chemicals

Chemical treatments are used successfully in several parts of the world to modify the state of dormancy in low chill areas. Numerous chemicals were found to promote growth and induce bud dormancy. Nevertheless, only a few are useful for field treatments. Promising results have been demonstrated with oil sprays either applied alone or



mixed with dinitro-ortho-cerol (DNOC), thiourea and potassium nitrate (12, 32). Mixtures of mineral oils with DNOC have been applied commercially in many parts of the world (30). Erez and Zur (30) found a direct correlation between breaking of lateral leaf buds and oil concentration between 2.4 and 8%. The increase in lateral leaf bud break resulted in more spurs and increased yield. In contrast, Strydom and Honeyborne (102) observed no beneficial effect of oil spray. However, the effect of oil spray depends on the treated cultivar and the stage of bud development (12).

Thiourea (Tu) mainly enhances the opening of leaf buds and improves yield by increasing apple size. Erez et al. (30) noted that Tu affected peach leaf buds more than flower buds. Furthermore, Biggs (11) has shown that Tu hastens bud break in peach. Cynamide is another important rest breaking chemical. Erez (32) reported that the effect of cynamide is similar to Tu, but stronger.

Gibberelins are known to be closely related to dormancy release. The bud breaking effect of GA varies for different species. Walker (116) found no response of apple buds to GA. Hatch and Walker (46) observed an increased leaf bud response on peach and apricot, but no responses were found for apple. Even when GA is effective it is not economically feasible for field treatments, because high concentration is required for good response.

The cytokynins are also reported to induce bud opening in several species. Most of these studies, however, concluded that the cytokynins involvement in dormancy starts only after some chilling was received or other prior changes were induced. Weinberger (118) reported that cytokinin treatments were only effective when little additional chilling was required to terminate the dormancy. Absciscic acid (ABA) is a growth inhibitor substance in plants. It increases in autumn and declines again during bud opening. Ethylene, on the other hand, is known to promote senescence and abscission. It has a role in the inhibition of bud growth. The results of its exogenous applications of either ABA or ethylene in promoting bud break has been debated, but effects are generally considered minimal (90). No other growth regulators are used as rest breaking chemicals. Auxins, however, might induce growth at low concentration, but high concentration has an inhibition effect (90).

So far there is no single chemical that can completely substitute for chilling requirements. However, the use of rest breaking chemicals to supplement normal chilling has allowed the growing of deciduous fruit trees in warm areas where it had never before been possible.

## B. Diagnosing Nutritional Disorders

### 1. Soil Testing

#### Introduction

The major objective of soil testing is to evaluate the nutrient status of a given soil and to determine the severity of any deficiency or toxicity. Soil testing may include a direct determination of nutrient concentration or measure other parameters that indirectly assist in nutrient availability evaluation. Although soil testing work was started as early as 1840 by Leibig (57), it was not until the 1940s it became widely accepted as an essential tool for fertilizer recommendations. Soil testing may be divided into four phases: collecting the soil samples, extracting and determining available nutrients, interpreting the analytical results and making the fertilizer recommendations (69).

The ideal goal of field sampling, as reported by Peck et al. (82), is to provide measures of the average of soil fertility in the field and its variability. However, the latter goal is sacrificed for simplicity, expediency, and cost. In general, field samples represent entire fields or management units.

There are many extraction procedures that are being used; however, only methods that actually measure available forms of soil nutrients are important. A

procedure should extract an element from the same labile nutrient pool in the soil that plants do. In addition, it should extract that portion of the total element that has some relationship to crop response. However, not every extraction procedure is suited for all soils; therefore, choosing the appropriate extraction procedure for any specific soil is important.

Procedures have been tailored to specific soil characteristics, and may vary for soils with different pH, organic matter and clay content (51). Furthermore, each extraction reagent and procedure is specific to an individual element or group of similar elements. Traditionally, separate extractions and analyses are made for different elements, but techniques are being developed to extract several elements or different groups of elements in one procedure (68, 125).

Interpreting the analytical results is the most important step in soil testing, because it is followed by fertilizer recommendations. Usually, interpretation is accomplished by establishing reference values from previous correlations between field crop response and soil tests. Meaningful interpretation will depend largely on proper correlation of test values with known field responses. Calibration studies have to be conducted with a large number of soils that range from low to high in the amount of nutrient being studied (37). Even with years of

work, more and better data are still required in order to improve calibration and recommendations (45).

Interpretation of soil test results must also consider characteristics and value of the crop to be grown and the cost of fertilizer (21). There are large differences in crop requirements. Viets and Lindsay (112) pointed out that crops differ in their susceptibility to micronutrient deficiencies, due to either their requirement for the nutrient or their ability to extract the nutrient from the soil. Soil tests have proven to be effective in separating soils that are deficient from soils that are not (121). Unfortunately, most soil tests do not provide a strong basis for determining the amount of fertilizer that should be applied. Application rates are dependent on the type of crop, expected yield, and characteristics of a specific soil.

### Nitrogen Soil Tests

Although nitrogen limits crop growth more than any other soil nutrient, analytical techniques for evaluating soil nitrogen are not satisfactory. This is because most nitrogen is present in complex organic compounds and subject to various changes throughout the season. Leaching, denitrification, immobilization and mineralization make nitrogen availability throughout the season difficult to determine from a single preseason evaluation.

Availability is affected by biological processes more than chemical or physical reactions. Therefore, soil moisture and temperature influence the content of soluble nitrogen in the soil solution through their influence on microbial activity. Soil sampling and drying procedures may also alter biological properties. Dahnke and Vasey (23) stated that field calibrations of nitrogen tests can be very misleading if certain factors such as the amount of initial inorganic nitrogen and sample handling are not considered.

There are two main approaches to evaluate the N status in soils. The first approach is to test for N availability indices. Briefly, these tests are measurements of the soil potential to supply N to plants. In this kind of test either biological or chemical availability indices can be used. One biological approach involves various types of incubation procedures where the amount of N released from organic components over a given time is quantified. In theory these tests should be reliable since native living organisms are used. Dahnke and Vasey (23) however, reported that this type of soil test is not practical where there is a high or nonconstant amount of residual inorganic nitrogen in the soil at the time of planting. There is simply no easy way to predict the changing moisture and temperature regimes that develop in the soil and their interactive effect on biological processes. Another biological procedure utilizes micro-

bial growth to quantify nitrogen status. Peterson et al. (83) found a high correlation between biological inorganic nitrogen test using Aspergillus niger and nitrogen uptake by tobacco plants. However, in the second crop the correlation decreased significantly. They attributed this to the consumption of most  $\text{NO}_3\text{-N}$  by the first crop. Neither incubating procedures, nor bioassays are routinely used, because their predictive value has not been clearly demonstrated. Furthermore, a longer amount of time is needed compared to the chemical availability indices. Total N, organic matter and various other nitrogen indicators have been proposed as chemical availability indices. Since varying soil environments dominate nitrogen behavior, chemical availability indices are also difficult to use.

The second approach for testing nitrogen is to measure the initial inorganic nitrogen in the soil. Ammonium nitrogen ( $\text{NH}_4\text{-N}$ ) and nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) are the main methods for initial inorganic nitrogen tests. The  $\text{NH}_4\text{-N}$  test however is of little importance and not routinely used in American soil testing laboratories. On the other hand, there is a widespread use of the  $\text{NO}_3\text{-N}$  test as a measure of available nitrogen, especially in low rainfall areas where leaching and denitrification is less of a problem than in humid areas.

### Sulphur Soil Tests

Sulphur is similar to nitrogen in that most of it occurs in organic matter and its microbial mineralization-immobilization cycle dominates its availability. Its availability also depends on climatic factors. Chemical and physical processes have a minor role. Determination of S in soils involves the estimation of sulphate ions, because plants absorb most of their S in this form. Extractions removing the readily soluble and portions of the adsorbed and organic S provide the best prediction of response in field trials (85). The most common determination of the available sulphate is a turbidimetric determination of  $\text{SO}_4\text{-S}$  as  $\text{BaSO}_4$ . Indirect sulphur determination in soil extracts by atomic absorption spectrophotometric methods as proposed by Galindo et al. (40) also work satisfactorily. Sulfate sulfur tests are not especially useful in humid areas where  $\text{SO}_4^{=}$  concentrations vary throughout the season. In arid areas a  $\text{SO}_4^{=}$  determination may be useful but plant requirements for this nutrient are quite low and deficiencies in arid areas are low (70). Sulfur toxicity is rare (70).

### Phosphorus Soil Tests

Phosphorus chemistry in soil is of major importance in the effectiveness of various soil tests. The amount of P in solution is very low, but there is a constant renewal



from weekly soluble forms. Calcium phosphate, Fe and Al phosphates, phosphate absorbed to soil colloids and organic phosphates are the most important soil phosphates (70).

The distribution of phosphorus compounds differs between arid and humid regions. In calcareous soils a surface coating of phosphate can precipitate on  $\text{CaCO}_3$ , while in neutral and acid soils P adsorbs to hydrated Fe oxides, Al oxides or clay minerals (106). Therefore, a single extraction may not be appropriate for different soil types. Moreover, the form of phosphate that is important for plant nutrition may differ from one soil to another. Susuki et al. (105) reported that Ca-P followed by Al-P were the most important sources of plant available phosphorus. On the other hand, Al-Abbas and Barber (1) concluded that Fe-P followed by Al-P contribute the most to plant uptake. A sequence of extractions which selectively remove different P forms have been used to chemically characterize soils. Chang and Jackson (19) used four extractants to extract phosphorus.  $\text{NH}_4\text{Cl}$  for soluble P,  $\text{NH}_4$  for Al-P, NaOH to remove Fe-P and  $\text{H}_2\text{SO}_4$  to remove apatite and other forms of insoluble phosphorus. However, routine commercial tests generally rely on a simple one step procedure. Soil tests for phosphorus generally correlate with yield responses to added phosphorus fertilizers. Available phosphate includes both

soluble soil phosphate and less available forms. The choice of a single extractant depends on the pH, CEC, and presence of free  $\text{CaCO}_3$  in the soil.

Water based extractants may also be useful in soils with low P concentration. A recent study by Luscombe et al. (60) on rye grass suggests that since water extraction procedures are not designed to remove specific phosphorus fractions, it is likely that the results obtained would be independent of soil type. Since current instruments are much more reliable when measuring low phosphorus concentrations, there is increasing interest in water extractions.

$\text{NH}_4\text{F-HCl}$ ,  $\text{H}_2\text{SO}_4\text{-HCl}$  and  $\text{NaHCO}_3$  are the three main P-extractants currently used in commercial soil testing laboratories. Different studies have compared the effectiveness of the above extractants in different soils. Martens et al. (63) found  $\text{NH}_4\text{-HCl}$  to be superior to  $\text{H}_2\text{HSO}_4\text{-HCl}$  in Virginia. In other studies  $\text{NH}_4\text{F-HCl}$  and  $\text{NaHCO}_3$  both correlated well with plant response (38). In addition, Welch et al.'s (120) study demonstrated a good correlation between soil test values and plant growth for all three extractants.

In recent years, Bray-1 (14), which is .03 N  $\text{NH}_4\text{F}$  and .025 N  $\text{HCl}$ , has been the most widely used phosphorus determination in acid soils. However, Mehlich I (66), which is .5 N  $\text{HCl}$  and .025 N  $\text{H}_2\text{SO}_4$ , has had wide acceptance in

sandy acid soils. In addition, Mehlich II (67) and Mehlich III (68) extractants are chosen as universal extractants.

In alkaline soils the Olsen bicarbonate (79) extraction is more suitable, especially when free  $\text{CaCO}_3$  is present. The Olsen method provides a higher correlation with yield response on calcareous soils than Bray (79). Ammonium bicarbonate (98) is also being adapted as a universal extractant. This, however, will be discussed in more detail in a different part of this review.

#### Potassium Soil Tests

The amount of K available to plants is much less than the total K present in the soil. Therefore, total K in soils is not an important index for the availability of K to plants. Soil tests attempt to measure plant available K. In most soils the amount of K, Ca, and Mg that is present in soil solution at any one time is very small in relation to the amount of that same element held in exchangeable form (27). The determination of available potassium (K) as reported by Carlson (18) involves the measurements of both soluble and exchangeable K. Pratt (84) has also stated that the most universal index to K availability in soils is the sum of the exchangeable and water soluble K. The water soluble potassium in nonsaline soils, however, is small. Soluble K relative to exchange-

soils, however, is small. Soluble K relative to exchangeable K is only an important component in saline soils.

The standard extractant used by most laboratories is a one normal solution of ammonium acetate. This solution is concentrated enough to effect a rapid exchange between the  $\text{NH}_4$  added in solution and the cations held in the exchange (27), and is ideal for flame photometric or atomic absorption procedures. Merwin and Peach (71), comparing 6 acetate salt solutions, concluded that only ammonium acetate solution provides consistent measurement of exchangeable potassium.

In addition to ammonium acetate, there are several other methods that give promising results. Extraction of K can be performed in cold dilute  $\text{H}_2\text{SO}_4$  as shown by Hunter and Pratt (48). Extraction with cold dilute acids removes about the same amount of K from most soils as does extraction with  $\text{NH}_4\text{OAC}$  when short extraction periods are used. Conyers and Mclean (20) have found that the amount of K removed by  $\text{NH}_4\text{OAC}$ ,  $\text{HNO}_3$ ,  $\text{HCl}$ , and  $\text{NaBPH}$  from soils prior to cropping generally correlated better with the amount of K uptake than did amounts of K removed by other extractants.

Carson (18) has mentioned that the Bray-1, sodium nitrate,  $\text{HCl}$ , and double acid ( $\text{HCl-H}_2\text{SO}_4$ ) extractants are alternate methods to determine K status in the United States. Some of these extractants (Bray-1 and double

acid) are used because of their capability to evaluate multiple nutrients which reduces the time and cost of soil tests. The Mehlich extractants removed the same amounts of K as did  $\text{NH}_4\text{OAC}$  (68) from the various K-equilibrated soils.

#### Calcium, Magnesium and Sodium Soil Tests

The same principles of determining K apply to Ca, Mg, and Na. Determination of available Ca, Mg, and Na is based on analysis of the exchangeable cations, because the greater proportion of these cations are in exchangeable form. The recommended soil test is 1 normal ammonium acetate. It has the same advantages when evaluating Ca, Mg, and Na that it has for K. Using strong acid extractions may dissolve Ca and Mg minerals in the soil, thus overestimating available amounts, while dilute acids will not remove all the exchangeable Ca and Mg (27).

#### Micronutrient Soil Tests

The ultimate goal of micronutrient soil testing is to determine whether micronutrient fertilizers will be profitable (21). Whitney (121) reported that micronutrient soil tests are effective in separating deficient from non deficient soils. Veits (112) pointed out that crops differ in their susceptibility to micronutrient deficiencies due to either their requirements or

their ability to extract the nutrient from the soil. The review by Cox and Kamprath (21) suggests that in some cases micronutrient tests must be supplemented with other information, such as pH, texture and free lime.

Micronutrients exist in soils in water soluble, exchangeable, adsorbed, and complexed forms, as proposed by Veits (112). Many primary and secondary minerals also contain them. The complexity of micronutrient chemistry has led to the development of numerous methods and analytical techniques to determine micronutrient availability in soil. Complexing agents, chelating agents, acids, bases and salts or various combinations have been used for assessing soil micronutrients. The following is a brief review of the most important micronutrient tests.

#### Zinc:

Until recently the most common analytical methods for Zn soil testing were 0.1 N HCl and ammonium acetate - diphenyl thiocarbazon (dithiazone) (113). The 0.1 N HCl method, however, is more effective in neutral to acid soils, but presence of the free lime in calcareous soils may alter results (121). However, Wear et al. (117) noted the importance of pH in interpretation when using dithiazone. Stewart and Berger (101), working on millet, have found that Zn extracted by 2 N  $MgCl_2$  correlated better with Zn concentration of millet than did HCl or

found that 2 N  $\text{MgCl}_2$ -extractable Zn was more closely related to Zn uptake than diathiazone or 0.1N HCl.

In Calcareous soils, where titratable alkalinity is significant, results for both diathiazone and 0.1N HCl are inconsistent and different calibration are required (75). In such soils, however, DTPA soil test appears to be one of the most promising micronutrient soil tests (58, 112). It has the advantage of simultaneously extracting Zn, Fe, Mn, and Cu in the same procedure. The EDTA-ammonium carbonate method developed by Trierweil and Lindsay (108) is also considered to be better and more convenient than the 0.1 HCl and dithiazone procedures there.

Currently, DTPA is becoming increasingly popular as a Zn extractant for a wide range of soil types. Brown et al. (16) concluded that DTPA is preferable to dithiazone, 0.1N HCl or EDTA and also reiterated that the dividing line between deficient and non deficient areas to be unclear using the diathiazone method.

### Iron:

Compared to Zn soil tests, there is less literature on the evaluation of soil Fe. Since iron deficiencies are almost always associated with high soil pH, and deficiency symptoms are distinct, less emphasis has been placed on Fe tests. A test for pH usually is all that is required to diagnose Fe deficiency in susceptible varieties. Iron may

diagnose Fe deficiency in susceptible varieties. Iron may exist in both ferrous and ferric states. However, determination of the total Fe was the common procedure in the past. This usually required decomposition of the soil sample, and was accomplished using either  $\text{Na}_2\text{CO}_3$  fusion or by using HF (77). Volumetric, gravimetric and colorimetric methods of determination of Fe have been described in more detail by Olsen (77). Recently, chelating agents like EDDHA and DTPA have been successful in evaluating soil Fe status. Lindsay and Norvel (58) developed the DTPA micronutrient soil test, which was found very useful in diagnosing Fe deficiency in 77 soils.

#### Manganese:

Historically, the most widely used method for Mn determination was hydroquinone. The principle of this method is to reduce the insoluble oxides of Mn to soluble divalent Mn, which is the form that plants utilize. One of the disadvantages of the hydroquinone method as mentioned by Veits and Lindsay (112) is that unavailable Mn is usually extracted. Hammes and Berger (44) have found that 0.1 N  $\text{H}_3\text{PO}_4$  was more reliable than hydroquinone. This extraction is being used in most central region laboratories in the United States (121). Browman et al. (14) have found that a  $\text{NH}_4\text{OAC}$  extractant can be a better method than hydroquinone. This is especially



soils, where the exchangeable Mn is the best estimate of immediately available Mn (93).

Chelating agents have not been as promising for Mn soil tests. Although DTPA is considered one of the most promising soil tests for micronutrients, it doesn't work as well for Mn as it does for Zn and Fe. Viets and Lindsay (112) stated that field experience with DTPA has been greatest for Zn, limited for Fe and very limited for Mn and Cu.

#### Copper:

Copper is present in soil in very small quantities. It ranges from about 1-3 ppm. Different extractions have been suggested to estimate copper availability in soils. Fiskell (36) listed the following extractants for copper:  $\text{NH}_4\text{NO}_3$ , acid  $\text{NH}_4\text{OAC}$  and dilute  $\text{HCl}$ .  $\text{NH}_4\text{NO}_3$  extracted only a small amount of Cu, while  $\text{NH}_4\text{OA}$  at pH 4.8 extracted more Cu than  $\text{NH}_4\text{NO}_3$ .

Grewal et al. (42) found that  $\text{NH}_4\text{CH}_3\text{O}_2$  was better than chelating agents or normal strength acids. However, some extractants may be more useful than others depending on the purpose of the test. For example, dilute hydrochloride is important in evaluating accumulated copper from copper spray or copper fertilizations since the soil organic matter readily chelates added Cu (35). In another

organic matter readily chelates added Cu (35). In another instance citrate-EDTA has been used for a quick test to determine toxic copper level exceeding 50 ppm (99).

#### Boron:

Boron can be present in soil in three phases: soil solution boron, adsorbed boron and mineral boron (3). The total boron concentration in soils varies with its parent material and the degree of weathering. Soil solution boron usually occurs as the undissociated acid  $H_3BO_3$ .

The most widely accepted method for evaluation of B status in soils is that of Berger and Truog (8) using a hot water extractant. This method was found to be better than acid extractant approaches (9). Recently, using hot .01-.02 M  $CaCl_2$  solution has been favored over hot water as it eliminates the need of using charcoal during filtration, which may interfere with extracted boron (80).

However, conventional methods of measuring boron have been criticized as they do not measure the fixing power of soils (95). Recently, Offia and Axley (76) have concluded that tests for boron should include both intensity and capacity measurements. They have suggested using a procedure where additional B is added to a soil before evaluating B status.

Conventional methods of soil testing are time and materials consuming. The search for rapid, economical and useful soil tests that combine as many evaluations as possible into a single procedure has become important in recent years. This is largely due to the development of new instruments that can make multi-element determinations on a single sample. One of the major problems is that when a universal extractant works satisfactorily for some types of soils and not for others. Although various universal extractants have been developed by various workers, and modified by others, the problems still exist.

The first successful universal extractant was developed by Morgan (72). This extractant is half normal acetic acid buffered at pH 4.8 with sodium acetate, and used to determine the important elements except for sodium. Sodium acetate and acetic acids will allow extraction of important soil nutrients, while low pH acts as a mild solvent for iron and aluminum. This universal soil testing system has been of great value in many sections of the United States as well as other countries (72).

Wolf and Ichisaka (124) have used Morgan's extractant and report good accuracy in determining the elements with certain changes in reagent and analytical procedure. Recently, Wolf (125) further improved Morgan's universal extraction solution by adding DTPA. Adding DTPA resulted

extraction solution by adding DTPA. Adding DTPA resulted in better prediction of leaf Zn and Fe than did Morgan's solution without chelating agents. He reported the possibility of determining the important elements except sodium in a single extractant and obtained better correlations of extracted trace elements with plant growth.

Mehlich (66, 67, 68) has developed a series of universal extractants known as Mehlich I, Mehlich II and Mehlich III extractants. Briefly, Mehlich I (66), which is known as double acid extractant (.05 N HCl - .025 N H<sub>2</sub>SO<sub>4</sub>), is used on acid soils for P, K, Ca, Mg, Na, Mn and Zn. However, this extractant doesn't work well on neutral to alkaline soils, where apatite is a predominant part of plant available phosphorus (67). It extracts more P than either Bray-1 or Olsen procedures when used under these conditions.

Later, Mehlich (67) introduced NH<sub>4</sub>F to displace P and deal with Ca-Al-Fe P complexes. He also included acetic acid because it decomposed apatite to a lesser extent than mineral acids. The new extractant, which is a combination of acetic acid, ammonium chloride, ammonium fluoride and hydrochloric acid, was designated as Mehlich II. Phosphorus uptake by millet grown in the greenhouse was highly correlated with the P extracted by this extractant (M2). Extraction of K, Mg and Ca were also highly correlated between this extractant and neutral N NH<sub>4</sub>OAC.

In 1984, Mehlich altered the Mehlich II extractant for two reasons. The first was to include Cu in the extraction and thus avoid using a separate extraction method for Cu known as Mehlich-Bowman (M-B). The second modification excluded hydrochloric acid to avoid the corrosive damage to laboratory equipment. Therefore, he substituted nitrate for chloride and added EDTA to the new extract. The new extractant, which is known as Mehlich III, is composed of (.2 N  $\text{CH}_3\cdot\text{COOH}$  - .25 N  $\text{NH}_4\text{NO}_3$  - .015 N  $\text{NH}_4\text{F}$  - .013 N  $\text{HNO}_3$  - .001 M EDTA). Using this extractant, Mehlich (68) found a high correlation of Cu extracted by M3 and the Mehlich-Bowling method. Potassium and Mg extracted by this method were correlated very well ( $r^2$ ) with ammonium acetate procedures. Phosphorus extraction, on the other hand, was 20% more than that of M2 and 4% higher than Bray 1.

In alkaline soils different simultaneous extraction procedures were developed in Colorado (98). This extractant is composed of 1 M ammonium bicarbonate ( $\text{NH}_4\text{HCO}_3$ ), .005 M of DTPA and has a pH of 7.6. Soltanpour and Schwab (98) found that the results obtained with this new procedure were highly correlated with results obtained with Olsen's P test, ammonium acetate K test and Lindsay and Norvell's DTPA-Zn, Cu, Mn test.

## 2. Plant Analysis

### Introduction

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. Plant tissue tests are often superior to soil tests and may give a better guide to diagnosing deficiencies.

Most systems of crop diagnosis utilize the critical nutrient concentration (CNC) approach for interpretation and fertilizer recommendations. Reference values for a specific type of tissue collected at a specific time or growth stage are utilized for making interpretations. Tissue concentrations that are substantially below or above reference values or ranges, suggest a need for management changes. Although in principle the approach is simple, many factors affect interpretation. Crop load, plant vigor, water stress, the effect of one nutrient on the levels of others, and a multitude of environmental factors can alter interpretation. There are often indistinct and ambiguous relationships between yield and leaf nutrients. Although plant analysis has many limitations, it is a well established tool to assist in

making management decisions. When used in conjunction with knowledge of a specific field, past performance, and soil tests, better fertilizer recommendations are possible.

#### Diagnosis and Recommendation Integrated System (DRIS)

The Diagnosis and Recommendation Integrated System (DRIS), developed by Beaufils (5, 6, 7) and later by Sumner (103), 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 (52). 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 (6, 7). 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.

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 perennial crops (2, 5, 7, 10, 35, 52, 87, 103, 104).

In a recent study on hazel nuts (2), DRIS was found to be useful in modifying current sufficiency ranges. More recently, Righetti et al. (87) have used the DRIS system as a means to evaluate current sufficiency ranges for elements that DRIS diagnoses as relatively deficient or excessive.

### C. Plant and Soil Responses to Added Nutrients

#### 1. Zinc

##### Zinc in Soil

The total amount of zinc varies greatly in soils, depending on the percentage of clay and organic matter levels. In general, total amount of zinc in normal soil zinc ranges from 10-300 mg/kg (3). However, total zinc is of interest only in indicating total reserves and provides diagnostic information only in areas of extreme deficiency or toxicity. Potentially plant available Zn is present as Zn in the soil solution, exchangeable zinc on the cation exchange sites, and organically complexed zinc in either



exchange sites, and organically complexed zinc in either the solution or solid soil phase (3). Both ammonium acetate-exchangeable and water soluble zinc are regarded as readily available to plants (113). Generally, the level of zinc in solution depends on the nature of soil surfaces and the level of zinc in the soil. High levels of hydrous oxides and calcium carbonate usually result in a low level of solution zinc.

The effect of pH on Zn availability to plants has been investigated. Soil pH has a strong effect on zinc adsorption. Therefore, soil pH should be considered when measuring zinc supply to plants. Barber (13) reported that adjusting the value for the level of calcium carbonate increases the value of some methods for measuring Zn availability on calcareous soils.

McBride and Blasink (64) have shown that the concentration of Zn in solution decreased 30-fold for every unit of pH increase in the pH range 5-7. This reduction of Zn concentration is believed to be due to Zn adsorption on hydrous oxide surfaces. Saeed and Fox (89) found that in acid soils, solution Zn reached a minimum at pH 7, but decreased further with increased pH in calcareous soils. They explained this reduction of solution zinc as pH increased as being due to an increase in the number of cation-exchange sites on soils with pH dependent charge.

There are several factors that contribute to the occurrence of Zn deficiency in soils. A large amount of free  $\text{CaCO}_3$ , low levels of organic matter in mineral soils, land leveling for irrigation, and soil compaction are some conditions that enhance zinc deficiency (74). Soil temperature also has an effect on Zn availability (62). Bauer and Lindsay (4) concluded that the main reason for Zn deficiency in cool weather is due to a decrease in solubility products rather than temperature-induced biological processes.

Correction of Zn deficiency can be accomplished by either soil or foliar application, depending on the species, soil type, and the severity of the deficiency. Soil application can be either broadcast or banded using either inorganic or organic sources of zinc. Generally, most Zn compounds that readily dissolve in dilute HCl are suitable for soil application of Zn to plants (74). Early studies detected little or no difference between different forms of Zn fertilizers. Wallace and Romney (117) reported that Zn uptake by sweet corn was increased more by Zn EDTA compared to  $\text{ZnSO}_4$ . Soil Zn applications may have residual effects for several years. Brown et al. (17) conducted greenhouse tests with sweet corn to measure the residual effect of soil applied Zn. They grew ten successive crops on six soils to which had been applied 0, 4 and 20 mg Zn

per 1600 gm of soil. The results showed that dry weight yield of the 4 mg Zn rate was adequate for 6 or 7 successive crops.

Foliar application, on the other hand, is usually used as an emergency treatment, and made after deficiency symptoms occur (62). Foliar application is generally considered a supplement and not a substitute for soil application. However, in some cases, especially tree fruits, foliar Zn applications are far more effective than soil fertilization (70).

#### Interaction of Zinc with Other Nutrients

Zn interacts with other micro or macro nutrients. Such interactions can be in soils or within the plant. The interaction between Zn and P has been investigated by many workers. High levels of P usually induce Zn deficiency. In general, this disorder in growth could be associated with a high level of available P or with application of phosphorus in the soil (78). Olsen (78) mentioned four possible causes for P-induced Zn deficiency: (1) a P-Zn interaction in soil; (2) a slower rate of translocation of Zn from roots to the top; (3) a simple dilution effect on Zn concentration in the tops owing to growth response of P; and (4) a metabolic disorder within plant cells related to an imbalance between P and Zn.

An interesting study on zinc-phosphorus interactions by Brown et al. (15) has shown that P application has accentuated Zn deficiency symptoms and Zn application also tends to accentuate P deficiency symptoms on low phosphorus plants. In both cases, however, the deficiency was corrected by the application of the appropriate element. They suggested that part of the Zn-P interactions may be explained on the basis of two limiting factors. Martin et al. (63) found that a high level of P induces Zn deficiency in tomatoes at low temperature, but not at high temperatures. The role of phosphate on the Zn availability within plants is poorly understood, but the old idea that Zn becomes ineffective in metabolism because it precipitates as  $\text{Zn}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$  can be ignored (70).

The interaction between Zn and Mg has been reported. Addition of liming that contains  $\text{MgCO}_3$  increased the severity of Zn deficiency (91).

### Zinc in Plants

The concentration of Zn in plant tissues is relatively low. Correspondingly, the Zn requirement of plants is small. In plant roots most of the total Zn may be adsorbed to the cell walls in the cortex (70). Zn deficiency can cause a dramatic impact on crop growth. In addition to interveinal chlorosis of leaves, Zn deficiency causes rosetting when internodes fail to elongate. Zn

deficient leaves are usually much smaller than regular leaves. Zn is not very mobile in plants, thus symptoms generally appear on young tissues. The form in which Zn translocates from the root to the upper part of the plant is not known.

Zinc plays an important role in protein synthesis, carbohydrate metabolism, and enzyme activation (70). The dramatic effect of zinc deficiency on growth is due to the influence of Zn on the auxin level. Skoog (97) has shown that the auxin content of the shoot apices is very low in zinc deficient plants. Moreover, Tsui (109) demonstrated that the auxin content decreases before the appearance of deficiency symptoms. When the supply of zinc is restored, the auxin level rapidly increases before the resumption of growth.

## 2. Potassium

### Potassium in Soil

Potassium is present in soil in relatively high amounts. The greatest amount is bound in primary and secondary clay minerals, such as micas, feldspars and illite. Therefore soils rich in clay are usually rich in K content. On the other hand, K content of organic soils or highly weathered sandy soils is very low.

Mengel and Kerby (70) describe three potassium fractions: soil solution potassium, adsorbed potassium in exchangeable form, and mineral potassium. Barber (3) adds an additional category of difficultly exchangeable potassium.

The main source of K for plants is soil solution potassium, which usually comes from the weathering of K containing minerals. The amount of K released from soil minerals to exchangeable and soluble forms depends on the kind of mineral that bears K. For example, feldspar requires a destructive weathering or complete breakdown to release K, and release of K is much slower than micas and illite, which require only a simple displacement of the interlayer K (47).

Soil solution potassium followed by exchangeable potassium are the most readily available forms for plants. However, soil solution potassium represents only a very small percentage of adsorbed potassium (47), and in turn both exchangeable and soluble K comprise a small percentage of total soil potassium. However, potassium moves from one category to another, and the speed and volume of movement varies between different categories.

Movement of potassium from one fraction to another depends on the solution removal and the amount of potassium added to the soil. Plant uptake is a major factor in solution removal. When plant uptake exceeds the amount of

K in both soil solution and exchangeable sites, potassium can move from nonexchangeable sites to soil solution and exchangeable forms. In some soils with high mineral K functions, K is constantly released to the solution regardless of plant activity. On the other hand, if plant uptake is less than the amount of K added to the soil, potassium may move from solutions and exchangeable to nonexchangeable forms. This is usually referred to as the K fixation process. Several other factors might affect this process, as reported by Mengel and Kerby (70), including the charge density of the minerals, moisture content, the concentration of potassium and the nature and concentration of competing cations in the surrounding medium.

### Potassium in Plants

Potassium is an essential element for all higher plants, and for almost all living organisms. Plant uptake of K is higher than any other element except nitrogen. It is very mobile in plants and often redistributed from older plant organs to younger tissues (43). Marschner (62) reported that potassium is mobile in plants at all levels within individual cells, within tissues, as well as in long distance transport via the xylem and phloem. It is also present in very high concentration in phloem sap.

Hausenbuiller (47), however, stated that K is not found in the nucleus, but occurs in the surrounding cytoplasm of the cell.

Despite the large amount of potassium required for normal growth of higher plants, its mode of action is not very clear. Nevertheless, K is believed to play a role in several physiological and biochemical functions of plants. Potassium is considered to function in osmotic process, in the synthesis of protein, membrane permeability, and in pH control (62). Moreover, Hausenbuiller (47) reported that K is also important in the absorption by roots of such anions as  $\text{NO}_3$ ,  $\text{H}_2\text{PO}_4$  and  $\text{HPO}_4$ , and the translocation and storage of carbohydrate compounds. Potassium is also important in the photosynthetic process. An increase in the external potassium concentration stimulates  $\text{CO}_2$  fixation. In addition, high potassium contents were found to be accompanied by increased rates of photosynthesis, photorespiration and RuBP carboxylase activity, but decrease in dark respiration (47). Potassium also promotes the denovo synthesis of ribulose biphosphate carboxylase (70).

Plants suffering from K deficiency usually show a decrease in turgor, and under water stress they easily become flaccid (70). Potassium increases turgor pressure, which drives solute transport in the xylem and balances the water in the plants. Maintenance of turgor also plays



a major role in stomatal openings. An increase in the K concentration in the guard cells results in the uptake of water from the adjacent cells, increasing turgor and thus stomatal opening.

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III. PRELIMINARY EVALUATION OF CHILLING REQUIREMENTS  
OF DECIDUOUS FRUIT TREES IN YEMEN

### Abstract

Methods of approximating chill unit accumulation from meteorological data are desperately needed in the Yemen Arab Republic. This study was initiated to provide the basis for implementing a chill unit accumulation procedure. Two peach varieties (Florida Bell; Florida King) and Anna apples were monitored at weekly intervals to determine when dormancy ends in Sanna, Yemen. Dormancy was considered complete when bud break occurred in shoots (18-20 cm) that were forced at room temperature (25°C) with the cut ends in water. Chill units that accumulated during dormancy were calculated from temperature data collected at the site using original and slightly modified versions of nine different chill unit estimation procedures. Three models used continuous (hourly) temperature data. Two models utilized daily minimum and maximum temperatures. Four models were based on average monthly temperatures.

The date of rest termination for all three varieties corresponded to their known chilling requirements. Most continuous or daily minimum, maximum temperature models severely underestimated chilling units, and slight modifications offered little improvement. Only the Crossa Raynaud formula approximated generally accepted chilling requirements for the varieties tested. Slight modification

of this formula further increases the precision of the model. Of models using the average temperature, the Weinberger Sharp model is best adapted to areas in Yemen where detailed meteorological data are unavailable.

Gibberellic acid (GA) treatments (0, 40, 80, 160, 320 ppm) were also used to obtain information on the depth of rest in the cultivars evaluated. Buds from both peach varieties responded to GA application, but apple buds, with the exception of the first application, did not. Low GA concentrations were adequate to break the dormancy in peach. A fairly linear decline in GA requirement with time was observed, rather than the bell shaped curve generally found in more temperate climates.



## Introduction

In many subtropical countries, problems arise from introducing varieties with chilling requirements that are too high for the local climate. In the Yemen Arab Republic considerable loss occurs because inappropriate varieties are being introduced. Although numerous tree fruits are being imported for orchard establishment, the potential success of a particular variety in a given area has not been previously evaluated.

An accurate method of estimating the amount of chilling that naturally occurs could greatly help in selecting varieties for a given region. This is especially important because, although the country is subtropical, altitudes and local climates vary considerably.

Conventional methods of determining chilling requirements of deciduous fruit trees involve the determination of the number of hours at temperatures of 0-7°C required to break dormancy. These include Crossa Raynaud, Weinberger, Sharp, and Damotu models, as cited by Ruck (13). In addition, the Weinberger Sharp model (16) that was developed by Sherman follows a similar approach and works very well under subtropical conditions. Several studies have shown various optimum temperatures for chilling accumulations in different varieties. Five °C is considered the optimum temperature for chilling unit accumulation in sour cherry (16), while a temperature of

20°C was the requirement to complete chilling in apples of long rest (17). On the other hand, Crocker and Sherman (3) reported that 13°C was fully as effective as 7°C in breaking rest in low chill peaches. Similarly, 10°C was found to be as effective as 7°C in low chill nectarine (7).

The negative effect of high temperatures further contributes to difficulties in developing accurate chilling accumulation models. While 15°C was found to nullify past accumulation of chilling requirements in sour cherry, (6), 18°C had no nullifying effect in low chill sungold peach (7). Exceptionally low temperatures may also prevent satisfaction of chilling requirements (7,12,15). Recently, Richardson et al. (12) developed a model involving a chill unit instead of chill hours. One chill unit is defined as one hour exposure to the optimum temperature, which is 6°C, and negative weights are assigned for temperatures greater than 16°C. Furthermore, chill units do not accumulate when temperatures are less than 1.4°C. This model, however, has not proven accurate when tested under mild winter conditions (4).

A disadvantage of the above models and other similar ones is that they are based on the influence of temperatures, and ignore the action of physiological factors that can modify the chilling requirement (10). Kaboyashi et al. (10) criticized models that are based upon available temperature data rather than physiological processes. They

reported that a growth stage (GS) model they developed is superior to other models. The incorporation of changing rates of rest development as a function of growth stage and temperatures, the effect of high temperatures on the deepening of rest, and the decreasing of rest due to various physiological and biochemical events improve model predictability (10). Saure (14) has also suggested that the difference between low chilling and high chilling cultivars might be physiologically similar to the difference between late and deep dormancy. This may explain why low chilling cultivars are less inhibited by higher temperatures.

These observations and others have led to a more recent concept called variable chill units (VCU). A chill unit previously defined as an hour exposure to the optimum temperatures, is now defined as an hour exposure to the optimum temperatures at the optimum time, during the chilling period. The central idea of this concept, as reported by del Real-Laborde (4), is that it is not only important to know how many chill units have been accumulated, but also when and how they were received. He concluded that a model considering VCU and preconditioning effects will better describe breaking of dormancy under subtropical conditions. Although chilling phenomena are complex and elaborate models may be more physiologically realistic, they do not appear to be easily applied to new

growing areas where limited data on tree performance is available.

The main objective of this study was to select and implement a model that estimates chill unit accumulation in order to determine what varieties are most appropriate for specific locations. A secondary objective was to determine rest intensity for Florida Bell, Florida King and Anna apple. This knowledge will help in making more intelligent decisions regarding various cultural practices.

### Materials and Methods

This experiment was located at the Alirra farm near Sanaa City, Yemen (latitude 14° 45' N at an altitude of about 2300 meters). The climate is predominantly dry (20-100 cm annual precipitation) with a scattered rainfall pattern that peaks during summer. Frosts can occur from October through March. Five-year-old bearing trees of two peach varieties (Florida King and Florida Bell) and Anna apple were utilized.

Twenty-five shoots (18-20 cm long) of each variety were collected weekly, from October 16 through January 21. Shoots were chosen at random from 20 trees of each variety. Each shoot contained about 10-15 buds. Five shoots of each variety were completely submerged in the following concentration of Gibberellic acid (GA): 0, 40, 80, 160, and 320 ppm for about 1.5 hours. They were then removed, set on

paper towels to remove the excess treatment solution, and placed upright in a plastic container having about 4 cm of water. Water was changed every other day to avoid fungus contamination. Room temperatures were controlled at about  $25^{\circ} \pm 2^{\circ}\text{C}$  using a heating fan controlled thermostatically. Treatment evaluations of terminal bud break were made two weeks after exposing twigs to the treatments. Bud break in at least three out of five terminal vegetative buds was required for the treatment to be considered effective in ending dormancy. The rest completion date for each variety was defined as the sampling time when bud break occurred in at least three terminal buds in control (0 ppm GA) treatments.

The amount of chill units that were accumulated prior to the rest completion date was calculated using each of the models listed in Figure 1.1. For the first three models a computer program was used to convert the 24 hr continuous daily temperature data to the equivalent chill units. In the next two models minimum and maximum daily temperatures obtained from the hydrothermograph were used to calculate daily chilling hours.

The last four models, shown in Figure 1.1, required only the average monthly temperatures to estimate the chilling requirements. Therefore, the average monthly temperatures for the period from October - December, during

which most of the chilling hours were accumulated, were used to calculate the chill units.

Results from all models were then compared to the universal number of chilling requirements of each variety. Total chill units for the entire season were also calculated and compared to our best estimate of what the station received. Since there are many different deciduous fruit varieties at the station, some of which flowered and some of which did not, their universal chill requirements were used to estimate chill units at the station (approx. 500-600).

After analyzing initial results, slight modifications were made of the original models to improve predictability. These modifications consisted of changes in various maximum or minimum threshold temperatures for the accumulation of chill units.

### Results and Discussion

The beginning of rest for all the three cultivars was not determined. The trees were already defoliated on October 16, which is the time of the first treatment. This, however, had little or no effect on calculation of chill units because temperatures at that time were high and rarely reached 7°C or below. This may imply that low temperatures are not necessary for dormancy development for low chill cultivars under subtropical conditions. The

termination of dormancy, on the other hand, was determined for all three varieties (Figure 1.2). Florida Bell was the first to complete the rest on Nov. 21, followed by Anna apple on Dec. 5 and lastly, Florida King on Dec. 12. This corresponds very well to their universal chilling requirements where Florida bell has the lowest chilling requirements (150-200), followed by Anna apple (300-400) and Florida King (400-450) chill units.

The rest intensity or depth of rest was determined, although not very precisely, for the two varieties of peaches (F. Bell and F. King). Florida King required a higher concentration of GA (160 ppm) than F. Bell (80 ppm) on October 16, while 40 ppm released the dormancy for the remainder of the rest period (Fig. 1.2). Eighty ppm of GA released the dormancy of F. Bell in the first treatments while the same 40 ppm was enough for the remainder of rest. This observation suggests that lower concentration of GA and an early beginning of the overall experiment would give more precise results if this or similar work is to be repeated. The curve for GA as a function of time that is characteristic for higher chill requirement varieties (9), was not observed. Large amounts of GA were not required throughout the dormant period. Rather, there was a fairly constant response after the rapid decline for the first week of evaluation. The data support the contention that low chill requiring varieties in subtropical climates

likely have a much shallower rest (3). Anna apple did not respond to GA<sub>3</sub>, therefore the depth of rest was not possible to estimate. These results are consistent with previous observations (9).

The Richardson model (12), which is known as the Utah model, didn't predict the completion of rest for any of the varieties tested. Rather, a negative value was obtained (Table 1.1). The trees didn't show any obvious deficiency of chilling, thus the model's assumptions are probably invalid. Weather conditions in Yemen are drastically different than in Utah. There is a high fluctuation of temperature extremes between day and night in Yemen. The high temperatures during the day account for the negative chill unit accumulation using this model. The optimum range of chill unit accumulation (2.5 - 9.1°C), which was developed for Redhaven and Alberta peach in Utah, apparently differs for F. King, F. Bell and Anna apple in Yemen. Modifications of this model by increasing the range of optimum temperatures and increasing the temperatures at which the nullification effect starts did not result in satisfactory results. Severe modification might result in improving the model under Yemen conditions. However, a drastic change in the assumptions may not be valid and should be supported by further experimental evidence.

Gilbert and Buchanan (7) and Shaltout and Unrath (15) models gave a very similar result and suffer from the same



limitations previously discussed. The Gilbert and Buchanan (7) model resulted in the highest negative chill unit accumulations, because it has a broader range of effective temperatures and higher optimum temperatures as compared to the Utah model. The Griffin et al. (8) model (general tables) also failed to estimate the completion of rest under Yemen conditions. These tables were also developed to fit temperate conditions, which are radically different than those of Yemen. Modification of these tables is rather difficult and unpractical.

The Crossa Raynaud formula, which was developed in Tunisia, on the other hand, is in close agreement with universal chill requirements (Table 1.1). This approach, as shown in Figure 1.3, involved summation of all the hours at 7°C or below. Slight modification of this formula by increasing the optimum temperatures from 7°C to 8°C, at which chill hours start accumulating, further improve the results (Table 1.2). Arbitrarily setting higher optimum temperatures (8°C instead of 7°C) may seem contradictory to most temperate literature but this is supported by specific studies in subtropical areas. Several workers on low chill varieties under subtropical conditions have concluded that temperatures higher than 7°C can be effective (1,2,3) Furthermore, Erez and Levee (5) have shown that higher temperatures have rest breaking ability. They state that the use of 45°C (7.2°C) as a limit below which hours of

chilling are accumulated is questionable. Moreover, in Reunion Island some varieties which usually require 120 to 150 chilling units set fruit even though temperature minima are above 7.2°C (2).

Misunderstandings arising from such findings are due to lack of real physiological and biochemical knowledge of the effect of chilling. To explain a wide variety of conditions models will become increasingly complex. For example, Anderson et al. (1) have recently suggested use of the ASYMCUR growing degree hour model in combination with the Utah model to predict the likelihood of incomplete chilling in deciduous fruit grown in climatic areas that are marginal for the cultivar. Unfortunately, complex models are difficult to implement. Adapting the modified Crossa Raynaud model for estimating chill units under Yemen conditions is recommended as a practical solution for an important problem until further investigation and more detailed experiments are conducted. Such a model is empirical in nature and has been criticized by other investigators (10,14). However, for practical purposes, the chilling hours summation will greatly help in selecting which cultivars to use for a given range of altitudes (1).

Results for the other four models which predicted the approximate chilling accumulation through the period from October - December 1 are included in Table 1.3. The best of these simpler models, The Weinberger Sharp model (Table

1.4), resulted in close estimates to the generally accepted amount of chilling required. This model uses the average coldest month of the year to estimate chilling accumulation and has been found to work very well under subtropical conditions (personal communication, Dr. W.B. Sherman). The model predicts that there are 540 chill hours under Alirra farm area conditions. This number is very close to being accurate, because varieties that require more than 600 chill units usually don't succeed in this area, where some varieties that require about 500 chilling hours, like Einshameir apple, grow satisfactorily. Therefore, this model can be recommended to be used in areas where detailed meteorological data are unavailable, and where only the average monthly temperatures can be estimated.

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### Continuous Temperature Models

- 1) Richardson et al. (1974) in high chilling peaches
- 2) Gilreath and Buchanan (1981) in low chill nectarine
- 3) Shaltout and Unrath (1983) in high chilling apples

### Daily Minimum and Maximum Temperature Models

- 4) Crossa Raynaud (1955) in Tunisia (general formula)
- 5) Griffith et al. in Utah (general tables)

### Average Monthly Temperature Models

- 6) Weinberger model (1956)
  - 7) Sharp model (1960)
  - 8) Weinberger Sharp model
  - 9) Damota Formula (1956)
- 

Figure 1.1. The nine models that were used to calculate chilling requirements.

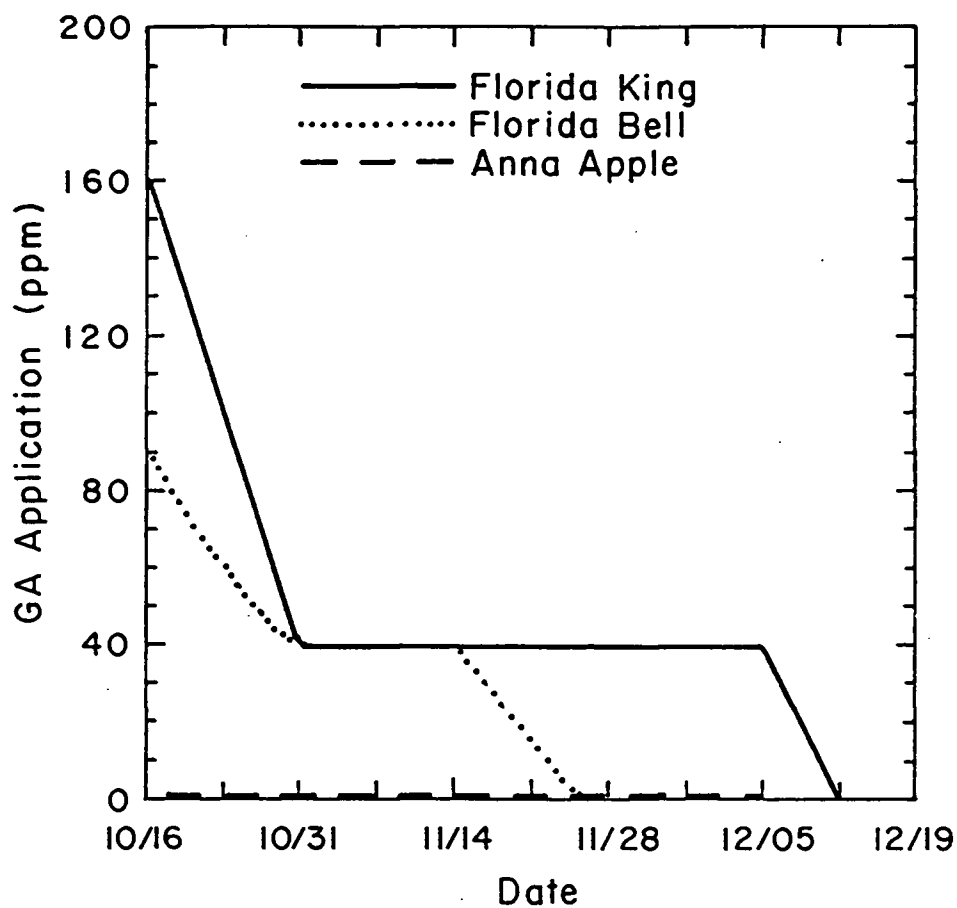


Figure 1.2. Minimum GA requirements for bud break.

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Crossa Raynaud Formula:

$$H_c = \frac{7.0 - m_l}{M_l - m_l} \times 24$$

Modified Crossa Raynaud Formula:

$$H_c = \frac{8.0 - m_l}{M_l - m_l} \times 24$$

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M = maximum daily temperature.  
m = minimum daily temperature.  
HC = hours of chilling.

Figure 1.3. Crossa Raynaud original formula and its modified version.

Table 1.1. Chilling requirements as calculated by first five models.

Variety and Dates	Rated	GB	SU	R	CR	G
Florida Bell Oct 16-Nov 21	150-200	-148	-376	-289	<u>131</u>	-67
Florida King Oct 16-Dec 12	400-450	-164	-371	-299	<u>316</u>	-51
Anna Apple Oct 16-Dec 5	300-400	-152	-384	-336	<u>276</u>	-48

GB = Gilbert and Buchanan

SU = Shaltout and Unrath

R = Richardson

CR = Crossa Raynaud

G = Griffin et al.

Table 1.2. Chilling requirements calculated from Oct. 1  
using the Crossa Raynaud formula and the  
modified version.

Variety	Rated	C.R.	Modified C.R.
F. Bell	150-200	150	207
F. King	400-450	335	400
Anna Apple	300-400	295	328



Table 1.3. Chilling requirements from Oct. 1 through Dec. 30 using Damota, Sharp, Weinberger and Weinberger Sharp models.

Variety	Chilling Accumulation
Damota	256
Sharp	171
Weinberger	less than 450
Weinberger Sharp	540

Table 1.4. Weinberger Sharp model.

January Mean (°F)	Estimated Chill Units
66	50
64	110
62	210
60	310
58	420
56	540
54	660
52	700
49	900

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IV. WATER-DTPA EXTRACTION AND ICAP MINERAL ANALYSIS  
AS A POTENTIAL SOIL TESTING PROCEDURE  
FOR ARID SOILS

### Abstract

Developing simple, rapid and efficient soil tests has been the objective of numerous investigators. The major goal of this study was to investigate the feasibility of using modern analytical equipment to make soil tests for arid regions cheaper, faster, and more efficient. Fifty soil samples from Yemen and 14 additional samples from Eastern Oregon and Eastern Washington were evaluated using conventional soil tests and an extraction procedure where 20 mls .005 M DTPA is used to extract 10 gm of soil.

The results clearly indicate that a simple water DTPA extractant and Inductively Coupled Argon Plasma (ICAP) spectroscopy can provide efficient measurements of B, K, Ca, Mg, Na, S, Cu, Fe, Zn, Mn and P in a one-step procedure. Results are highly correlated with values obtained by conventional approaches. Sodium Absorption Ratios (SAR) and Potassium Absorption Ratios (PAR) can also be calculated from the major cation concentrations. Although electrical conductivity can be approximated from the total milliequivalents of the major cations (Ca, Mg, Na, and K) from a saturated paste, including DTPA and a small amount of  $\text{NH}_4\text{OH}$  to dissolve it, extracts more Ca, Mg and Na is extracted than a water saturated paste. Therefore, an EC

estimation based on the sum (meq/lt) of major cations was not very accurate.

ICAP measurements of carbon can be used to estimate total  $\text{CO}_3^{=}$  and  $\text{HCO}_3^{-}$ . A good correlation was obtained between total C in a water-DTPA extractant and conventional measurements of  $\text{HCO}_3^{-}$ . Although  $\text{CO}_3^{=}$  is not an important parameter, in soils that have a pH lower than 8.5, its value could be algebraically calculated from total carbon and soil solution pH. Chloride can be estimated by subtracting the total milliequivalents of  $\text{SO}_4^{=}$  (S) and carbonates (C) from the total milliequivalents of major cations when the latter are estimated by an independent measurement of EC.

When evaluating previously conducted field trials for potatoes, the water-DTPA extractant and conventional approaches predicted plant uptake of phosphorus and yield responses equally well.

## Introduction

Most standard soil tests were designed for analytical equipment that existed over fifty years ago. Although present tests are useful, new extraction methods and utilization of new instruments could improve current procedures.

Currently utilized procedures for routine analysis of soils as conducted in OSU's soil testing laboratory require up to six or more different extracting procedures to measure pH (18), electrical conductivity and soluble salts in a saturated paste (15), hot water soluble B (2),  $\text{NH}_4\text{HCO}_3$  extractable P (13), buffered  $\text{NH}_4\text{OAC}$  extractable Na, Ca, Mg, and K (16), and DTPA extractable Fe, Mn, Cu, and Zn (6). Routine analysis of S and Cl are not conducted, but procedures do exist for their determination (5, 6, 14). Considerable gains could be made by developing techniques that limit the number of extractants.

Standard procedures also require up to six or more different analytical techniques. A conductivity bridge to measure E.C.; ion specific electrodes to measure pH,  $\text{NO}_3^-$ , and  $\text{Cl}^-$ ; atomic absorption spectroscopy which requires separate determination for Na, Ca, Mg, K, Fe, Mn, Cu, and Zn; turbidimetric estimations of S; titration techniques to estimate  $\text{HCO}_3^-$  and  $\text{CO}_3^-$ ; colorimetric determination of P; and an additional analytical procedure for B are all required.

Inductively Coupled Argon Plasma (ICAP) spectroscopy allows simultaneous measurements of multiple elements



on a single sample (4). This has led to a quest for multiple element extractants that would allow fewer extractions, which when followed by ICAP analysis could greatly improve the efficiency of soil testing procedures.

The idea of developing a universal extractant that can extract most of the macro- and micro-elements in one procedure is not new. Morgan (12) was the first to develop a universal extractant for the most important soil nutrients. This was later adjusted for more accuracy by Wolf and Ichisaka (21) and more recently by Wolf (22). Wolf (22) reported that all important elements except sodium can be determined in a single extractant. This extractant produces better correlations between extracted trace elements and plant growth than conventional tests.

Mehlich (8, 9, 10) has developed a series of universal extractants known as Mehlich I, Mehlich II and Mehlich III extractants. Briefly, Mehlich I (8), which is known as double acid extractant (.05 N HCl - .025 N H<sub>2</sub>SO<sub>4</sub>) is suitable for P, K, Ca, Mg, Na, Mn and Zn measurement. However, this extractant doesn't work well on neutral to alkaline soils where apatite is a predominant component of plant available phosphorus (10). It extracts more P than either Bray 1 (3) or Olsen (13) extractants when used under these conditions.

Later, Mehlich (9) introduced NH<sub>4</sub>F to displace P and deal better with Ca-Al-Fe P complex. He also included

acetic acid because it decomposed apatite to a lesser extent than mineral acids. The new extractant, which is a combination of acetic acid, ammonium chloride, ammonium fluoride and hydrochloric acid, was designated as Mehlich II (9). Phosphorus uptake by millet grown in the greenhouse was highly correlated with the P extracted by this extractant. Furthermore, extraction of K, Mg and Ca were highly correlated with the conventional neutral  $\text{NH}_4\text{OAC}$  extractant.

In 1984, Mehlich proposed additional changes for two reasons. The first was to include Cu in the test since Cu was extracted by a different method known as Mehlich-Bowman (M-B), and the second was to exclude the chloride base to avoid the corrosive damage to the laboratory equipment. Therefore, he substituted nitrate for chloride and added EDTA to the new extract. The new extractant, which is known as Mehlich III (10) is composed of (.2 N  $\text{CH}_3\cdot\text{COOH}$  - .25 N  $\text{NH}_4\text{NO}_3$  - .015 N  $\text{NH}_4\text{F}$  - .013 N  $\text{HNO}_3$  - .001 M EDTA). Mehlich (10) found a high correlation of Cu extracted by MIII with the Mehlich-Bowling method. Phosphorus extraction was 20% more than at of MII and 4% higher than Bray 1. However, the results from all extractions were highly correlated. Extraction of K and Mg extracted by this method correlated very well with  $\text{NH}_4\text{OAC}$  extraction.

In alkaline soils different simultaneous extraction of macro and micro nutrients were developed in Colorado (19). This extractant is composed of 1 M ammonium bicarbonate

( $\text{NH}_4\text{HCO}_3$ ), .005 M of DTPA and has a pH of 7.6. Soltanpour and Schwab (19) found that the results obtained with this new procedure were highly correlated with results obtained from Olsen's P (13), ammonium acetate K (16) and Lindsay and Norvell's DTPA-Zn, Cu, and Mn (6) tests.

In arid soils, a water extractant may be appropriate. There are several water based extractant values (EC, SAR, PAR,  $\text{HCO}_3^-$ ,  $\text{NO}_3^-$ , B, and  $\text{Cl}^-$ ) that may be difficult to estimate from complex extraction solutions. Although current soil extraction procedures are based on the concept of approximating plant available nutrients, it is not clear if this approach is generally better than an approximation of the soil solution, especially when the latter is accompanied by an estimate of the soil's buffering capacity.

The general objective of this study was to develop a water based extractant to approximate current soil testing procedures for B, EC, SAR, PAR, Ca, K, Mg, Na, P, S, Zn, Cu, Mn, and Fe. The second goal was to analyze as many soil parameters as possible with a single procedure. I believe that a single extractant followed by ICAP analysis could be used to obtain the same or better information at about one-fourth the cost of current procedures. With some refinement, bicarbonates may also be evaluated with the ICAP, which would allow a subtractive estimation of Cl. Thus it could be possible to duplicate the entire array of

soil testing procedures with one extractant and one analytical procedure.

## Materials and Methods

### Preliminary Evaluation of Universal Extractants

Fifty soil samples that varied greatly in their texture and mineral contents were collected from various locations in Yemen Arab Republic. The samples were then air dried, crushed and sieved through a 2 mm mesh. The pH of the soils was 7.0 or greater.

The following universal extractants were then used to extract these samples:

- 1) ammonium bicarbonate DTPA (1M  $\text{NH}_4\text{HCO}_3$ , .005 MDTPA, 7.6 pH);
- 2) Mehlich III extractant (.2 N  $\text{CH}_3\cdot\text{COOH}$  - .25 N  $\text{NH}_4\text{NO}_3$  - .015 N  $\text{NH}_4\text{F}$  - .013 N  $\text{HNO}_3$  - .001 M EDTA);
- 3) ammonium chloride DTPA (1 M  $\text{NH}_4\cdot\text{Cl}$ , .005 M DTPA);
- 4) water DTPA ( $\text{H}_2\text{O}$ , .005 MDTPA).

Details of preparing extractant 1 and 2 are presented elsewhere (19, 10) respectively. Ammonium chloride DTPA was prepared by adding 1.97 gm DTPA to 800 ml of water. About 2 ml of 1:1  $\text{NH}_4\text{OH}$  was added to facilitate dissolution. When most of the DTPA was dissolved, 53.4 gm  $\text{NH}_4\text{Cl}$  (one mole) was added and the mixture stirred gently until dissolved. Water DTPA was prepared by adding 1.97 gm of

DTPA to 800 ml of water with 2 ml of 1:1  $\text{NH}_4\text{OH}$ . When most of the DTPA was dissolved the solution was then adjusted to one liter.

The extraction procedures for ABDTPA and MIII were exactly the same as previously described (19, 10). Extraction methods of  $\text{NH}_4\text{Cl}$  DTPA and water DTPA were accomplished by adding 20 ml of the extracting solution to 10 gm of soils. The soil mixture was shaken on an Eberbach reciprocal shaker for 15 minutes at 180 cycles/minute. The extractants were then filtered through Whatman 42 filter paper for analysis.

The four extractants were then analyzed for B, Ca, P, K, Fe, Cu, Zn, Mn, and S using Inductively Coupled Plasma instrument (ICAP). The same soils were also analyzed for P, K, Ca, Mg and B using the conventional techniques: the Olsen method for P, ammonium acetate for K, Ca and Mg and the hot water method for B. The correlation coefficients between the four universal extractants and the conventional techniques were then calculated.

#### Additional Evaluations of Universal Extractants

Based on preliminary results of the 50 Yemen samples, the water-DTPA extractant was selected for additional study. Fourteen additional soils were collected from Eastern Oregon and Eastern Washington for further analysis. The water-DTPA procedure described above and a similar

procedure where distilled water was used in place of the water DTPA extractant was employed.

The B, K, Ca, Mg, Na, S, Cu, Fe, Zn, Mn, and P on both extractants were analyzed using the ICAP. Electrical conductivity was approximated from the total milliequivalents of the major cations. Sodium Absorption Ratios (SAR) and Potassium Absorption Ratios (PAR) were also calculated from the major cations. ICP measurements of carbon were used to estimate  $\text{CO}_3^{=}$  and  $\text{HCO}_3^{-}$  concentrations based on the assumption that other organic carbon would be negligible and  $\text{CO}_3^{=}$  would be minimal at the soil pH's less than 9.

Carbon in the water DTPA extracting solution was subtracted as a blank to obtain total C for the water-DTPA samples. Chloride was estimated by subtracting the total milliequivalents of  $\text{SO}_4^{=}$  and  $\text{HCO}_3^{-}$  from the total milliequivalents of major cations. Conventional soil tests were conducted on the same soils for saturation extract EC, Na, K, Ca, and Mg; SAR, PAR,  $\text{HCO}_3^{-}$ ,  $\text{CO}_3^{=}$ , and Cl; exchangeable Na, K, Ca, and Mg; water extractable B; NaOAC extractable P, S; and DTPA extractable Fe, Mn, Cu, and Zn.

Water and Water-DTPA extractant values were correlated to each other and conventional analyses were correlated to both extractants. Multiple regressions using a combination of water-DTPA and spiked water-DTPA variables to predict conventional analysis were used when appropriate. Published and unpublished historical data were used to further

evaluate subtractive approaches ( $Cl = (Na + Ca + K + Na) - (HCO_3 + CO_3 + S)$ ) to estimate total chloride.

### Fertility Trials

Both conventional and water-DTPA soil tests were completed on soils collected from previously conducted field trials on potato to determine which approaches better predicted the yield responses and plant uptake of phosphorus. Yield, P uptake, Olsen P measurements and original soil samples were provided by Dale Westerman at the USDA ARS Research Station in Kimberly, Idaho.

### Results and Discussion

The correlations between the standard methods and the four universal extractants for the Yemen samples are shown in Table 1. The Mehlich III extractant wasn't expected to produce high correlations, since it was developed mainly for acidic soils. Surprisingly, ammonium bicarbonate (ABDTPA) resulted in a poor correlation for P and K which was not anticipated. Soltanpour et al. (19) found that ABDTPA extractant correlated well with results obtained with Olsen's P and ammonium acetate K tests. However, higher pH and calcium carbonate in these soils may explain the contrasting results. The amount of bicarbonate in ABDTPA may not be concentrated enough to extract high levels of Ca and Mg or completely extract Ca-P complexes

likely to occur in such soils. Ammonium chloride DTPA and water DTPA were superior to Mehlich III and ammonium bicarbonate DTPA as a universal extractant. Ammonium chloride was very good for K and Mg, good for Ca and fair for P and B. Water DTPA gave very good correlation for B and K, good for P and Mg and poor for Ca. The poor correlation for Ca is probably due to high  $\text{CaCO}_3$  contents in these soils. A water extractant would not be expected to mimic conventional procedures on calcareous soils. However, conventional procedures for Ca on these soils are not very informative. Total meq of cations extracted from calcareous soils are usually greater than the CEC, suggesting an overestimate of Ca. It is virtually impossible to have a soil induced Ca deficiency in calcareous soils. The nutrition problems caused by excess Ca are possibly more important. An accurate measurement of soil solution Ca may be more informative than conventional tests. Calcium:Mg and Ca:K ratios have important nutritional consequences (11), and they could be better evaluated with solution measurements. On non calcareous arid soils a water based extract would be expected to correlate better with conventional tests. Results of fifty soils from Hermiston, Oregon gave a high correlation between water soluble Ca vs  $\text{NH}_4\text{OAC}$  ( $R^2 = .80$ ) (unpublished, George Clough, personal communication). Since conventional measurements of Ca on calcareous soils are not very valuable and better correlations were anticipated on non



calcareous soils, a water DTPA extract was adapted for further tests since it is simpler and gave a high correlation with other elements.

A major concern was whether the DTPA and small amount of  $\text{NH}_4\text{OH}$  used for dissolving the chelate would alter the behavior of the water DTPA extract. Correlations between water-DTPA and water extracts varied for different elements (Table 2.2). The relationship was very strong for B, Na, S, P, and Fe; fair for K, Ca, and Mg; and poor for Cu, Mn, and Zn. The low correlation of K, Ca, and Mg was likely due to the removal of exchangeable cations caused by the ammonia in the water-DTPA extractant. The results show that water DTPA generally extracted higher amounts of almost all nutrients. The dramatic increase of micronutrients was predominantly due to DTPA, which indicates its importance for these nutrients. The small increase of the amount of phosphorus was probably due to the efficiency of DTPA in extracting some organic phosphorus complexes. The greater amount of P in the DTPA extraction is beneficial because low values of P in water extracts approach the detection limits of the ICAP. The increase in the amount of major cations (K, Ca, Mg, Na) could be mainly due to including  $\text{NH}_4\text{OH}$ , which may displace some of these cations from the exchangeable forms. In addition, the slight acidic effect of DTPA may result in dissolving some of the  $\text{CaCO}_3$ ,  $\text{CaHCO}_3^-$  and  $\text{MgHCO}_3^-$  which led to the increase of

these two cations. Boron and S were only slightly increased in water DTPA compared to water alone, but the correlation was very high between them.

These differences between the two extractants is best viewed as an advantage of using water DTPA rather than water alone. This is supported by the results where correlating water alone vs. conventional procedures produced poorer correlation of almost all elements compared to using DTPA (Table 2.2). Therefore, the slight acidic effect of DTPA and the small amount of  $\text{NH}_4\text{OH}$  is beneficial rather than detrimental. Unfortunately, this lessens the practicality of predicting both conventional and water extract values in the same procedure for macronutrient cations.

Table 2.3 represents the regression coefficients between water DTPA and the conventional methods for the 14 soils collected from eastern Oregon and Washington. An excellent relationship was obtained for B, Na, Zn, Cu, Fe, Mg, and S; and a very good correlation for Ca, K, and Mn. Water DTPA P did not correlate as well as the other nutrients. The poor correlation of phosphorus was mainly due to soil number one, which had a very high tendency to fix phosphorus. The recovery of phosphorous from this soil was almost zero using water DTPA. If this soil is excluded the relationship is much stronger ( $r^2 = .51$ ) and similar to results obtained with the 50 Yemen soils. Furthermore, regressing DTPA spike recovery (described in detail in next

chapter) as a second variable increased the correlation for this element. Including a second buffering variable is neither necessary nor helpful for other elements.

Luscombe et al. (7) have shown a very good relationship between increase in dry matter yield and amount of water extractable P in soils ( $r^2 = .97^{**}$ ). This was more consistent than Olsen and Truog values. They concluded water extraction has a potential as a soil testing procedure for determining the phosphorus status of soils which have received fertilizer P. Furthermore, Van der Paauw (20) stated that phosphorus water values provide a reliable estimate of soil phosphorus availability to the plant in a wide variety of soil types. These and other studies have shown the potential of using water for phosphorus determination. The weaker correlation with conventional procedures does not imply that conventional procedures are better.

Extractants that are more acidic or alkaline than the soil solution might extract a higher portion of the elements than what is available to plants. Relationships between plant response and water extractants are sometimes more correlated than other measures of nutrient availability. A criticism of water extractants is that they may not be reliable for predicting long term response since water doesn't extract all of the extractable P or exchangeable K. However, there is a fair correlation between water-DTPA K and exchangeable K, and conventional tests for P. Even when

when anomalous soils are included, conventional P values are predictable if a second variable is added to a regression equation. Perhaps water extracted values and a measure of buffering capacity would be more useful than conventional tests. Furthermore, the simplicity and efficiency of the water based methods can make soil tests cheaper.

The regression equation and coefficient of determination ( $R^2$ ) between standard methods and water DTPA extractant for EC, SAR, PAR,  $\text{CO}_3$  and  $\text{HCO}_3$  and chloride are presented in Table 2.4. There is generally an excellent relationship between total milliequivalents cations and EC (1). A low correlation was obtained for the estimated E.C. (sum of major cations \* 10) vs. actual E.C. measurement. This is mainly due to greater extractions of Ca, K, and Mg when using water DTPA (Fig. 2.1).

The Exchangeable Sodium Ratio (ESR) and Exchangeable Potassium Ratio (EPR) can be derived from the water-DTPA data. The prediction of conventional SAR and PAR from water DTPA extractants was also very reliable and a highly significant correlation obtained. These two parameters are important to know when evaluating the equilibrium relationships between soluble and exchangeable cations, especially for alkaline soils. Although the saturated paste solution values for Ca and Mg could not be estimated from a water-DTPA extract, SAR and PAR estimations were not as severely

affected. A higher amount of  $\text{NH}_4$  in the extracting solution would have likely led to more release of exchangeable cations and weakened this relationship.

Estimation of carbonate and bicarbonate through determination of C concentration by ICAP is possible. A good correlation ( $r^2 = .65$ ) was obtained between determination of bicarbonate by the standard approach and total C in the water-DTPA extract (Table 2.4). However, titratable carbonate was not detectable. This is not surprising, since none of the soils' pH values in this study exceeded 8.5. Since total C was related to bicarbonate, carbonate approximation in soils that have a mix of the two species is not difficult. The relative amounts of the two species are a function of solution pH, thus if both solution pH and total C are known the amounts of bicarbonate and carbonate can be algebraically determined. There are better choices of C wavelengths for ICAP analyses. Our measurements were not completed with the optimum wavelengths because vacuum analyses were not possible. With a small investment, the current instrument could produce even more accurate readings.

Soil analysis for chloride is not a routine soil test in most labs; however, determination of this element is possible by subtracting the total anions ( $\text{CO}_3^{=}$ ,  $\text{HCO}_3^{-}$ ,  $\text{SO}_4^{=}$ ) from the total cations ( $\text{K}^{+}$ ,  $\text{Mg}^{++}$ ,  $\text{Ca}^{++}$ ,  $\text{Na}^{+}$ ). The fourteen soils that were used for this study were found to contain a very small amount of chloride, which led to a

poor correlation. Previously published data (1) that included the EC, major cations (K, Ca, Mg and Na), and the anions ( $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ) for soil extracts (1) have been used for further evaluations. The cation sum (total meq cations) was approximated by multiplying EC \* 10. Chloride was then calculated by subtracting the milliequivalents  $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ , and  $\text{SO}_4^{2-}$  from the approximated cation total. These data clearly indicated the reliability of a subtractive approach when  $\text{Cl}^-$  is present in appreciable quantities. A highly significant relationship ( $r^2 = .84$ ) obtained between calculated and measured chloride (Fig. 2.2). Although an independent measurement of EC would be required, this would allow an estimation of Cl from an ICAP analysis of a water DTPA extract. Since EC measurements are among the simplest to complete, this may be easier than an independent measurement of Cl.

There are several advantages of a water-DTPA extract over ABDTPA procedures. Measurements of carbonates in ABDTPA extractants would not be possible due to the bicarbonate in the solution. Furthermore, the relationship between water-DTPA and conventional P evaluations is strong enough that ammonium bicarbonate isn't required. Several studies also suggest that a water soluble P test is more strongly related to crop response. A water-DTPA extractant also better correlates to exchangeable Ca and Mg values than a ABDTPA extractant. This is likely due to the re-

lease of Ca and Mg that results from the addition of bicarbonate. In view of this additional release of Ca and Mg, it is unlikely that ABDTPA procedures could ever estimate SAR or PAR. With a simple additional measurement for EC, Cl can be algebraically estimated from a water-DTPA evaluation. An ABDTPA procedure would require separate measurements for Cl and carbonates. A final advantage is that water-DTPA extractants could be used as the background sample in two-step procedures to measure buffering capacity for various elements. A soil's buffering relationships are likely altered when measured in conventional extracting solutions. This would not be a problem in water based solutions.

Results of three phosphorus fertility trials (Fig. 2.3) on potatoes further demonstrate the usefulness of a water-DTPA extract. A high correlation was obtained between P uptake and either water-DTPA P ( $r^2 = .71, .36, .3$ ) or P values ( $r^2 = .76, .25, .56$ ). In addition, P values in both approaches correlated very well ( $r^2 = .76$ ). Yield response was predicted similarly using either Olsen or water-DTPA values. Complete data for the P field trials is included in the appendix.

In general, a simple distilled water DTPA extractant when accompanied by the ICP shows great promise for obtaining most of the important soil testing parameters in one simple procedure.

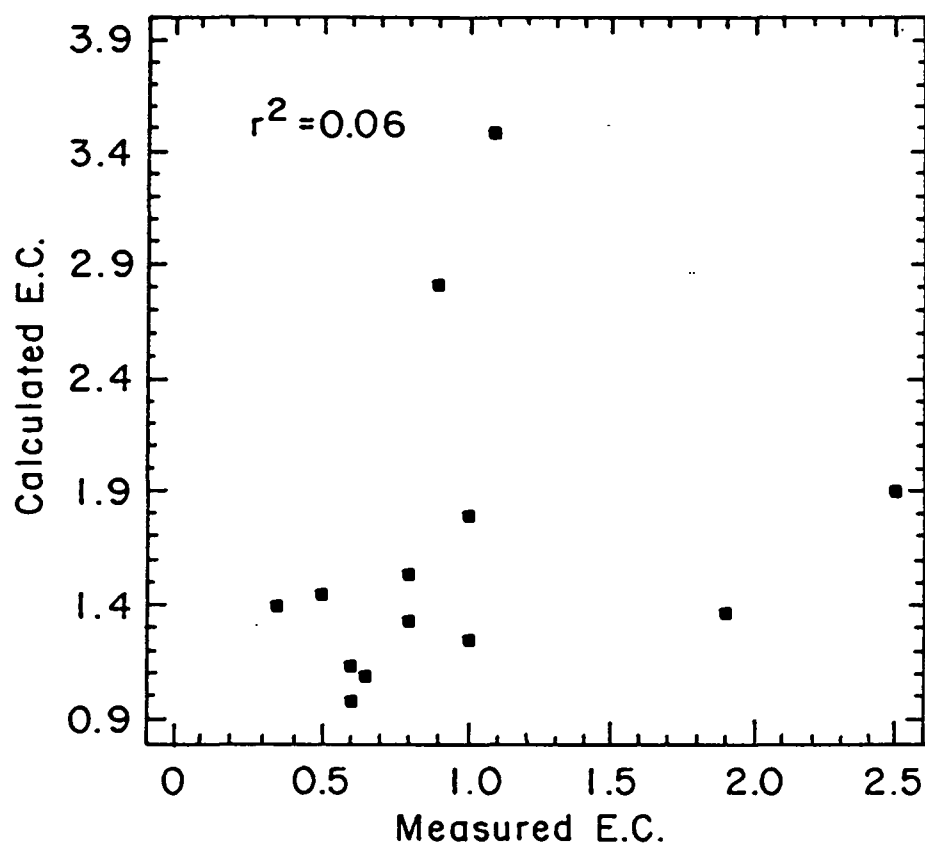


Figure 2.1. The relationship between calculated E.C. and measured E.C.



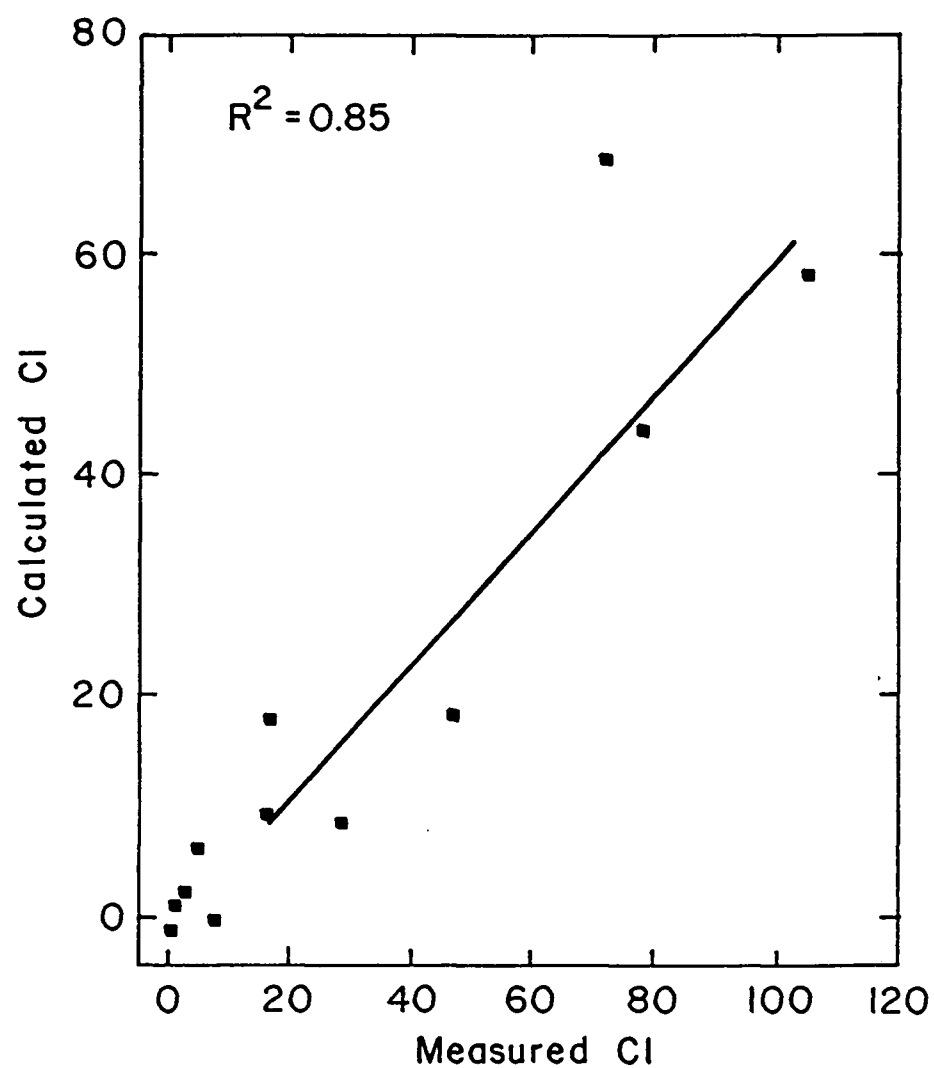


Figure 2.2. The relationship between calculated and measured chloride.

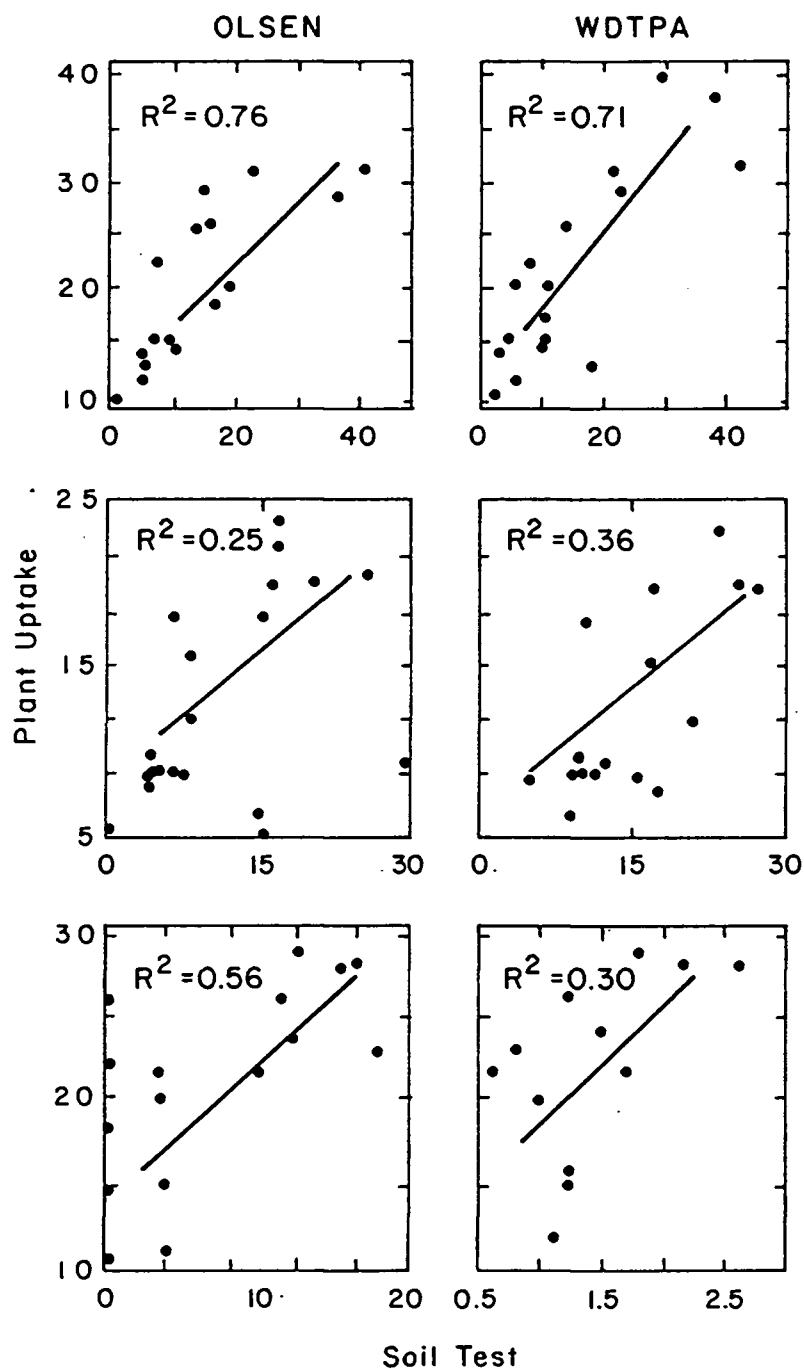


Figure 2.3. The relationship between plant uptake of phosphorus (kg/ha) and soil testing for phosphorus using both Olsen and WDTA soil tests.

Table 2.1. The coefficient of correlation (R) between standard methods and the four universal extractants for fifty soil samples from Yemen.

Universal Extractant	B	Ca	K	Mg	P
Ammonium chloride DTPA	.57	.67	.96	.92	.58
Water DTPA	.94	.23	.88	.66	.68
Mehlich 3	.00	.5	.06	.82	.44
ABDTPA	.39	.07	-.34	-.14	.26

Table 2.2. Correlations between water and water-DTPA soil extracts, and the mean values for the respective extracts for P, K, Ca, Mg, Na, S, Mn, Fe, Cu, B, and Zn.

Element	Regression Coefficient $R^2$			Water Mean	Water-DTPA Mean
	Water DTPA vs. Standard Procedures	Water DTPA vs. Water	Water vs. Standard Procedures		
P	.24	.79	.20	1.23	5.8
K	.50	.20	.13	19.7	58.15
Ca	.68	.19	.07	27.7	210.0
Mg	.84	.28	.13	6.4	40.26
Na	.95	.83	.72	12.14	24.9
S	.82	.92	.35	4.7	6.3
Mn	.60	.01	.00	.01	55.7
Fe	.86	.61	.58	1.12	31.6
Cu	.79	.01	.00	.03	1.1
B	.99	.98	.98	.17	.24
Zn	.90	.00	.00	0.00	1.5

Table 2.3. Regression coefficient for DTPA values and conventional tests.

Element	Test	R <sup>2</sup>	Equation
P	Single	.24	$y = 2.23 + .19xz$
	Multiple	.52	$y = 13.2 + 4.1x - .62x_1y$
K	Single	.5	$y = .29(x^{**1.18})$
	Multiple	.54	$y = 184.6 + 19.7x - 15.3x_1$
Ca	Single	.68	$y = 50.6(x^{**}.59)$
	Multiple	.60	$y = -9.2 + .06x = .02x_1$
Mg	Single	.84	$y = 17.9 + 5.9x$
	Multiple	.92	$y = -5.2 + .03x + .05x_1$
Na	Single	.95	$y = 75.1 + .97x$
	Multiple	.92	$y = -.7 - .004x + .014x_1$
S	Single	.82	$y = x / [.09(x) + .46]$
	Multiple	.38	$y = 5.5 + 1.2x - .1y$
Mn	Single	.6	$y = 26.1 + 2.7x$
	Multiple	.67	$y = -6.8 + .18x + .18x_1$
Fe	Single	.86	$y = .83 + 1.8x$
	Multiple	.9	$y = 4.9 + .61x + .52x_1$
Cu	Single	.79	$y = .24 + .81x$
	Multiple	.80	$y = -.52 + .97x + .08x_1$
B	Single <sup>a</sup>	.99	$y = -.03 + .38x$
	Multiple <sup>b</sup>	.99	$y = .26 + 2.96x - .32x_1$
Zn	Single	.9	$y = .75(x^{**}.97)$
	Multiple	.94	$y = 1.5 + 1.0x - .27x^2$

y = DTPA water (x).

z = DTPA water (x) + DTPA spike (x<sub>1</sub>).

Table 2.4. Regression equation and regression coefficient between standard methods and water DTPA.

Method	R <sup>2</sup>	
E.C.	.06	$y = 1.3 + .28 x$
S.A.R.	.91	$y = .34 + .59 x$
P.A.R.	.74	$y = .32 + .17 x$
HCO <sub>3</sub>	.65	$y = -1.8 + 46.22 x$
Cl <sup>z</sup>	.01	$y = 1.59 + .09 x$

zCl calculated as  $(Na + Ca + Mg + K) - (SO_4^- + HCO_3)$

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V. ESTIMATION OF SOIL BUFFERING CAPACITY  
IN WATER-DTPA EXTRACTS

### Abstract

The sorption isotherms of K, Ca, Mg, Na, P, S, Fe, Mn, Cu, Zn and B were determined on 14 soils from arid environments. Samples were collected from a variety of cultivated and native sites in Eastern Oregon and Eastern Washington. Data from all elements except Mn and Fe generally suggest that a plot of added vs. equilibrium solution concentrations is linear when agriculturally realistic rates are utilized. In some cases Cu and Zn isotherms were not linear, but this was rare.

A solution containing intermediate levels of all 11 elements (spiked solution) was used to estimate the recovery of each of the elements in a single procedure. By subtracting the amount of element in an unspiked sample from the amount found in the spiked treatments the percent recovery could be calculated. Similar experiments were conducted in both water and water DTPA solutions.

The percent recovery of individual elements in the multiple spiked solution varied most for P and K. Results were similar in both water and water DTPA. Boron, Na, Ca, Mg and S recoveries were relatively constant and also similar in both solution types. Recovery of Mn, Fe, Cu and Zn in DTPA spiked solutions was approximately 100% and didn't give a valuable measurement of buffering capacity.

Unfortunately, detection limits of the ICAP make utilization of water spiked solution difficult for micronutrient cations. No clear cut relationships were found for Mn and Fe.

The linear regression constants for P and K sorption isotherms corresponded very well to the percent recovery in the multiple spiked solution. This suggests that predicting the slope for sorption isotherms, which approximate the buffering potential of the soil, is possible for P and K in a single two-step procedure.

Recoveries for Mg and Ca were not as strongly related to the slopes of sorption isotherms, but strongly buffered soils could be distinguished from weakly buffered ones. Buffering relationships for other elements couldn't be predicted in a multiple spike solution.

### Introduction

Factors other than soil test element concentrations must be considered when making fertilizer recommendations. These may include previous crops, previous fertilizations, soil type, slope, degree of erosion, and yield potential. In addition, soil buffering capacity or fixing power of the soil can be a significant variable.

In recent years, considerable research work has been devoted to improve soil test procedures and making them faster and more efficient. McLean et al. (7) have shown that soils vary widely in percentage of P and K recovery. Therefore, the average recovery of P (22.5%) and K (60%) that are used to calculate fertilizer recommendations may not be accurate for all soils. They suggested instead a quick test that quantifies the tendencies of individual soils to fix added P and K, which can be used as a first approximation for adjusting fertilizer recommendations to maximize yield under most conditions. More recently, an improved recommendation based on a two step alternative soil test procedure for K (6) and P (5) were developed. These studies suggest that fertilizer recommendations of K and P can be improved with short term equilibration (2 hours) procedures that measure K and P fixation tendencies for individual soils.

Sorption isotherm studies, which give information about buffering capacity of the soil, were developed

primarily for phosphorus (2) and later for boron (11). Phosphate sorption isotherms have been used to evaluate the residual effects of phosphate fertilizers (2, 4). Fox and Kamprath (2) reported that using phosphate sorption isotherms provides a method for studying reactions of P fertilizers which is more closely related to plant needs than some of the classical studies on solubility of P reaction products. In addition Ozanne et al. (10) concluded that phosphate sorption can be a good estimate of phosphate required in the field by plants. They mentioned, however, that measurement of phosphate sorption and buffering capacity takes appreciably longer in the laboratory than does the determination of soluble phosphate. Boron adsorption isotherms also appear promising. Boron adsorption capacity of the soil has been found to depend upon its texture (12). Shumway and Jones (11) suggest that at low B concentrations, a plot of added B vs. equilibrium solution B will be linear. Therefore, the B fertilizer required to adjust the equilibrium soil B solution concentration can be calculated from initial boron and the isotherm slope. Furthermore, Offiah and Axley (9) found that boron extracted with hot water to which additional boron was added had a higher correlation with plant response than non spiked extractable boron. They concluded that some fixing sites in soils have to be satisfied before the hot water test works well.

Universal extractants that combine several conventional extractions into a single procedure offer possibilities of improved soil test efficiency (1, 8, 13, 14). This is especially true with the development of sophisticated instruments that can make multiple elemental analyses on a single sample. However, tests that supplement universal extractants with a measure of buffering capacity have not been developed.

We have recently developed a water-DTPA soil extraction, ICAP analysis procedure for arid soils (1). Although two-step procedures are not new (5, 6), our interest was to develop a two-step procedure using our initial water-DTPA extract as the background sample. With this modification all the information currently collected in conventional soil tests could be obtained during a two-step analysis for K and P. Information on buffering relationships of other elements, although not as important as K and P, could also be obtained in the same procedure. The major objectives of this work were to:

- 1) Develop additional soil tests to supplement water-DTPA extraction procedures with a measurement of soil buffering capacity.
- 2) Verify that sorption isotherms are linear for realistic rates of applications on arid soils, thus providing a basis for two-step predictive procedures.

- 3) Evaluate the predictability of sorption isotherms for routinely tested soil nutrient elements from a simple two-step multiple element spiked procedure.

### Materials and Methods

We have proposed a water-DTPA universal extractant (1) for arid soils for three reasons: (1) its simplicity and relative cost, (2) its high correlation with conventional methods, and (3) the predictive value that has been demonstrated in field experiments. The same fourteen natural to alkaline soils collected from Eastern Oregon and Washington that were used in developing the water-DTPA extractant were utilized in these experiments. The soils were air dried, crushed and passed through a 2 mm mesh, before being utilized in the following procedures.

### Sorption Isotherms Development

The sorption isotherms developed for B, K, Ca, Mg, Na, Cu, Fe, Mn, Zn, S and P were accomplished as follows. One liter of standard solution was prepared for each individual element in separate containers with 4, 150, 200, 100, 100, 12.5, 12.5, 12.5, 12.5, 100 and 75 mg/ml for the above elements respectively. Four rates (0, 5, 10, 20 ml) of two replicates were added to eight 10-gm subsamples of each soil from each elemental spiked solution. Distilled water

was added to adjust the volume to 20 ml per 10 gm of soil in the first three rates (0, 5, 10).

The following is an approximation of treatments concentrations of each element.

- Potassium (0, 35, 75, 150 mg/ml) as potassium phosphate
- Phosphorus (0, 17.5, 35.5, 75 mg/ml) as potassium phosphate
- Calcium (0, 50, 100, 200 mg/ml) as  $\text{CaCl}_2$
- Magnesium (0, 25, 50, 100 mg/ml) as magnesium sulphate
- Manganese (0, 3.125, 6.25, 12.5 mg/ml) as metal Mn
- Iron (0, 3.125, 6.25, 12.5) metal iron
- Copper (0, 3.125, 6.25, 12.5) metal copper
- Boron (0, 1, 2 and 4 mg/ml) as boric acid
- Zinc (0, 3.125, 6.25, 6.5) as metal zinc
- Sodium (0, 25, 50, 100 mg/ml) as NaCl
- Sulphur (0, 25, 50, 100 mg/ml) as magnesium sulphate

The samples were then allowed to equilibrate for 48 hours, interrupted three times by hand shaking. The hand shaking was applied directly after adding the solution, after 24 hours and after 48 hours just before filtering. The solution was then filtered using Watman 42 filter paper. The filtrate was then analyzed by ICAP for all the above elements.



### Multiple Spiked Samples

The multiple spike solution was prepared by adding all the above elements into a single container that resulted in the same concentrations previously mentioned. Elemental sources were similar except Cl salts of Fe, Mn, Cu, and Zn were used. Ten ml of this spiked solution was added to 10 gm of each soil with two replications. After 48 hrs of equilibration 10 ml of double strength water DTPA solution was added, resulting in an equilibrium solution with the same DTPA concentration as our proposed extractant. These were hand shaken and left for 24 hrs more to equilibrate, then filtered and analyzed on the ICAP as described above.

This procedure was repeated using an identical approach except distilled water was used in place of the double strength water DTPA solution. This provided us with both control and multiple spike analyses of water and water-DTPA extractions.

### Statistical Analysis

A commercially available statistical package (SIGSTAT) and DBase III+ (Ashton-Tate) were the software programs used for data management and statistical analyses. The regression coefficient ( $R^2$ ) and slope for adsorption isotherms of all elements were calculated. Although the data were arranged with the amount added on the y axis and the amount in solution on the x axis, regression slopes

were modified for further analyses. The regression constant (k) was defined as the reciprocal of the isotherm slope. Therefore, the following equation applies:

$$\text{Amount added} * k = \text{Amount in solution}$$

The value k is then directly analogous to the percent recovery in the two-step multiple element spiked procedure. The percent recovery for each element in the multiple element spiked procedure for both water and water-DTPA experiments is defined below:

$$\% \text{ recovery} = \frac{\text{spiked recovery} - \text{control}}{\text{amount added}}$$

where:

spiked recovery = the total amount of nutrient in the filtrate (20 mls) after equilibration with the spiked solution.

control = the total amount of nutrient in the filtrate (20 mls) for the unspiked control.

amount added = the amount of each nutrient added in the 10 mls of multiple spiked solution.

k values for sorption isotherms were then regressed against percent recovery for each element tested.

### Results and Discussion

Linear regression coefficients for sorption isotherms of all elements are shown in Table 3.1 for all 14 soils. Since relationships between added vs. recovery appear to be linear in arid soils, a two step procedure (control and spiked evaluations) could be used to estimate buffering capacities. Standard procedures that have been proposed for estimating the amount of fertilizer required to bring the soil solution to an optimal level (2, 4, 7, 9, 10) can be initiated with a two point sorption isotherm.

A strong relationship was obtained for almost all elements except for Fe and Mn. These two elements adsorbed strongly to the soil, thus only a small percentage was recovered. Higher rates, however, might improve the development of sorption isotherms of these two elements. The same explanation applied to Zn in soils 7, 10 and 14 where no detectable recovery of added element was found. The data in this table suggest that predicting the amount added to reach a specific level in soil solution is possible at least for B, Na, Ca, Cu, K, Mg, P, S and Zn. The linear regression constants ( $k$ ) for adsorption isotherms of all 11 elements are shown in Table 3.2. The corresponding percent recoveries of both water-DTPA and water spiked experiments are shown in Table 3.3 and 3.4. The goal was to relate the percent recovery in the two step procedure to the  $k$  value derived from the sorption

isotherms. Unfortunately, only two important elements responded well to the relationship. Only phosphorus and potassium  $k$  values could be predicted from recoveries in a two step multiple element spike procedure. A glance at Tables 3.2, 3.3 and 3.4 explains this trend. For elements that vary only slightly in  $k$  values, the natural variation in the two step assay will obscure differences in recovery that are due to differences in buffering capacity.

Phosphorus and K vary greatly in their percent recovery and in the slope of their sorption curves. Potassium varies from about 20 to 75, while P varies from 0.0 to 90 in their percent recovery. This is due to the greater dependence of recovery for these elements on soil characteristics.

Potassium recovery depends on types and amount of clay minerals that tend to fix this element in non exchangeable form. Phosphorus is adsorbed on clay surfaces, precipitated by Ca containing compounds at high pH, and by Mn and Fe at low pH.

The presence of competing nutrients and DTPA in the multiple spike solutions could also alter absorption relationships and result in different recoveries than would be predicted from the simple absorption isotherms. With the exception of Na, K, and P, the recovery in water and water-DTPA are generally poorly correlated (Table 3.4) with each other. However, although the DTPA and  $\text{NH}_4$  in the water-DTPA extractant alter recoveries, a multiple spike

water extract doesn't correlate with k values any better than the water-DTPA extract. This suggests that differences between multiple-spike recoveries and k values are largely due to competing nutrients in the multiple spike solution.

Fortunately, K and P relationships are not severely affected by either DTPA or competing nutrients. The regression equation and regression coefficients ( $R^2$ ) for both water and water-DTPA spiked recoveries versus isotherm regression constants are shown in Table 5. The relationship is similar for both water and water DTPA, indicating that DTPA will have no effect on the P and K prediction of buffering power to soils.

The percent recovery plotted against k values is shown in Figure 3.1 for P and Figure 3.2 for K. It is obvious that knowing the percent recovery can provide a relatively good estimate of the buffering capacity of the soils in a single two step procedure for those two elements. Since water-DTPA values for K and P are related to water extractable values (1), a crude sorption isotherm can be constructed from the two-step data. Further investigations may reveal the possibility of predicting this parameter for Ca and Mg where approximately 40 and 25 percent of the variability in k values could be explained by the variation in the recoveries determined in a two step procedure.

Although the relationships for Ca and Mg are not particularly strong, extremely high or low buffered soils could be identified, thus multiple spike solutions containing P, K, Ca, and Mg may be appropriate. Including the weakly buffered nutrients Na, S, and B provides little information. Similarly, added Zn, Mn, Fe, or Cu in a multiple-spike water-DTPA solution provides little additional information. The DTPA recovers a large amount of the added micronutrient cations so recovery in a water-DTPA spiked solution is not meaningful. Multiple spiked water recovery of Zn, Mn, Fe, and Cu was less than 10% and resulted in analytical problems, due to the low sensitivity of the ICAP instrument. By adding large amounts of the micronutrient cations to a water sample, accurate recoveries of Zn, Mn, Fe, and Cu could likely be estimated in a two step procedure. However, values high enough to be measurable would likely interfere with the other elements in a multiple spike solution. Furthermore, our interest is to use the water-DTPA extractant as the first step in a two step procedure.

In conclusion, it is possible to evaluate buffering relationships for K and P in a two step procedure using a water-DTPA extractant as the background sample. Therefore, most of the information currently collected in conventional soil tests could be obtained during a two-step analysis for K and P. Crude estimations of buffering relationships can

also be obtained for Ca and Mg in the same procedure.

Since adding additional elements does not produce useful information, relationships could possibly improve if just K, Ca, Mg, and P are included in a multiple spike solution.

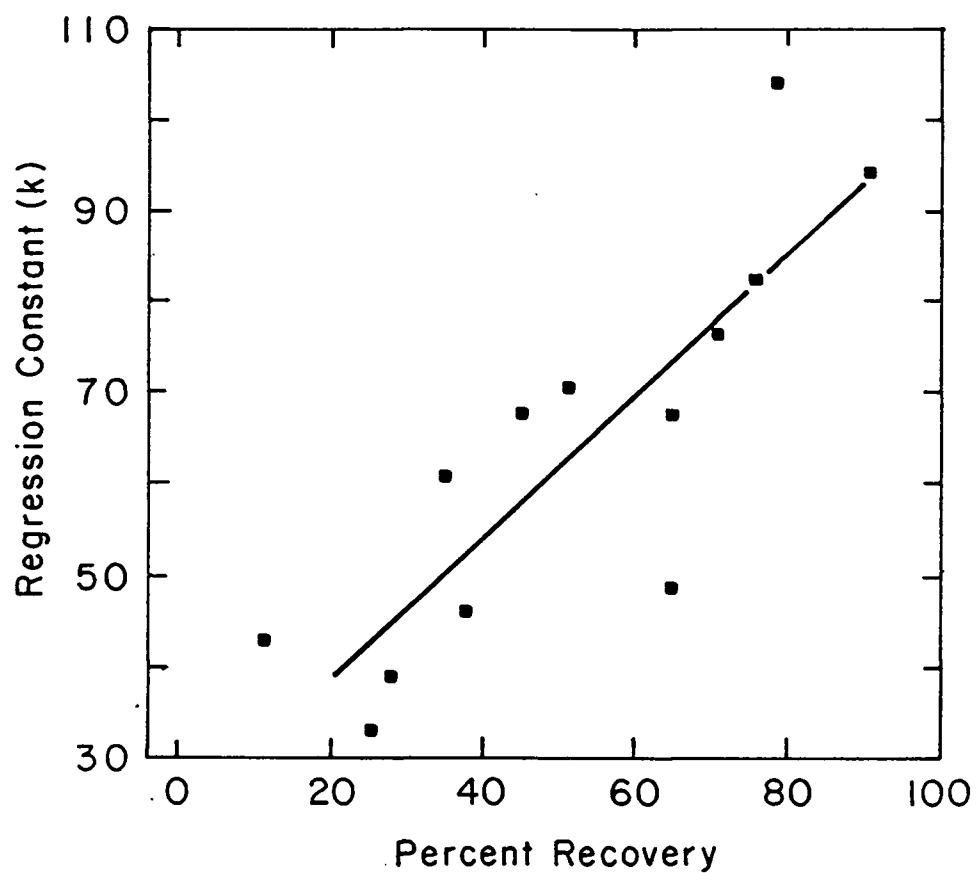


Figure 3.1. The relationship between percent recovery and the regression constant (k) for P.



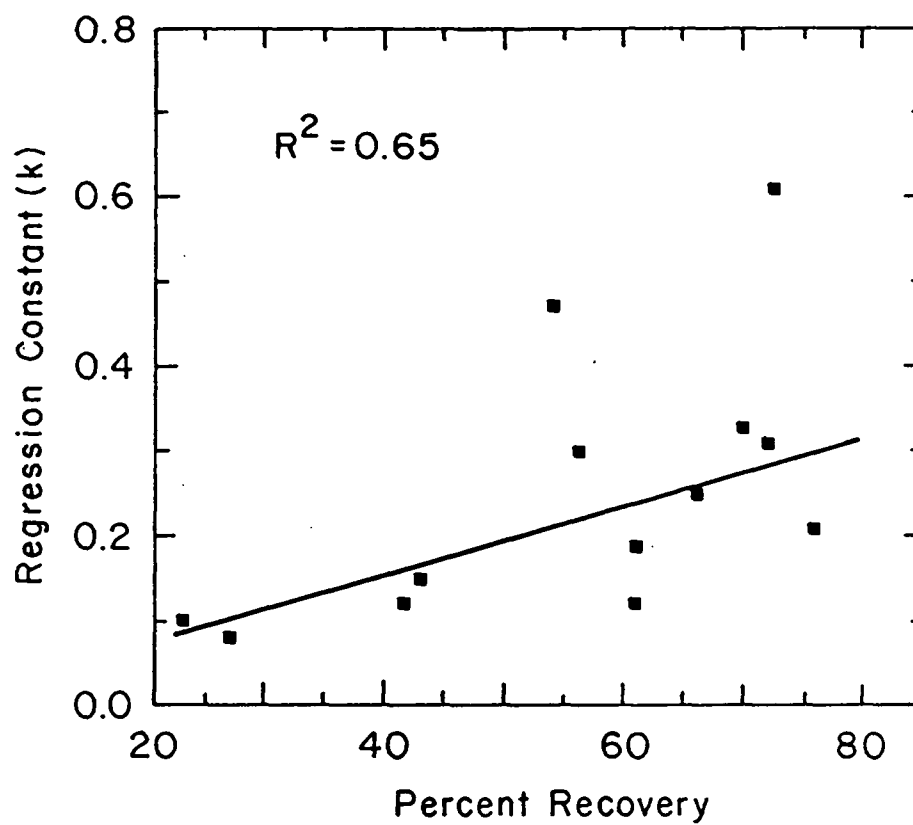


Figure 3.2. The relationship between percent recovery and the regression constant (k) for K.

Table 3.1. Regression coefficient ( $R^2$ ) for adsorption isotherms of all elements.

Soil No.	B	Na	Ca	Cu	Fe	K	Mg	Mn	P	S	Zn
1	.99	.99	.99	.71	.74	.98	.98	.93	.96	.99	.84
2	.99	.99	.96	.46	*	.99	.98	*	.98	.77	.77
3	.99	.99	.99	NS	*	.98	.99	*	.96	.99	.83
4	.99	.99	.94	.84	NS	.98	.94	NS	.94	.95	.85
5	.99	.94	.99	.79	NS	.99	.99	NS	.98	.99	.84
6	.99	.97	.99	.88	NS	.98	.98	NS	.97	.99	.71
7	.99	.99	.99	.79	*	.98	.99	NS	.99	.99	*
8	.99	.99	.99	.94	NS	.98	.99	.87	.99	.99	.87
9	.99	.99	.99	.97	NS	.99	.99	NS	.99	.99	.81
10	.99	.99	.99	.95	NS	.98	.98	NS	.99	.98	*
11	.99	.99	.99	.95	NS	.99	.97	*	.49	.99	.81
12	.99	.99	.87	.95	NS	.98	.98	NS	.99	.99	.80
13	.99	.99	.98	.92	NS	.99	.98	.63	.96	.99	.84
14	.99	.99	.98	.97	.79	.98	.98	.77	.95	.99	*

\* = No detectable recovery of added element.

NS = Relationship not significant.

Table 3.2. Linear regression constants (k) for adsorption isotherms of all 11 elements.

Treat- ment	B	Na	Ca	Cu	Fe	K	Mg	Mn	P	S	Zn
1	0.30	0.76	0.83	0.00	0.02	0.34	0.15	0.02	0.01	0.76	0.06
2	0.34	0.71	0.77	0.01	0.00	0.15	0.34	0.00	0.44	0.85	0.00
3	0.31	0.34	0.48	0.00	0.00	0.12	0.49	*	0.37	0.82	0.00
4	0.43	0.41	0.48	0.03	*	0.12	0.38	*	0.81	0.79	0.03
5	0.43	0.31	0.62	0.02	*	0.31	0.47	*	0.66	0.85	0.02
6	0.35	0.30	0.56	0.00	*	0.21	0.45	*	0.59	0.74	0.01
7	0.38	0.24	0.59	0.00	0.00	0.08	0.43	*	0.69	0.85	-0.02
8	0.45	0.80	0.67	0.01	*	0.61	0.47	0.01	0.75	1.92	0.02
9	0.39	0.30	0.62	0.01	*	0.19	0.39	*	0.47	0.79	0.01
10	0.38	0.83	0.77	0.01	*	0.30	0.36	*	0.66	0.97	0.05
11	0.44	1.18	0.77	0.02	*	0.47	0.51	*	0.93	1.02	0.02
12	0.47	1.00	1.00	0.00	*	0.33	0.51	0.00	1.03	1.11	0.05
13	0.35	0.80	0.71	0.01	*	0.25	0.45	0.07	0.31	0.93	0.02
14	0.30	0.59	0.42	0.01	*	0.10	0.43	*	0.41	1.02	0.01

Table 3.3. Percent recovery of spiked water-DTPA samples.

Soil No.	B	Na	Ca	Cu	Fe	K	Mg	Mn	P	S	Zn
1	27.00	101.04	86.28	38.70	144.60	60.60	76.38	60.06	0.00	83.40	63.28
2	68.00	83.74	137.90	100.78	5.60	42.68	81.46	*	37.56	102.08	104.72
3	49.00	80.86	82.82	93.80	87.20	41.46	112.86	*	27.66	97.66	100.42
4	67.00	108.36	101.78	102.64	288.80	60.98	92.40	59.00	75.76	98.70	106.86
5	45.00	89.90	102.40	97.84	120.00	71.96	87.80	*	64.48	100.38	104.14
6	52.00	82.58	93.30	89.94	*	75.60	94.54	*	34.66	100.40	97.58
7	83.00	85.88	114.34	106.04	95.40	26.82	111.30	*	50.88	105.04	109.58
8	37.00	90.78	107.44	97.84	99.40	71.96	91.20	22.72	70.70	93.52	102.28
9	57.00	88.48	111.30	101.54	105.20	60.98	83.98	33.68	64.84	100.26	106.72
10	57.00	88.00	80.74	103.10	31.60	56.10	65.88	200.60	44.92	99.42	106.00
11	83.00	95.18	120.20	106.82	123.20	53.66	83.56	93.60	90.56	104.38	109.72
12	61.00	106.28	97.90	105.72	145.80	69.52	97.98	110.22	78.26	99.38	110.72
13	33.00	89.62	105.54	92.42	*	65.86	83.16	*	25.14	102.46	101.28
14	102.00	147.62	69.00	131.42	*	23.18	93.16	128.82	11.08	135.66	140.28

\* Recovery of 0 or less.

Table 3.4 Percent recovery of water spiked samples.

Treat- ment	B	Na	Ca	Cu	Fe	K	Mg	Mn	P	S	Zn
1	12.0000	58.62	55.13	0.34	0.25	44.00	42.16	18.30	0.33	36.14	1.75
2	30.0000	65.61	117.70	0.5426	0.0800	31.25	71.00	0.3077	10.44	62.07	0.2143
3	14.0000	62.38	62.00	0.3876	0.0800	25.00	75.27	1.6154	5.41	58.19	0.2857
4	10.0000	128.95	54.30	0.8527	0.2400	37.50	83.12	3.6154	19.81	58.70	1.5000
5	8.0000	48.87	58.90	0.4651	0.0800	43.75	64.52	4.1538	11.49	46.45	1.4286
6	14.0000	58.56	57.90	0.3876	0.2400	62.50	43.01	0.0769	6.40	60.16	0.0000
7	11.0000	64.02	72.80	0.1550	0.0000	12.50	75.27	0.0769	16.72	57.06	0.0714
8	20.0000	62.49	79.50	0.9302	0.3200	56.25	75.27	1.8462	21.27	66.30	1.5000
9	16.0000	57.31	78.55	0.3876	0.0800	37.50	86.02	0.0000	16.91	56.88	0.4286
10	16.0000	49.91	90.10	0.4651	0.6400	56.25	48.31	0.0000	14.91	54.72	0.0000
11	0.0000	53.10	83.35	0.3876	0.1600	35.00	53.76	1.7692	27.67	55.19	0.3571
12	30.0000	104.48	60.10	0.7752	0.5600	43.75	86.02	1.8462	21.99	63.26	0.2857
13	8.0000	51.63	72.30	0.1550	0.2400	43.75	96.77	0.0769	3.43	55.87	0.2143
14	96.0000	132.19	60.30	0.3876	0.2400	31.25	32.26	0.0000	3.95	58.27	0.0000

Regression Coefficients ( $R^2$ ) Percent Recovery Water vs. Percent Recovery Water-DTPA

.13	.70*	.17	.00	.01	.60*	.04	.01	.88*	.01	.05
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\* indicates that the relationship between percent recovery in water and water-DTPA is significant ( $p < .05$ ).

Table 3.5. Regression equation and regression coefficients ( $R^2$ ) between spiked recovery (SR) and regression constant (k) for both water-DTPA and water.

Element		Equation	$R^2$
<b>B</b>	Water DTPA	$k = .42 - .05(SR)$	.04
	Water	$k = .4 - .001(SR)$	.19
<b>Na</b>	Water DTPA	$k = .33 + .005(SR)$	.03
	Water	$k = .61 - .0001(SR)$	0.00
<b>Ca</b>	Water DTPA	$k = 1/2.2 - .006(SR)$	.41
	Water	$k = 1/2.4 - .01(SR)$	.60
<b>Cu</b>	Water DTPA	$k = -.002 + .002(SR)$	.02
	Water	$k = .004 + .01(SR)$	.1
<b>Fe</b>	Water DTPA	$k = -.18 + .007(SR)$	.02
	Water	$k = 0.26 + .49(SR)$	.08
<b>K</b>	Water DTPA	$k = 1/14.2 - 1.8(SR)$	.64
	Water	$k = 1/12.9 - .18(SR)$	.59
<b>Mg</b>	Water DTPA	$k = 1/3.4 - .02(SR)$	.24
	Water	$k = .42 + .0001(SR)$	.002
<b>Mn</b>	Water DTPA	$k = .018 + .0003(SR)$	.005
	Water	$k = .005 + .01(SR)$	.15
<b>P</b>	Water DTPA	$k = .22 + .022(SR)$	.72
	Water	$k = .28 + .02(SR)$	.74
<b>S</b>	Water DTPA	$k = 1.37 - .008(SR)$	.017
	Water	$k = -.9 + .03(SR)$	.27
<b>Zn</b>	Water DTPA	$k = .02 - .0005(SR)$	0.00
	Water	$k = .014 + .006(SR)$	.04

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r diagnosis of soil



VI. EVALUATION OF DIAGNOSIS AND RECOMMENDATION  
INTEGRATED SYSTEM (DRIS) ON APPLES

### Abstract

Fertilizer use for pome fruit on sandy soils in the Yemen Arab Republic has been minimal. This study was initiated to investigate the feasibility of utilizing tissue analysis to assist in prioritizing fertilizer needs for specific locations. The goals were to develop Diagnosis and Recommendation Integrated System (DRIS) norms for apple and determine if a DRIS diagnosis would identify the relative severity of deficiency.

As a first step, DRIS norms and DRIS derived sufficiency levels were developed from data collected in the United States. A visual evaluation of orchards throughout Yemen suggested widespread Zn deficiency. The response to N was expected since nitrogen had not been supplied, and although P responses are rare in tree fruits, this may not be the case in these sandy soils. Tissue samples were collected, DRIS and conventional interpretations evaluated and a field trial conducted to verify leaf tissue diagnoses. The effect of soil applied N, P, K, B and Zn and foliar applied B and Zn on twig growth was evaluated for Anna apple at Alirra, Yemen.

DRIS diagnosis generally agreed with the diagnoses made by the sufficiency range method. DRIS derived sufficiency ranges were similar to published sufficiency

ranges. A Nutritional Imbalance Index (computed as the sum of DRIS indices irrespective of sign) was a good indicator of nutritional limitations to maximized growth. Although only Zn revealed a significant statistical response when comparing means, DRIS was excellent in predicting relative nutrient responses. DRIS diagnosed zinc as the most limiting factor, phosphorus as the next most limiting, followed by nitrogen, boron, and potassium. This relative ranking of DRIS indexes corresponded very well to the respective growth responses for the fertilizer treatments.

## Introduction

Fruit trees in general and apples in particular suffer from various nutritional problems in Yemen. The most obvious visible nutrient deficiency symptom is zinc (Figure 4.1). Rosettes of small stiff leaves, short internodes, and reduction in growth which are the classical symptoms of this element, are apparent in almost every apple orchard. The total Zn content in soils is usually adequate, but the availability is the important limiting factor. This is likely due to high soil pH and high  $\text{CaCO}_3$  concentration. According to Mengel and Kerby (11), the concentration of water soluble Zn in soil solution falls with increasing pH. Yemen farmers do not routinely fertilize, so one would expect almost universal N deficiency. Although responses to P additions only rarely occur for apples, the sandy texture of Yemen's soils may be an exception. Potassium deficiency is not expected to occur in alkaline soils, to a degree that potassium fertilizers are not imported for Yemen's farmers. However, symptoms resembling potassium deficiency have been observed in several orchards (Figure 4.2). The very high leaf calcium content (Table 4.2) may be the main reason for this disorder. In view of the limited availability of resources, identifying the nutritional limitations of specific areas and prioritizing fertilizer distribution according to probable responses is essential. Conducting field trials

at multiple locations is expensive and time consuming. Therefore this study was initiated to evaluate the feasibility of using tissue analysis to assist in prioritizing fertilizer needs for specific locations. Since Yemen samples are commonly deficient in several elements, determination of which limitations are most severe is difficult.

Standard methods of plant analysis may not reveal relative severity of nutrient deficiency or possible nutrient antagonism. The Diagnosis and Recommendation Integrated System (DRIS) has an advantage in that it provides a measure of nutritional balance rather than evaluating only a single deficiency or excess at a time. It uses nutrient concentration ratios, rather than concentrations themselves, to interpret tissue analysis (2). Details of DRIS procedures are discussed elsewhere (1, 2, 3, 4, 5, 6, 9, 10). The approach produces a series of indices that will be either negative, implying a relative deficiency, positive, implying a relative excess or zero which implies that the element is in "balance" with other nutrients. When placed in decreasing order, indices can theoretically rank elemental imbalances in severity from most excessive to most deficient. Various studies have concluded that DRIS can provide a better explanation of nutritional status than conventional sufficiency range approaches. Previous studies on hazelnuts (1) have shown that supplementing sufficiency range diagnosis with DRIS

indices when severe nutritional imbalances occur, may assist in interpretation of tissue analysis and alter recommendations.

The objectives of this study were: (1) to diagnose the important mineral deficiencies in Yemen and initiate field trials to confirm the diagnosis; (2) develop DRIS norms for apple; (3) determine if DRIS evaluations were consistent with conventional sufficiency range diagnostic evaluations; and (4) investigate the feasibility of using tissue analysis to prioritize deficiencies likely to occur in Yemen.

## Materials and Methods

### Preliminary Observations

Apple and peach orchards were visited throughout Yemen to evaluate obvious visual deficiency symptoms. The Alirra Experiment Station was selected as representative of many of Yemen's commercial production areas, and tissue and soil samples were collected. Routine analyses of soil and plant tissue were conducted using standard Oregon State University plant analysis and soil testing procedures.

### Development of DRIS Norms

Published and unpublished data consisting of leaf mineral composition and corresponding yield for apples grown at various Oregon and British Columbia locations were

obtained for N, P, K, Ca, Mg, Fe, Zn, Mn and B for norm development. Data were collected from orchard surveys and experimental plots. Leaf sampling and tissue analysis were generally similar for all sources of data. Mid-shoot August leaf samples were collected for mineral analysis. For all samples nitrogen determinations were made with an autoanalyzer after standard microkjeldhal digestion (13). Spark emission spectroscopy (8) was used after dry ashing samples at 500° for 24 hrs to measure P, K, Ca, Mg, Mn, Fe, Cu, B, Zn and Al for the Oregon samples. Phosphorus was measured colorimetrically in kjeldahl digests and K, Ca, Mg, and Mn by atomic absorption (14) in the British Columbia samples.

The observations were divided into high (highest 20%) and low (lowest 20%) yield subpopulations for each individual year that data was available. High and low yielding groups were then combined. Thus, desirable and undesirable groups for the entire bank of data were obtained. A total of 400 individual data entries were evaluated with 75 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 (10).
- 2) If the variance of a nutrient ratio was significantly different for high and low yielding subpopulations, the ratio was considered important (4).

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 Beaufils' original two equation version of DRIS general calibration formula (1, 2). DRIS indices were calculated on several thousand historical apple leaf analyses previously conducted at the Oregon State University Plant Analysis Laboratory 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 only ratios involving N, P, K, Ca, Mg, Mn, and Zn. 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 (1, 9).

DRIS was also used to evaluate the previously collected Alirra samples. Samples were collected from three categories of trees:

- 1) Leaves with visible nutrient symptoms suggesting Zn deficiency.
- 2) Leaves with visible nutrient symptoms suggesting K deficiency.
- 3) Leaves without visible nutrient deficiency symptoms.

Leaves in category three were considered most representative of the Alirra station and the DRIS evaluation of those samples was evaluated to determine if DRIS and conventional sufficiency range approaches would predict the results of field trials.

### Field Trials

The fertility trials were located on the Alirra farm near Sanaa City, Yemen. The climate is arid with cool winters and hot, dry summers. The soil is a silty loam with a pH of about 7.5. The EC and SAR are in the acceptable range.

The trial was conducted on five-year-old, bearing trees for two varieties of peaches and Anna apples. Previous soil and tissue analysis have revealed a serious

zinc deficiency and possible N, P, K, and B deficiency (Tables 4.1 and 4.2). Two trials, one involving N, P, and K treatments and the other involving B and Zn treatments, were initiated on both apples and peaches. Conditions at the station did not promote accurate yield measurement. Therefore, growth measurements were the only criterion evaluated for treatment response. Three randomly chosen shoots were marked 6 cm from the tip for each tree. At the end of the growing season the increase in growth was measured and the average of the three shoots was calculated for statistical analysis. Cultural practices like watering, thinning, pesticide spray, and pruning, were made as uniform as possible within each block.

Eight NPK fertilizer treatments were established, with 6 replications in a randomized block design. Unfortunately, 3 of the initial replications were unusable, thus the experiment was analyzed as having 3 replications.

Treatments were as follows:

1. (control) - no additions
2. (N) - 1.5 N per tree
3. (K) - 2 lb K per tree
4. (P) - 1 lb P per tree
5. (NK) - 2 and 3 as above
6. (NP) - 2 and 4 as above
7. (KP) - 3 and 4 as above
8. (NPK) - 2, 3, and 4 as above

These treatments were purposely high to insure responses, but not sufficiently high to cause injury. Nitrogen was provided with urea (46% N), K with potassium sulphate (43% K) and P with triple super phosphate (20% P). Separate rows were treated as an individual block (replication). The treatments were assigned randomly to each block. The fertilizers were hand broadcast around each tree during the dormant season, followed by mechanical incorporation. Similarly, seven B,Zn treatments were established in a randomized block design. Treatments were as follows, with replication as described above:

1. (control) - NPK application as above but no B or Zn.
- 2) (B)<sub>s</sub> - NPK application as above but with soil applied B.
- 3) (B)<sub>f</sub> - NPK application as above but foliar applied boron.
- 4) (Zn)<sub>s</sub> - NPK application as above but with soil applied Zn.
- 5) (Zn)<sub>f</sub> - NPK application as above but with foliar applied Zn.
- 6) (B + Zn)<sub>s</sub> - NPK application as above but with soil applied B and Zn.
- 7) (B + Zn)<sub>f</sub> - NPK application as above but with foliar applied B and Zn.

Soil applications of B and Zn were applied during the dormant season. Boron was applied as solubor at 15 gm of Boron per tree. Zinc was applied as chelated zinc at 45 gm per tree zinc. Foliar applications, on the other hand, were conducted about 14 days before full bloom for boron and before petal falls for zinc, at 100 and 200 ppm respectively. Trees were sprayed just before sunset to avoid high evaporation during the days.

Both of the experiments described above were also initiated on peach, with the exception that 6 usable replications were available. Although results are similar to the apple data, tissue analysis and DRIS norms could not be utilized. Therefore, results are only presented in the Appendix.

### Statistical Evaluations

Statistical analysis of the data was done by utilizing SIGSTAT and SAS statistical software. Treatment effects were tested using analysis of variance, and treatment means were compared using LSD at 1, 5 or 10% level. Transformation of the data was utilized when appropriate.

In developing DRIS norms SIGSTAT statistical software was used to detect differences of the mean and variance between low and high subpopulations.

## Results and Discussion

All NPK fertilizer treatments increased vegetative growth in apples over the control (Figure 4.3). However, this increase was not significantly ( $P < .05$ ) different. At a  $p < .20$  differences for N and P are significant. Unexpectedly, the NPK treatment gave the lowest increase of all the treatments, possibly due to a combined effect. As previously stated, rates were purposely high. It is possible that high rates of both K and N were undesirable. However, the low solubility of super phosphate should not create problems.

The B and Zn experiment, on the other hand, resulted in significant increases for log transformed data. The least significant difference (LSD) test revealed that Zn and BZn treatment in both foliar and soil application were significantly different from the control, while only a small increase resulted from boron alone. The result suggests that zinc is the most limiting factor, and either soil or foliar application corrects the deficiency. However, soil application is favorable for the long term since the residual effect can last for several years as concluded by Brown (7).

DRIS norms, that is the ratios selected as important by both mean and variance, are presented in Table 4.4. Thirty ratios were found to discriminate between high and low yield subpopulations. Seventeen ratios were selected

by the variance and eleven by the mean, whereas only four ratios were selected by both mean and variance. Including more ratios is more reliable (1, 4). If either the variance or the mean selection procedures are used alone to determine important parameters, a smaller number of ratios will be used to calculate the indices. This will make the index highly dependent on fewer parameters.

Mineral concentrations for the samples that were collected from the three categories of trees at the Alirra station are presented in Table 4.2. The corresponding DRIS indices of the same elements are presented in Table 4.3. There was good agreement between both diagnostic approaches. The critical nutrient concentration approach diagnosed zinc to be severely deficient while N, P, and K are marginal. DRIS, on the other hand, assigned relative deficiencies for Zn, P, N, Mg and Cu, while relative excesses for K, Ca, Mn, Fe and B were apparent. However, both sufficiency ranges and DRIS approaches consistently identified the severe Zn deficiency and likelihood of N and P deficiency. Potassium was diagnosed as relatively in excess by DRIS, while it was marginal according to the sufficiency range approaches.

Care must be taken when evaluating DRIS diagnoses. The major limitations will be identified, but these imbalances affect the other indices. Interpreting minor limitations is difficult due to the symmetry of DRIS, since the

nature of DRIS expression will always make a relative diagnosis (9). The relatively small indices for Mg, Cu, Fe, and B are diagnostically of little importance. Although K is diagnosed as relatively in excess by DRIS this may be due to other imbalances being more severe. For this reason DRIS is best utilized as a supplement to traditional approaches.

NII was a good indicator of nutritional imbalances. It diagnosed the healthy tissue sample to have a lower value, indicating that the imbalance is much less than from samples showing visual Zn deficiency symptoms. Although zinc values were still severely deficient in this sample, no visible symptoms were observed. Establishing a threshold NII value as suggested in previous studies (1, 9) is very important to consider when making fertilizer recommendations. Insufficient independent yield data are not available as previously described (9), therefore establishment of such a threshold was not possible. However, if using the broad assumption that samples with an NII higher than the mean plus one standard deviation for a large data base will be severely imbalanced (1, 9), all the Alirra samples would be severely imbalanced.

DRIS analysis using fewer elements (N, K, P, Ca, Mg, Mn, and Zn) had similar results (Table 4.5). Zinc followed by phosphorus are the most limiting factors while Mn and Ca

are the most excessive. NII also is smaller in sample without visual symptoms.

DRIS evaluation of the two fertility trials provides good information on relative fertilizer responses. According to Figure 4.3 of the NPK experiment, P gave the highest increase in vegetative growth, followed by N and K. This corresponded very well to P, N, and K indices in Table 4.3 and 4.5. Phosphorus was the most limiting (most negative) nutrient followed by N and K. Therefore, higher responses were obtained. The N index was also negative although not as severe as P, whereas the K index was positive. Thus a higher response was expected for nitrogen than potassium.

Similarly, in the BZn experiment, zinc was by far the most limiting factor and a significant response to both foliar and soil applied Zn was obtained. Plotting relative growth increases and the respective DRIS index for each element further demonstrates the usefulness of balance evaluation (Fig. 4.5). DRIS was a good indicator in explaining the fertilizer performances. A high correlation was obtained between the respective DRIS index and fertilizer responses ( $r^2 = .81$ ). Zinc application that resulted in highest vegetative growth response was associated with the lowest index, while the lowest responses for B and K were associated with higher indices. Phosphorus and nitrogen were intermediate in both relative response and intensity of imbalance when diagnosed by DRIS.



In conclusion, DRIS norms for apple have been developed which provide a diagnosis that is in general agreement with conventional approaches. Zinc, nitrogen, and phosphorus deficiencies are probable in Yemen and need to be addressed. Further work is required to investigate possible K deficiency since neither DRIS nor conventional procedures suggest severe deficiencies even though K like deficiency symptoms appear. Tissue sample collection throughout Yemen should be initiated and when both conventional and DRIS evaluations are conducted, the Ministry of Agriculture could better prioritize fertilizer needs for various regions and act accordingly.



Figure 4.1. Symptoms resembling zinc deficiency.

25% COTTON CONTENT



Figure 4.2. Symptoms resembling potassium deficiency.

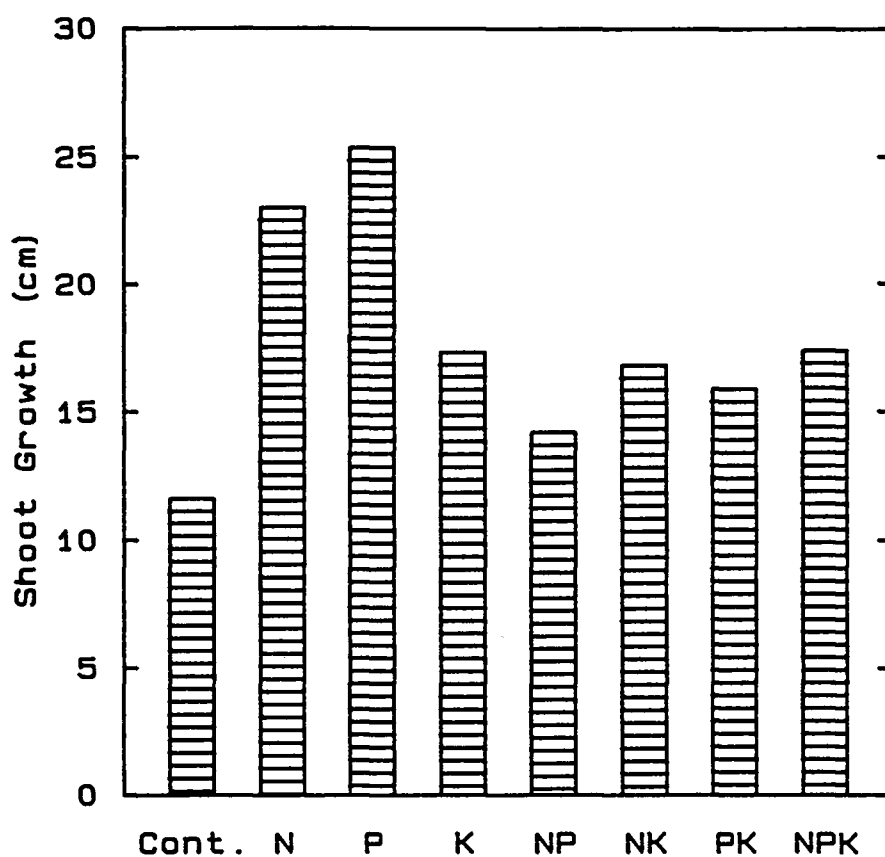


Figure 4.3. NPK experiment on apple. The response of vegetative growth to fertilizer treatments was not significantly different from the control ( $P < 0.05$ ).

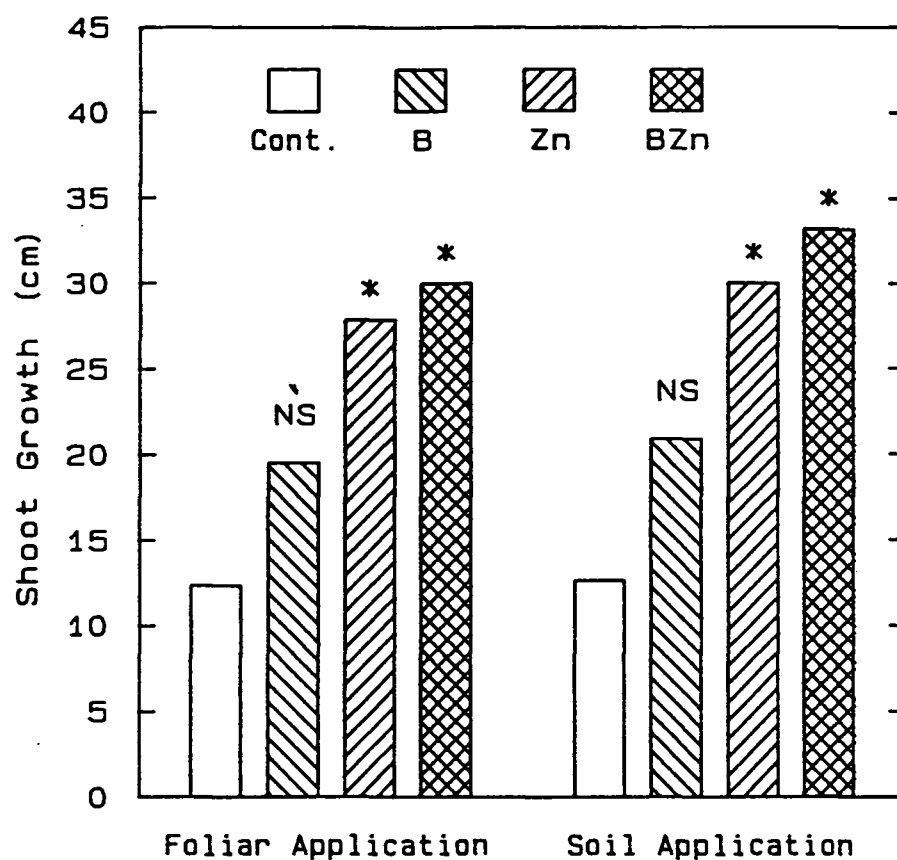


Figure 4.4. Effect of B and Zn applications on apple shoot growth. The values with an asterisk are significantly different from the control treatment. (Transformed data ( $P < .05$ )).

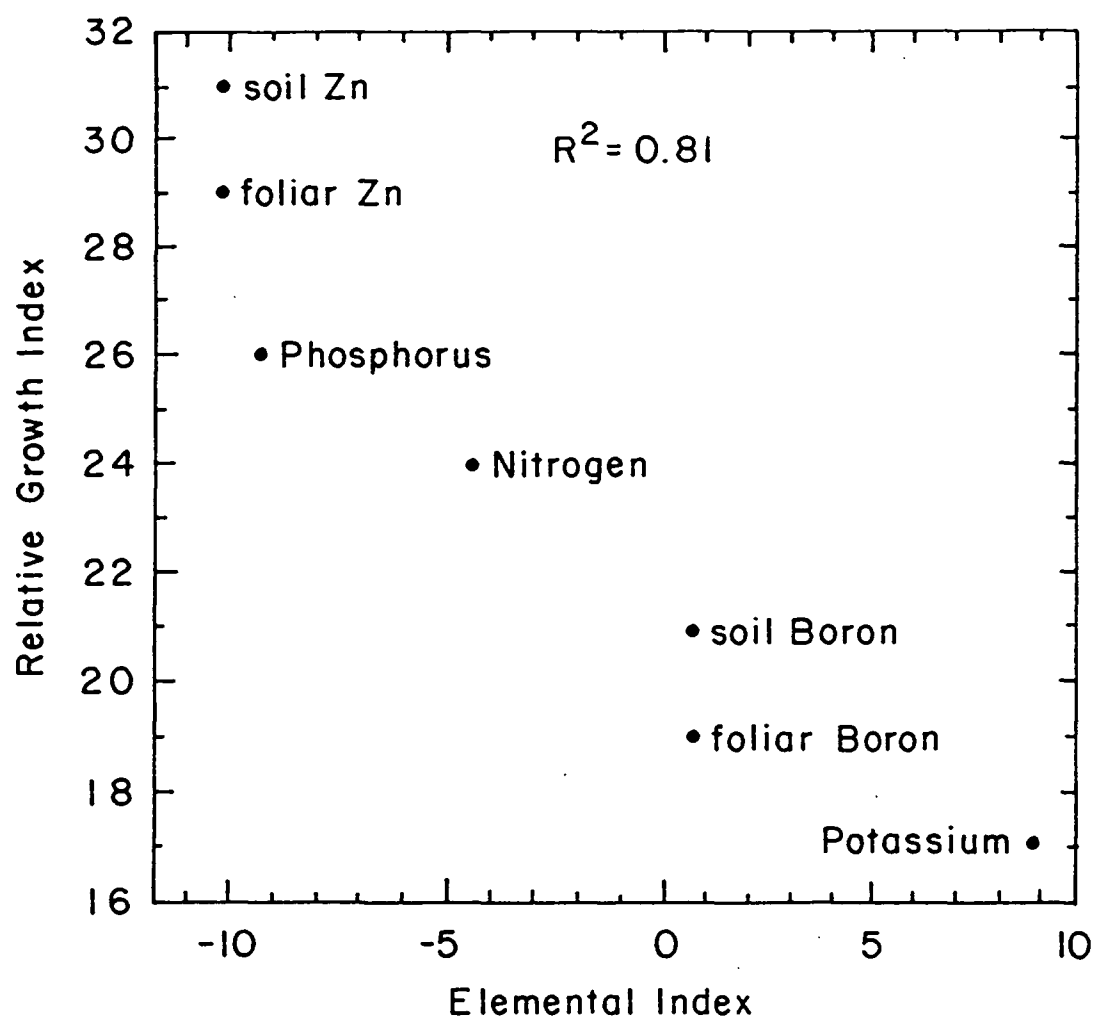


Figure 4.5. Elements' indices and relative growth response on Anna apple.

Table 4.1. Soil analysis results in ppm from  
Alirra Station.

P	K	Ca	Mg	B	Mn	Zn	Fe	Cu
6	230	9200	114	.38	3.6	1.1	10.2	6

Table 4.2. Nutrient concentration of the three samples (healthy, possible Zn deficiency and possible K deficiency).

Sample	N	K	P	Ca	Mg	Mn	Fe	Cu	B	Zn
Possible Zn Deficiency	1.68	1.22	.1	3.0	.28	165	288	5	35	7.0
Possible K Deficiency	1.59	1.4	.09	2.7	.34	251	226	4	33	6.0
Healthy	1.85	1.83	.12	2.4	.27	196	246	6	37	8



Table 4.4. Means and standard deviations of nutrient ratios selected as important by either significant differences in variance or mean.

Ratio	Mean	Standard Deviation	<u>Method of Selection</u>	
			Mean	Variance
NMn	.0775	.134		**
KFe	.014	.0046		**
KB	.0549	.0246	**	**
KZn	.185	.089	**	**
KN	.839	.086	**	
PFe	.00246	.0076		**
PCu	.0629	.0325		**
PZn	.03	.0164	**	**
PMg	.697	.242		**
PK	.103	.043		**
PN	.0846	.034		**
PMn	.02003	.02177	**	
CaFe	.013	.004	**	
CaB	.0498	.0229	**	
CaMg	3.8	.839	**	
CaN	.47	.18	**	
CaK	.577	.2549		**
MgCu	.0829	.0806		
MgK	.149	.043		**
MgN	.15	.0247	**	
MnK	25.24	8.57		**
FeZn	12.86	5.04		
CuCa	3.59	1.35	**	**
CuFe	.042	.00928		
ZnK	15.8	13.5		**
ZnMn	.676	.608		**
BMg	108.3	45.8	*	
BFe	.28	.074		*
PCa	.206	.09	**	

Table 4.4. Means 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
NMn	.0775	.134		**
KFe	.014	.0046		**
KB	.0549	.0246	**	**
KZn	.185	.089	**	**
KN	.839	.086	**	
PFe	.00246	.0076		**
PCu	.0629	.0325		**
PZn	.03	.0164	**	**
PMg	.697	.242		**
PK	.103	.043		**
PN	.0846	.034		**
PMn	.02003	.02177	**	
CaFe	.013	.004	**	
CaB	.0498	.0229	**	
CaMg	3.8	.839	**	
CaN	.47	.18	**	
CaK	.577	.2549		**
MgCu	.0829	.0806		
MgK	.149	.043		**
MgN	.15	.0247	**	
MnK	25.24	8.57		**
FeZn	12.86	5.04		
CuCa	3.59	1.35	**	**
CuFe	.042	.00928		
ZnK	15.8	13.5		**
ZnMn	.676	.608		**
BMg	108.3	45.8	*	
BFe	.28	.074		*
PCa	.206	.09	**	

Macronutrients expressed in percent; micronutrients expressed in ppm x 100.

Table 4.5. DRIS indices and NII for the three samples using ratios containing only N, K, P, Ca, Mg, Mn, and Zn.

Sample	NII	N	K	P	Ca	Mg	Mn	Zn
Possible K Deficiency	3926	131	330	-498	943	-120	969	-934
Possible Zn Deficiency	5228	-165	260	-644	809	62	1612	-1675
Healthy	3243	-188	43	-364	565	-152	912	-1019

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## VII. SUMMARY AND CONCLUSION

The Modified Crossa Raynaud formula is the best model to approximate chilling hours, at least under Sanaa, Yemen conditions. The Weinberger Sharp model can be used where detailed meteorological data are unavailable. Based on these two models one can suggest that trees requiring from 0-500 chill hours can be introduced in Sanaa with no hesitation. For trees that require from 500-600 chill hours, other factors should be considered before distributing them to farmers. Trees that require over 600 hours must be tested experimentally before any distribution. Data from other areas should be evaluated with these models to provide better guidelines for those locations.

Soil testing results showed that a simple water DTPA extractant has great potential as a soil test for Yemen arid soils. It is simple, accurate, and much less expensive than conventional tests. Estimation of soil buffering capacity is possible for P and K in water DTPA with a simple two step procedure. When buffering evaluations accompany a water DTPA soil test, more information is obtainable than by standard methods. The Diagnosis and Recommendation Integrated System (DRIS) can be a useful tool to supplement standard leaf analysis procedures.

It may not be possible to provide specific recommendations to the individual farmers in Yemen at this time. However, in the future both soil and plant tests may provide more meaningful fertilizer recommendations. In the meantime, I hope to implement improved soil tests and plant analysis procedures for Yemen. Initial emphasis should be placed on categorizing geographic areas and soil types rather than providing individual recommendations.

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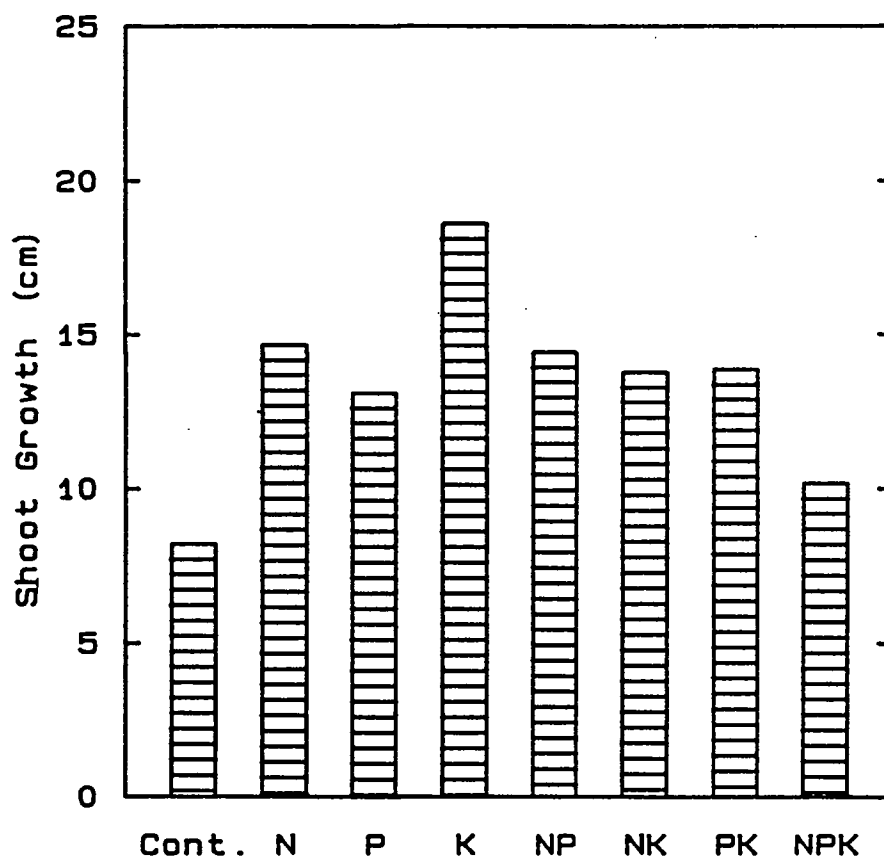


Figure 5.1. Effect of NPK applications on peach shoot growth. The response of vegetative growth to fertilizer treatments was not significantly different from the control ( $P < 0.05$ ).

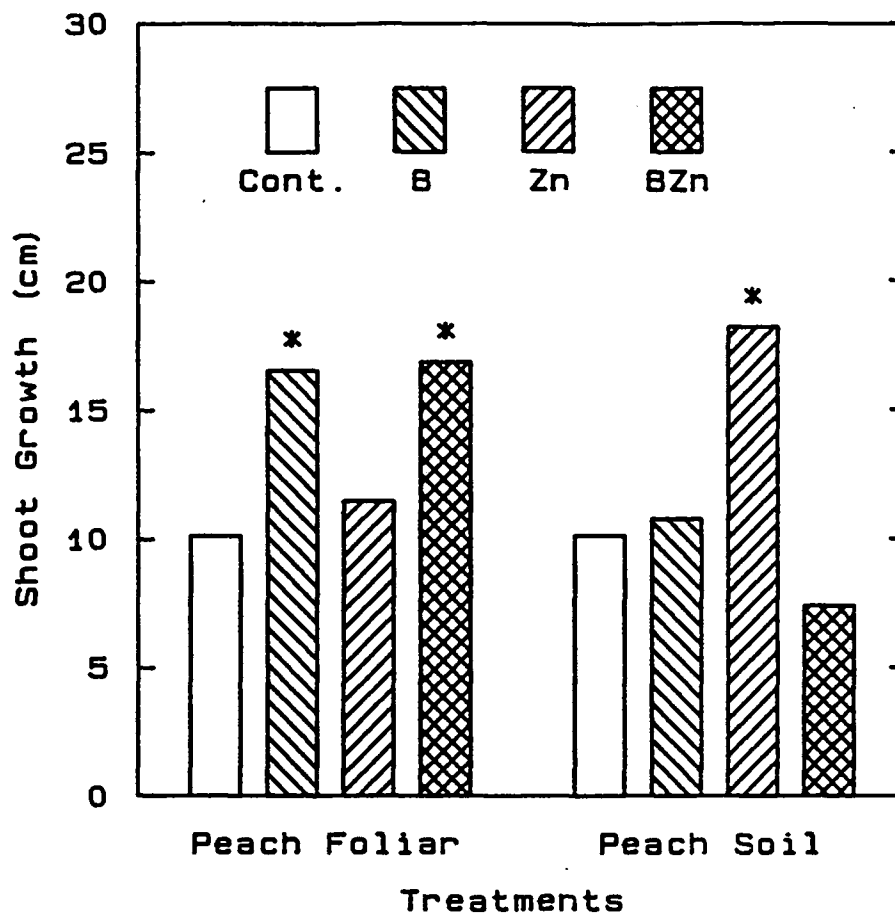


Figure 5.2. Effect of B and Zn applications on peach shoot growth. Values with an asterisk are significantly different from the control treatment. (Transformed data ( $P < 0.05$ .)

## IX. APPENDIX



Table 5.1. Plant uptake, Olsen values and water DTPA values of phosphorus from potatoes experiment.

Record	Experiment 1			Experiment 2		
	Olsen values	Water-DTPA values	P uptake	Olsen values	Water-DTPA values	P uptake
1	11.30	1.21	16.70	6.60	0.99	16.50
2	43.30	2.13	35.00	17.50	1.15	20.90
3	4.30	1.55	13.10	14.50	1.12	24.10
4	15.20	1.60	23.90	2.90	0.76	9.80
5	9.60	1.20	14.40	12.80	0.83	7.90
6	3.70	0.98	12.10	24.70	0.90	10.70
7	37.70	1.81	26.20	6.20	0.96	9.90
8	19.50	1.00	19.10	3.90	0.85	10.20
9	5.40	0.92	15.20	17.50	1.18	20.80
10	37.90	1.76	27.80	5.10	0.87	18.70
11	13.30	1.38	23.60	3.10	0.85	11.10
12	19.00	1.14	14.00	14.60	0.69	22.80
13	42.20	2.65	28.50	6.70	1.07	13.10
14	18.40	1.24	19.10	5.10	0.88	10.10
15	8.20	1.21	15.00	3.30	0.84	10.10
16	14.10	0.80	11.00	14.00	1.00	20.60
17	3.70	0.86	14.00	3.00	0.83	9.20
18	6.50	1.10	20.90	13.20	0.83	18.90
19	16.70	1.23	17.80			
20	44.50	2.48	33.70			
<hr/>						
Experiment 3						
1	3.40	0.75	21.62			
2	3.50	0.84	19.87			
3	4.00	0.87	10.16			
4	3.90	0.90	14.42			
5	10.40	1.01	21.58			
6	11.00	1.00	22.89			
7	12.00	0.90	26.29			
8	12.90	1.03	29.24			
9	16.00	1.22	28.21			
10	12.70	0.96	23.90			
11	16.60	1.12	28.43			
12	18.10	0.79	23.03			