INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

Order Number 9322763

Nutritional evaluations of Cabernet Sauvignon grape and some rootstocks in calcareous soils under greenhouse conditions

Juarez Gonzalez, Rogelio Ausencio, Ph.D.

The University of Arizona, 1993

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

NUTRITIONAL EVALUATIONS OF CABERNET SAVIGNON GRAPE AND SOME ROOTSTOCKS IN CALCAREOUS SOILS UNDER GREENHOUSE CONDITIONS

by

ROGELIO AUSENCIO JUAREZ GONZALEZ

A Dissertation Submitted to the faculty of the

DEPARTMENT OF SOIL AND WATER SCIENCE

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 9 3

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Rogelio Ausencio Juarez Gonzalez

entitled Nutritional Evaluations of Cabernet Savignon Grape and Some Rootstocks in Calcareous Soils Under Greenhouse Conditions

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy

Gordon R. Dutt	4-15-93
Dr. Gordon R. Dutt	Date
Jack Stroehlein	Apr 15, 1993
Dr. Jack Stroehlein	Date
David M. Hendricks	4-15-93
Dr. David Hendricks	Date
Michael Kilby	4/15/93
Dr. Michael Kilby	Date
James W. O'Leary	4/15/93
Dr. James O'Leary	Date

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

Gordon R. Dutt — 4-15-93

Dissertation Director — Date

Dr. Gordon R. Dutt

STATEMENT BY AUTHOR

This dissertation has been submitted in partial fulfilment of the requirements for an advanced degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the library.

Brief quotations from this dissertation are allowable without special permission, provided that accurate acknowledgment of source is made. Request for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: ____________________

ACKNOWLEDGMENTS

The author would like to express his gratitude to Dr. Gordon Dutt, my major advisor, and Dr. Jack L. Stroehlein, for their guidance, support, encouragement, and suggestions during the course of my study, research, and the writing of this dissertation.

The author would also like to express his appretiation to Dr David Hendricks, Dr. James W. O'Leary, and Dr Michael W. Kilby for serving as members of the research committe and reviewing this dissertation.

Many thanks are expressed to my wife Rosa Amelia and my childrens Marco Alejandro, Maira Azucena, and Mauricio Aaron, for their patience, love and understanding without wich my studies could not have been completed.

The author wishes to thank the INIFAP - MEXICO for their financial support during the course of this study.

DEDICATION

I am very proud to dedicate this study to the memory of my son, Marco Alejandro, who was sixteen when he died after my final exam in January 1993. My three children Marco Alejandro, Maira Azucena, and Mauricio Aaron inspired me to follow a Ph.D. program and they needed to sacrifice a normal social enviroment; however, Marco Alejandro did not have the chance to see my complete degree.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT

Greenhouse studies were carried out to determine the effects of three calcareous soils on the foliar growth and elemental composition of a vinifera variety, three common roostocks, and the variety grafted to the three roostocks. Soils, water, shoot growth, tissue analyses, and cation uptake were evaluated in grapevines on which grape variety rootstocks and grafted materials were established on Mohall, Sonoita, and Casa Grande soil series in PVC columns collected from three agricultural areas in Arizona.

Grapevines have a root system that explores the subsoil as well the surface of the soil; however, in calcareous soils with high pH and high lime content, some micronutrient are relatively insoluble, also calcium tends to be precipitated forming calcium carbonate and becomes water insoluble; therefore, the purpose of this study is to evaluate the roostock effect in the nutritional uptake.

Good compatibility was observed between rootstocks and scions, also all grafted vines grew very well and no chlorosis or foliar elemental deficiencies were obserbed during the experiments. In this study, roostocks showed bigger shoot growth in grapevines than the rest of the treatments.

Grafted grapevines contained higher foliar potassium than the rest of the treatments. Also all material evaluated had calcium and iron deficiencies with content less than 1.2

percent and 70 mg kg-1, respectively, and no one had more than 0.5 percent of sodium content, foliar grape content reported by California that can be a problem. Cabernet savignon had the highest magnesium content in the three soils.

Cation balance was used to measure the cation uptake for the evaluated materials; consequently, grafted plants had higher cation uptake than nongrafted plants. In this evaluation, Cabernet savignon grafted to 41 B had the highest cation content in comparision with every treatment; therefore, it was the highest in potassium, calcium, magnesium, and iron content.

No one treatment had a deficient level of manganese; although, the studied soils were basic with high pH. In relationship with copper uptake, Dogridge had the highest copper uptake in the three evaluated soils.

CHAPTER ONE

INTRODUCTION

Grapes (Vitis vinifera) are becoming an important crop in human consumption, because vineyards can produce quality fresh fruits, dry fruits, juices, jellies, and wines; One cup of table grape contains about 100 calories; also, grapes are low in sodium and provide vitamin C and potassium (The Paker, 1991). Grape plants have fewer mineral deficiencies and lower nutrient and water requirements than most crops, but also because they are adapted to wide varieties of soil types and climatic conditions. Grapes are one of the main crops which provides high employment and high profit.

Grapevines can adapt themselves to a wide range of soils. The root system of the vine explores the subsoil, as well as the soil surface; however, in calcareous soils with high pH and high lime content, the micronutrient cations are relatively insoluble. With these conditions, the micronutrients cations react with hydroxyl ions, precipitating as hydrous metals and oxides. Under these conditions, grapes often can not absorb enough of these metals, especially iron and zinc.

Deficiency of zinc in grapes results in a deficiency of auxins and causes a failure of the shoots to grow normally.

Iron is indispensable in the synthesis of chlorophyll. A lack of usable iron in the vine tissues causes a characteristic yellowing of the foliage called chlorosis.

Lime content in the vineyard is generally a problem in the western United States, when the lime content of the soil exceeds 15 percent, leading to zinc and iron deficiencies, or lime induced shatter of flowers and chlorosis.

This study includes three calcareous soils that were collected from vineyards in these areas of Arizona, and includes an evaluation of a variety with three rootstocks.

The main objective of this study was to determine the nutritional growth response of the variety, Cabernet savignon, in comparison with three common rootstocks and the variety grafted to the three rootstocks, in addition an evaluation of iron and zinc uptake from the three Arizona soils by these seven variety-rootstock combinations was made.

CHAPTER 2

LITERATURE REVIEW

Plant nutrition is the process of absorption and utilization of essential elements for plant growth and reproduction. Most of the plants are known to need at least 16 essential elements to growth. Plants absorb some elements in large amounts from soil and fertilizers and they are called macronutrients; also other elements are absorbed in lesser quantities and they are called micronutrients.

Macronutrients

Potassium is one of the macronutrients that is supplied as a component of common minerals, but it is not readily plant-available because these minerals are only slowly soluble (Donahue et al., 1983). Potassium has several important roles in plant nutrition associated with the quality of a product and increases the sugar content of fruits. It increases the thickness of the epidermal layer of cells, adding to insect and disease resistance and to the shipping and keeping qualities of thin-skinned fruits (Follet et al., 1981).

Calcium is a part of plant cell walls and is needed for cell division. Many calcium minerals are moderately soluble, and the calcium cation is adsorbed on exchange surfaces (Donahue et al., 1983). Calcium is necessary for cell elongation, protein synthesis, and normal cell division. It influences the uptake of water and other plant nutrients. Calcium regulates the traslocation of carbohydrates, regulates cell acidity and permeability (Follet et al., 1981).

Magnesium is a chlorophyll component, and exchangeable cation, and is supplied to plants mostly from exchangeable forms (Donahue et al., 1983). Chlorophyll contains about 2.7 percent magnesium as an essential constituent. About 10 percent of the magnesium in plants is found in the chloroplasts; therefore, the most important function of magnesium in plants is the formation of chlorophyll (Follet et al., 1981).

Micronutrients are essential plant food elements required in very small amounts for proper plant nutrition. Although required in very small amount, they are absolutely essential and play major roles in plant growth and development. Calcareous soils which contain sufficient metal carbonates, mostly as calcium carbonate, have a basic pH which reduces the solubility of micronutrients, especially iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) (Donahue et al., 1983). Arizona, which is becoming an important grape producer, has calcareous soils in different areas growing grapes; therefore, vineyards sometimes show micronutrient deficiencies of iron and zinc in soils with high lime content and pH.

Function of the Iron and Zinc in Plant Nutrition

Micronutrients are required for growth in low amounts and serve mainly as constituents of prosthetic groups in metaloproteins and as activators of enzyme reactions. As constituents of prosthetic groups, micronutrients catalyze redox processes by electron tranfer, they form enzyme-substrate complexes by coupling enzyme and subtrate, or they enhance enzyme reactions by influencing the molecular configuration of an enzyme or subtrate (Römheld and Marschner, 1991).

The roles of iron and zinc in grape metabolism have been deduced largely from observation of what happens when a particular element is withheld or restricted. Most of the deductions are evaluated by experimental evidence. Iron is indispensable in the synthesis of chlorophyll, even though it does not enter into the chlorophyll molecule. The form of iron in plant tissues often governs its influence in chlorophyll synthesis. Chlorosis from iron deficiency is sometimes found in leaves that contain as much iron as green leaves; the iron present is in an unavailable form. In such instances it has probably been precipitated and is stored in insoluble compounds. Some of the enzymes and carriers that function in the respiratory mechanism of living cells are iron compounds. Some of these are catalase, peroxidase, and cytochromes, which have important roles in cellular metabolism. Although zinc is essential for plants, it is not a part of the molecules of carbohydrates, proteins, or fats. It seems to have a function in the catalyzing of certain processes such as the system producing trytophane, which is a precursor of auxin. A deficiency of zinc results in a deficiency of auxin and a failure of the shoot to grow normally (Winkler et al., 1974).

Uptake of Micronutrients

The plant influences both diffusive and convective movements of nutrients to roots. The transpiration rate directly affects the rate of water movement and, hence, convection to roots, while its rate of nutrient absorption influences the concentration gradient near the root surface and, hence diffusion. Rates of nutrient absorption into plant roots in soils are governed both by the ionic enviroment of the root and the relation between the ionic enviroment and rate of absorption. Where these two parameters have been defined, they may be used in association with data for transpiration to calculate the relative importance of mass flow and diffusion in the movement of nutrients to roots (Wilkinson, 1972). The absorption zone of a root system for water and mineral nutrient uptake is located in the tip portion of the small rootlets, which keep growing into unexplored soil. Such rootlets may survive for the full season and eventually become branch roots with new rootlets emerging from them in the following year, or they may die during the current season (Amberg, 1983).

Zinc uptake is stongly affected by soil temperature. Soil zinc levels that are adequate in one season may be deficient the following year due to a to lower soil temperature regime and subsequent reduced root development during the cold period, or early parts of the growing season. Later these deficiency symptoms may diminish in intensity or disappear entirely (Hunter et al., 1981). Also Harter (1991) reports that micronutrient adsorption soil reactions are likely to be a major factor in the availability of zinc to plants. There are important types of soil surfaces that adsorb the micronutrient and determine the relative amounts retained under given conditions.

Roberts and Ahmedullah (1987) studied the effect of soil applied zinc as $ZnSO_4$ in Concord grapes. They found with a Diethylenetriaminepentaacetic acid (DTPA) foliar analysis that was relatively low, after that, one more year when no zinc was applied the test result remained nearly constant or decreased slightly. Wallace and Abou-Zamzam (1989) found that both Zn and Ca decreased Fe concentration in leaves in bush beans. It seems that very low concentrations of Fe in leaves with high Zn and Ca levels prevented Ca from protecting against the Zn toxicity at that level. Calcium tended to decrease Fe in roots, but Zn tended to increase it.

One aspect of micronutrient transport is the effect that the reactive nature of the micronutrient cations has on the transport of these species into and within plants. The micronutrient cations are potencially toxic species in biological systems, because of their tendency to react with organic ligands, and because some of the micronutrient cations can be involved in oxidation-reduction reactions that can produce harmful free radicals (Kochian, 1991).

Iron and Zinc Deficiencies in Plants

Certain soil types often develop micronutrient problems. Sands, mucks, and peats may often exhibit micronutrient deficiencies. Some geographic areas are naturally deficient in available micronutrients. Overliming, heavy macronutrient fertilization without considering micronutrient needs, land leveling, poor management practices, and intensive cropping over long periods of time are examples of problems caused by man (Cunningham, 1972). Physical factors such as high soil density or water saturated soil may produce a lack of oxygen and can reduce or stop rootlet growth. A high concentration of lime in the soil frequently causes deficiency symptoms of several elements, because the presence of lime may hamper the absorption of other elements. Iron deficiency is the most commonly visible symptom. Many of these problems may be solved by cultural practices. However the roots of several grape varieties are unable to overcome some of these soil problems. They are lacking sufficient tolerance to function under difficult conditions (Amberg, 1983).

A plant requires a continuous supply of Fe to maintain proper growth. Any factor that interferes with absorption, translocation, or metabolism of Fe may cause Fe chlorosis. Factors such as high pH of soil, and excesses of phosphate, bicarbonate, and Ca salts in the growth medium can interfere with Fe uptake. Excesses of Cu, Mn, Ni, and Zn also are known to induce Fe chlorosis. Once a causative factor in Fe chlorosis has become established in the soil, it may not always be easily removed (Brown et al., 1972). Although Fe is usually abundant in most soils, it is frequently deficient in pourly aereated soils (low in O_2) with a high clay content and particularity those containing a large amount of carbohydrates. Iron deficiency is evident by a chlorotic condition of leaves, usually refered to as "iron chlorosis". It is caused by excess of calcium, phosphorus, high soil moisture and poor air soil conditions, and humus deficiency in alkaline soils (Hollerith, 1982).

Interaction may be an influence, mutual or reciprocal action, of one element upon another in relation to plant growth, and the differential response to one element in combination with varying levels of a second element applied simultaneously; that is, the two elements combine to produce an added effect, or negative effect not due to one of them alone. For example, a yield response may be measured for applied P or Zn, but the sum of these individual responses may be significantly less than the response when both are applied (Olsen, 1972). Zinc is essential for proper development of the grape plant. A deficiency at bloom results in poor pollination; at harvest, in stem paralysis. In alkaline soils, zinc absorption is drastically reduced (Hollerith, 1982). Knox 1982 observed that a Minnesota vineyard experienced a number of nutrient deficiency problems on different grape varieties in different parts of the vineyard. He found a common relationship of zinc deficiency which has been associated with sandy soils and sites previously used for poultry or as corrals. Zinc deficiency has sometimes been found where there is a high level of phosphorous, especially on calcareous soils.

Iron and zinc deficiencies are most prevalent on calcareous soils; therefore, in the DTPA soil test, the extractant was designed specifically to avoid excessive dissolution of $CaCO_3$ with the release of occluded micronutrients, which are normally not available for absorption by roots (Lindsay and Norvell, 1978). Lehr (1972) reported that solubilty properties, rather than compositional form, appears to be the important factor among all these reaction compounds. The Fe compounds have characteristically low water solubilities, and some also are acid insoluble. Also a strong concern is the reaction of Zn with the P component of carrier fertilizers. These reactions of zinc are the same types of insoluble crystalline compounds. Yahya (1990) found that different grape varieties growing in acid soils with high Al, Fe and Mn resulted in higher accumulation of these elements in grape leaves whereas the uptake of nutrrients, especially Ca, Zn, and Cu were reduced. Field plants exhibiting P deficiency syptoms resulting from high Al and Fe had deficient levels of P, K, Ca and Zn.

The determination of the Fe status of the plants by assaying tissue for its Fe content is a highly questionable procedure. Tissue Fe concentration may or may not be realated to the appearance of Fe-deficiency symptoms. Frequently chlorotic plants have an equal or higher total Fe concentration in their leaves than nonchlorotic plants. In relationship with zinc, the critical concentration in mature leaves for many crops is around 15 mg kg-1 of Zn which is unique since, for other micronutrients, critical concentration varies considerably with species. Normally a zinc deficiency is likely when leaf or plant contents are less than 20 mg kg-1 (Jones, 1991). Micronutrient deficiencies are often corrected by application of micronutrient fertilizers to soil since recommended application rates are much lower for micronutrients than macronutrients fertilizers. Applying micronutrients with N-P-K fertilizers may result in problems due to chemical reactions between some components of the N-P-K fertilizers and the micronutrients sources (Mortvedt, 1991).

Soil applications of inorganic Fe sources are ineffective for controlling Fe chlorosis except at very high rates. These sources are either too insoluble to be effective at low to moderate application rates or they become unavailable because of insoluble reaction products formed in soils. Foliar spray applications of soluble Fe compounds can generally correct Fe chlorosis in plants, although repeated applications are necessary since traslocation of the absorbed Fe is not sufficient for new plant growth. Soil application of inorganic Zn as $ZnSO_4$ can be used to correct Zn deficiencies at lower rates when banded rather than broadcast applications are used. The greater efficiency of the banded $ZnSO_4$ is due to the lower amount of Zn-soil contact and, hence to slower reversion of the applied Zn to unavailable forms. Also, inorganic and organic Zn sources can be used to alleviate Zn deficiencies by spray application of Zn on plant foliage (Martens and Westermann, 1991).

Soil pH

Knowledge of the H^+ ion activity in soil solution for understanding the physical and chemical properties of soils and plant root enviroments is of great importance. Soil pH determination is important because it is an indication of many other soil characteristics such as acidity and alkalinity of the soil, form of cations held by soil colloids, nutrient availability, and chemical reactions between soil components and certain trace elements. Thus, soil pH is one of the most widely measured chemical property of a given soil. The pH of a solution has been defined as the negative logarithm of the effective hydrogen ion activity (Bohn et al., 1985).

Soil pH is one of the most important factors in nutrient availability because hydrogen ion concentration in soil solution affects the ionic forms of many elements. Soil pH can produce a substantial effect on plant growth and the quality of plant production. Also pH affects the soil media, this includes the uptake of inorganic mineral nutrients, and nutritional imbalances caused by antagonistic effects between chemical elements. Moreover, the rate and direction of chemical and biological processes ocurring in soil, mineralization of organic materials and dissolution of soil minerals are strongly dependent on soil pH (Bohn et al., 1985).

A pH value of soil can indicate something about percent base saturation and lime requirements. Also, a pH of a soil paste lower than 5.5 indicates significant amount of exchangeable Al and H and below 7.5 would indicate an absence of free alkaline earth carbonate. Similarly, very low pH, less than 4, will indicate the presence of free acids and excess soluble Al and Mn. Likewise, higher soil pH values from 7.8 to

8.5 will be an indication of free $CaCO_3$ content in such soils (McLean 1982). Cummings and Lilly (1984), in a study done with soil pH levels from 5 to 8, found in high pH soil, Ca and Mg concentrations were increased and also foliar concentrations of Mg increased whereas K, N and Mn decreased. Fruit size, soluble solids, and concentrations of P, Fe, Zn, Cu, and B in the foliage or fruits were not affected.

Islam et al. (1980), in a study of pH optima for crop growth, found that poor iron nutrition depressed the growth of maize and wheat at pH 8.5, despite the use of Fe-EDDHA as an iron source. This compound is reported to be stable over a pH range 4 to 8 but was not entirely satisfactory at higher pH.

<u>Soil Solution</u>

Soil solution is the medium from which plants absorb nutrients and it is the center of all soil chemical processes and where numerous chemical reactions occur. The soil, which is a dynamic system, changes constantly due to fluctuating temperatures, moisture relationships, and biological activity. The elemental concentrations in soil solution are in constant flux, influenced by a host of factors including moisture, pH, temperature, oxidation-reduction status, fertilizer additions, and plant uptake (Shuman, 1991). Nevertheless, solid phases provide ultimate control of the concentrations of their constituent ions in solution. By knowing which micronutrient elements are present in soils, and their thermodynamic properties and reaction rates, the solubility of micronutrients in soils can be better predicted. Equilibrium, in its true sense, is probably never attained in soils. In one soil a mineral may precipitate and be stable; in another it may be unstable and dissolve. Rapidly changing conditions often favor the formation of amorphous or poorly crystallized solids, with partial substitution of secondary ions (Lindsay, 1991).

Iron in soil solution can exist in a number of forms, depending on the pH of the system. Above pH 8, ferric iron (Fe^{+3}) is associated with hydroxyl ions to form the $Fe(OH)^{4-}$ species. The equilibrium between ferrous (Fe^{+2}) and ferric ions also involves relatively insoluble ferric hydroxide and is affected both by soil solution, pH and the partial pressures of oxygen in the soil atmosphere.

In relationship with zinc uptake by plants, this has been determined to be controlled primarily by diffusion to the roots in the soil solution. However, available zinc is not represented only by the zinc in the soil solution, because a significant amount of solubilized zinc is present in the soil and this supply of zinc readily replenishes that absorbed by plants from the soil solution (Hunter et al., 1981).

Welch and Lund (1989) in a study of Zn movement, found a close relationship between pH and depth of Zn. In this case using a sludge-amended soil layer pH was the dominant soil property controlling the movement of zinc. Shuman (1988a) found that increasing organic matter increased iron and zinc solubility. This result was expected, since organic matter would increase oxidation-reduction activity and metal solubility. Also, the organic matter, when broken down, would increase organic complexing of the metals thus enhancing their plant availability. The high organic matter in finer textured soils had the highest Zn adsorption capacities. Bart-tal et al. (1988) found the affinity of the Zn and fulvic acid complex to the clay is appreciably lower than that of ZnOH; hence, an addition of fulvic acid to a solution reduces Zn adsorption.

Singh et al. (1988) found no consistent correlations between soil properties and metals associated with carbonates and organic matter. This means that the distribution in the soil of trace metals among various chemical forms is not significant to changing soil properties.

Depending on the nature of the soil as well as the methods of application and rate, the reaction of acid fertilizers will vary when they are applied to soils (Jones, 1984). Acid addition to fluid formulations is a recent development in fertilizer technology that causes soils to become more acidic with time.

Water quality

The presence of high Ca and SO_4 concentrations in the irrigation water reduced gypsum solubility in soils containing a layer of gypsum. In the other hand, Mg and Cl in the irrigation water increase the solubility of gypsum. When Ca and SO_4 existed in the applied water, their concentrations remained high in the percolating solution and in the whole profile. Sodium and Mg ions were leached from the profile faster when Mg and Cl were present in the applied water. Soils containing a layer of gypsum improves the percolated water quality by lowering its Sodium Adsorption Ratio (SAR) (Arslan, 1990).

Alkaline irrigation waters used in arid and semiarid regions often contain high concentrations of Ca^{++} and bicarbonate (HCO_3^-). These ions can form calcite deposits, commonly known as lime, when waters are exposed to the atmosphere or to elevated temperatures. Precipitated lime often causes incrustation and plugging of irrigation systems, especially of water pumps and trickle irrigation emitters. Lime deposits can also cause plugging of tile drains (Stroehlein et al., 1978).

Metal Chelates as Fertilizers

Chelating agents are added to soils because they increase the solubility and mobility of metal cations, and frequently improve micronutrient metal availabilty to plants.

The effect of chelation is reduced by the adsorption of chelates species on solid phases, and by the decomposition of chelating ligands by microorganisms (Norvell, 1991). The use of Fe chelates to correct Fe chlorosis is not economically feasible for most field crops. Furthermore, the continued use of chelating agents may lead to additional soil problems not yet identified. Both the growth medium and the plant species must be considered as factors in the development of Fe chlorosis, as a potential problem on most calcareous soils. Thus, it seems desirable to taylor or select a plant to fit a soil, rather than change the soil to fit the plant, especially when we know that the adaptation is genetically controlled (Brown et al., 1972).

Plants under some degree of iron deficiency will usually take up more iron than iron-sufficient plants, but plant varieties differ in how they respond to an iron stress. It appears that each variety or species of plant has a particular iron stress at which the uptake of iron is at a maximum. Iron-deficient plants do not take up iron and the chelating agent from iron chelate in equivalent quantities. Although there has been some disagreement about the relative quantities of iron and chelating agents absorbed, it is now generally agreed that chlorotic plants preferentially take up iron from a solution of iron chelates. Nonchlorotic plants do not show this pronounced differential uptake and they take up less iron than chlorotic plants. When plant roots are not injured, both chlorotic and green soybean plants take up approximately 5 percent of the chelating agent in the nutrient solution. Differential uptake of iron and chelating agent by iron-deficient plants has been demonstrated by adding more iron to the nutrient solution after uptake has ocurred. The red color of FeEDDHA is evidence that the chelating agent remains functional in the nutrient solution (Brown, 1968).

Critical Levels of Nutritional Elements in Vineyards

Plant analyses has many aplications, one of them is to estimate critical nutrient levels in deficient, questionable, adequate, excess, and possible toxicity ranges. The relationship between nutrient concentration and yield of plant or product forms the basis of most schemes for using plant analysis to asses plant nutrient status. The forms of relationship are observed in a curve that comprises three parts; an ascending portion where yield increases with nutrient concentration, a level portion where yield is not limited by nutrient concentration, and descending portion in which yield declines with further increase in nutrient concentration (Reuter, 1986). Christensen (1972) reported for Fresno County, critical levels of essential nutritional elements in the tissue of important grape varieties established by personnel of the University of California and other research institutions (Table 1). Also, Christensen (1984) reported a study of nütrient level comparision of leaf petioles and blades in twenty six grape cultivars over three years, 1979 through 1981. This study shows that petioles at the bloom stage had an average K content of 1.55 percent and at véraison was 1.14; also in bloom for zinc was 25 mg kg-1, and in véraison was 30 mg kg-1.

Table 1. Critical levels of essential nutritional elements in the tissue (petioles) of grape varieties.*

Nutrient	Deficient	Questionable	Adequate
Potassium (%)	< 1.0	1.0 - 1.5	> 1.5
Magnesium (%)	< 0.2	0.2 - 0.3	> 0.3
Calcium (%)	< 1.2	1.2 - 2.5	> 2.5
Sodium (%)	Possible problem over 0.5		
Manganese(mg kg-1)	< 20	20 - 25	> 25
Iron (mg kg-1)	Range from 70 to 200		
Zinc (mg kg-1)	< 15	15 - 26	> 26
Copper (mg kg-1)	< 3	3 - 6	> 6

*Data from Kearney Agricultural Center U.C Davis. Christensen (1972)

Rootstocks and Variety Effect on Micronutrient Uptake

During the present time with increasing economic presures on grape production, some growers ask: can the use of tolerant rootstocks increase the economy of my vineyard operation? It is common knowledge that Vitis vinifera varieties need to be grafted (Amberg, 1983). There is an increasing need for new rootstocks as more of the old vineyard sites are replanted. The grower should be able to identify rootstocks and recognize the relative characteristics of the different varieties.

The effect of high lime content on nontolerant species is to cause lime chlorosis. The high pH reduces the availability of iron to the vine, resulting in iron deficiency symptoms. Early efforts, recognizing that Vitis vinifera was lime tolerant, were made by crossing riparia with vinifera; the results were not superior in phylloxera resistance, either the vinifera predominated and phylloxera resistance was inadequate or the American species predominated and the lime tolerance was inadequate. The rootstocks with the greatest lime tolerance are 41 B and 333EM: each is the result of berlanderi x vinifera cross and each tolerates up to 40 percent active lime in the soil (Howell, 1987). Also, Howell (1989) reported that rootstocks 5BB and Dog Ridge were moderately tolerant to the lime content and 41B was highly tolerant to lime content.

Arbabzadeh and Dutt (1987), studying salt tolerance of grape rootstocks, found that Salt Creek, 5BB, 1613 and SO4 were more salt tolerant than others. Rootstock 41B was more sensitive to salinity and showed the highest growth reduction.

Characteristics of variety and Rootstocks

CABERNET SAUVIGNON is a variety of the Bordeaux region which is responsible for the great wines of the Medoc. The wine is highly colored, very tannic, has characteristic "violet" bouquet, and unless blended with other varieties, usually requires a long period of aging. It is a vigorus variety, but small producer. Budbreak is very late, an advantage against spring frost. Maturity is late midseason and the teeth of the leaves turn red in fall. While it is very suceptible to powdery mildew and phomosis, it has some resistant to botrytis. The principal rootstocks used for Cabernet Sauvignon are SO4, 420A, and Riparia Gloire, followed by 44-53M, 5BB, 3309, 99R, and Rupestris St. George (Galet, 1979).

DOG RIDGE. Munson found this variety in Bell County, Texas, in the Dog Ridge mountains. It is a natural hybrid of rupestris-candicans; this and similar hybrid vines were grouped together by Planchon as "V. Champini", but they are not a distinct species. Since it is only moderately resistant to phyloxera and lime and very difficult to root, Dog Ridge has never been of commercial importance in France. Its good resistance to nematodes has been useful in California in light, sandy irrigated soils, and it can also be a useful rootstock in its native Texas. Dog Ridge is a very vigorous variety (Galet, 1979), imparting great vigor to its scions. It is resistant to nematodes and moderately resistant to phylloxera. Because of its high vigor, scions frequently show symptoms of zinc deficiency. Dogridge is only recomended for use in lighter, less fertile sandy soils (Kasimatiis and Lider, 1972).

Perry and Escamilla 1985 reported that Dogridge was one of the rootstocks that had proven to be fairly tolerant to root rot (Phymatothrichum omnivorum), also tolerant to calcareous soils. Also they suggest that excess vigor of the scion induced by Dog Ridge will become a challenge to the viticulturist. The vineyard manager will need to be careful when applying water, fertilizer, and possibly growth regulators, and to prune for balanced growth.

41 B MILLARDET ET DE GRASSET. Obtained by Professor Millardet in 1882 at Bordeaux, 41 B was first tested on the property of Marquis de Grasset at Pezenas. A short vegetative cycle and exceptionally high resistant to lime are the chief characteristic of this variety. It is used almost exclusively in the chalky Cognac and Champagne regions although it is also

used in southern France to hasten the ripening of table grapes. 41 B has slow initial development, but the mature vines are characterized by good fruit set and yield. Its resistance to phylloxera is sufficient, but not absolute. It has excelent resistance to lime at levels as high as 40 percent soil content, although during a wet season this resistance is lower. It is not resistance to salt, and the foliage must be protected against downy mildew. 41 B does not root well, between 15 and 40 percent depending on the health of the wood. Slow or difficult rooting reduces the success of bench grafting. Field grafting results, however, are good (Galet, 1979).

5 BB SELECTION KOBER. In 1886, a French nurseryman, Reséguier, sent 10 kilograms of "Berlandieri" seeds to Sigmund Teleki in Hungary who planted 40,000 of them. In 1904, Teleki sent some of the most interesting plants to an Austrian viticulture inspector Franz Kober who studied them and made a further selection. One variety he called the 5 BB. This vigorous rootstock had a shorter vegetative cycle than 420 A or 161-49 C, which means that the mother vines can be grown successfully in cooler climates. It produces a great amount of wood for propagation. The 5BB is suited to humid, clay soils and is not recommended in extreme dry situations. It tolerates up to 20 percent active lime and has a good resistance to nematodes. While this variety roots well, it can prevent some

problems in grafting, especially field grafting where there is an unusually high incidence of scion rooting and subsequent death of the rootstock. (Galet, 1979).

Green-Wood Grafting

Green-wood grafting of grapes consists of uniting by a splice graft, the green-wood scion and the green wood growth of one year old rootstock. The splice graft ranges in length from about 2 to 4 cm and generally is made without a tongue. The name implies grafting an herbaceous scion on an herbaceous rootstock shoot during the active growing season (Harmon, 1948). Also a modified procedure was reported by Harmon in 1955; the green-wood grafting consisted of placing the green-wood scion on the 1-year old wood of the rootstock cuttings midseason of the first, or root-forming year. Rootstock cuttings planted in nursery rows in the spring and grafted by this modified green-graft procedure, after rootstock cutting are well rooted, have produced grafted vines in one season suitable for field planting.

CHAPTER 3

MATERIALS AND METHODS

This is a greenhouse study designed to evaluate foliage growth, nutritional response, and micronutrient uptake of a grape variety and three commonly used rootstocks. A direct planted Cabernet savignon grape variety, three direct planted grape 41-B, 5-BB, and Dogridge rootstocks, and the Cabernet savignon variety grafted on the three rootstocks were grown on three different soils collected from grape producing areas in Tucson, Sonoita, and Maricopa, Arizona.

Grape plant propagation

Grape cuttings, 41-B, 5-BB, and Dogridge rootstocks and a Cabernet savignon variety, were collected from the Vina Sonoita vineyard located SW of Elgin Arizona, in February 1988. Cuttings were placed in wet sand during 30 days to promote callous in the dormant buds, using greenhouse conditions that always had warmer temperatures and higher relative humidity than the natural enviroment. In March 1988, one group of the rootstock cuttings were bench grafted with the Cabernet savignon variety and grown in one liter wax paper milk cartons filled with a mixture of equal ratios of silica sand, peat moss, and perlite. Groups of Cabernet savignon and rootstocks were also planted. Each individual vine was placed in a box and they were irrigated with tap water using a sprinkler system unit on the greenhouse bench. The vines were checked daily and left to grow; however, most of the scions of the grafted materials did not grow very well but the cutting rootstocks and the variety began rooting early in April.

In March 1989, the new growing bud rootstocks were grafted using the green wood grafting method (Harmon 1955) in which it is necessary to use controlled enviromental conditions of temperature and high relative humidity. Using this grafting method scions were successfully grown with almost a 90 percent survival. At the same time, the new vines and grafted vines were planted in 10 cm diameter and 90 cm long P.V.C. columns that were filled with the three collected soils. During the 1989 season, that was aproximately from March to September, the vines grew well but they did not produce enough leaves to get sufficient quantities of samples for tissue analysis.

Soil Chemical Analysis

Soil samples collected from the surface 0 to 60 cm layer from Sonoita, Tucson, and the Maricopa Agricultural Center were air dried, ground and passed through a 2 mm sieve. These soil samples were analyzed for $CaCO_3$, pH, K, Ca, Mg, Na, Fe, Cu, Zn, and Mn content (Table 2). The pH and electric conductivity were measured in the saturated paste; Mn, Fe, Zn and Cu were extracted with DTPA and atomic absorption spectrophotometric determination (Lindsay an Norvell 1978).

In this extraction, chelates reduce the activity of free metals ions in solution through the formation of soluble metal-chelates complexes. Replenishment of free ion concentration in the soil solution from solid phases occurs in response to this complexation. The quantity of micronutrient extracted by a chelate reflects both the initial concentration in the soil solution and the ability of the soil to maintain this concentration (Viets and Lindsay, 1973). The Ca and Mg were determined by atomic absorption spectrophotometry and K and Na were determined by flame emission spectroscopy (Page, 1982).

Soil clasification

The Mohall soil was collected east of Tucson near freeway I-10 and Wilmont Road is clasified as fine-loamy, mixed, hyperthermic, Typic Haplargid. The Sonoita soil was collected from Sonoita vineyards near Elgin the serie is clasified as coarse-loamy, mixed, thermic, Typic Haplargid. The Casa Grande soil was collected from the Maricopa Agricultural Center and is clasified as fine-loamy, mixed, hyperthermic, Typic Natrargid, reclaimed.

Greenhouse experiments

The P.V.C. columns were filled and packed uniformly with mixed, ground, and sieved soils, in order to avoid soil variation and heterogeneity. One liter of fine quartz sand forming a small layer was used in the botton of each P.V.C. column to get good water drainage and to keep the soils free of soluble salts; also 15 cm of free space was left in the top of the colums to maintain some volume for irrigation water. Tap water of good quality with SAR 1.75 and EC of 0.43 (Table 3) was used for irrigation and columns were irrigated every day.

During March, one day of each week, five liters of nitrogen solution (200 N mg kg-1) was applied in the irrigation water to mantain the vines growing and provide foliage growth.

Temperature and humidity were fairly constant (18 to 28^{0}C, and 30 to 60 percent of relative humidity) in the greenhouse which was cooled by evaporative cooler in summer (Appendix I).

<u>Plant Tissue Chemical Analysis</u>

During the 1990 season, vines grew very well and every plant looked healthy with no chlorosis, necrosis or other foliar damage. Plant petiole samples, that were collected in September from the vines, were oven dried at 65 ^{0}C and ground in a Wiley mill to pass a 40-mesh screen (Page, 1982). Wet ashing was used to digest the petioles utilizing nitric acid, sulfuric acid, and perchloric acid. To control the reaction intensity and to eliminate a possible explosion, the plant material is pretreated with nitric acid (Greweling, 1976).

Calcium, Mg, Mn, Fe, Cu and Zn were determined by atomic absorption spectrophotometry. Potasssium and Na were determined by flame emission spectroscopy.

Sampling and Variables Measured

Soils and greenhouse water were analyzed prior to installing the P.V.C. column experiments to obtain the nutritional content and the water quality data. Shoot length of leaves were measured from all plots in September 1990 for all vines; at the same time, petiole samples were collected for nutrient composition and micronutrient analysis, to obtain the nutritional response for each treatment.

A randomized complete block design was used in each soil experiment with seven treatments, Cabernet savignon variety, 41-B, 5-BB, Dogridge, Cabernet savignon grafted to 41-B, Cabernet savignon grafted to 5-BB, and Cabernet savignon grafted to Dogridge with four replications of each treatment. Analysis of variance was conducted for all treatments for which data were available. A combined analysis of variance (ANOVA) and the Duncan test for the three soil experiments were used. Least Significant Difference (LSD) at 5 percent level was used for all comparisions (shoot lengths, individual cations, sum of cations, and micronutrients) to determine significant difference between treatments.

CHAPTER 4

RESULTS AND DISSCUSION

The main objective of this study was to find a grape variety and appropiate rootstocks for nutrient uptake from three calcareous soils, collected from three agricultural areas in Arizona. One important parameter for this study is to measure the foliar content of each element and the foliar growth related to soil properties.

Growth parameter measurement depends on the use that is to be made of the plant analysis data. Plant yield is the parameter most commonly used to measure nutrient uptake, but it is not the most appropiate measure for many purposes. One important measure of plant nutrient uptake is the sum of absorbed cations from a given soil.

Soils

The chemical properties of the soils show some similar properties (Table 2). However, in relationship with calcium carbonate, electric conductivity and pH, Mohall soil that contained 21 percent of calcium carbonate and high electric conductivity of 7.4 dSm-1 indicates very high amount of calcium carbonate and a pH of 8, in comparision with the other soils that have pH 8.1 with very low calcium carbonate percent that seems inconsistent, because higher pH values from 7.8 to 8.5 indicate high calcium carbonate content (McLean,

Table 2. Physical and chemical properties of the soils used in the grape variety and rootstocks evaluations.

Soil parameters	MOHALL	SONOITA	CASA GRANDE
Clay (%)	17	18	8
Silt (%)	29	14	35
Sand (%)	54	68	57
Texture	Sandy clay loam	Sandy loam	Sandy loam
Organic matter (%)	0.91	0.15	0.17
Calcium Carbonate (%)	21	6	6
pH (saturated paste)	8.0	8.1	8.1
EC (dSm-1)	7.4	2.8	2.2
<u>Exchangeable cations</u>			
Ca (meq/100 g soil)	18.8	14	16.9
Mg (meq/100 g soil)	1.1	0.7	2.7
Na (meq/100 g soil)	1.9	1.4	1.3
K (meq/100 g soil)	1.2	1.8	1.6
ESP *	8.3	7.8	5.7
<u>DTPA Extractable</u>			
Fe (mg kg-1)	3.8	3.1	6.0
Cu (mg kg-1)	0.42	0.74	0.37
Zn (mg kg-1)	0.11	0.36	0.12
Mn (mg kg-1)	23	14.7	23

* Exchangeable Sodium Percent

1982). In relationship with exchangeable sodium percentage (ESP), Mohall soil has the highest ESP with 8.3 followed by Sonoita with 7.8 and Casa Grande with 5.7.

The three soils have low clay and organic matter content, also the three soils have high amount of sand that benefits water permeability; therefore the cation exchange capacity (CEC) is low. This suggests that the nutrient uptake would tend to be low, however in this study some rootstocks had good nutrient uptake with these conditions.

The greenhouse water that was used in the studies was of good quality for agricultural use with Sodium Absorption Ratio (SAR) of 1.75, electrical conductivity of 0.46 dS.m-1, 151 mg L^{-1} of bicarbonates and pH of 7.6 which will not cause calcium carbonate precipitation (Table 3). This water does not have any restriction on agricultural use according water quality guidelines (Ayers and Westcot, 1976).

Table 3. Chemical analysis of greenhouse water used in the grape variety and rootstocks evaluations.

pH	7.6
EC x 10^3 (dSm-1)	0.46
Ca (mg/l)	43
Mg (mg/l)	3
Na (mg/l)	44
K (mg/l)	12
Cl (mg/l)	42
SO4 (mg/l)	38
CO3 (mg/l)	0
HCO3 (mg/l)	151
SAR *	1.75

* Sodium Adsorption Ratio

Rootstocks

An important factor in the growth of grafted grape plants is the genetic compatibility between the rootstock and scion and for this study lime tolerance.

Cabernet savignon variety was used as scion that is vigorous variety, but small producer. The three rootstocks used with Cabernet savignon scions were 5 BB, Dogridge, and 41 B. Of all the rootstocks used with Cabernet savignon, 5 BB is most common and tolerates up 20 percent active lime (Galet, 1979), Dogridge is very vigorous and is recomended for use in less fertil sandy soils (Kasimatis and Lider, 1972). 41 B has excellent resistance up to 40 percent soil lime content (Galet, 1979).

In these evaluations, all grafted vines grew very well and no one showed any foliar damage related to lime and to the union between rootstocks and scions.

Grapevine Shoot Growth

The effect of variety and rootstocks on plant growth is given in Table 4. Shoot growth is mainly influenced by balanced elements like nitrogen, potassium, and zinc (Donahue et al., 1983). In this evaluation, nitrogen was applied at the same rate in every plot; however, potassium and zinc were not applied and grapevines translocated them from the soil potassium and zinc content. Sonoita soil shows higher potassium and zinc content with 1.8 and 0.36 meq/ 100 g soil

Table 4. Grapevine shoot growth for variety and rootstocks grown in three Arizona soils.

Variety and rootstocks	SOILS MOHALL	SONOITA	CASA GRANDE	Treatment Means
	cm			
Cabernet savignon	85 e*	59 d	106 c	83.3
41-B	156 b	94 c	102 c	117.3
5-BB	190 a	134 b	125 a	149.6
Dogridge	110 c	160 a	54 d	108.0
Cab.sav./41-B	51 g	99 c	54 d	68.0
Cab.sav./5-BB	89 d	96 c	111 b	98.6
Cab.Sav./Dogridge	77 g	61 d	47 e	61.6
Soil Means	108.3	100.4	85.6	

*Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

respectively than Mohall and Casa Grande soils with 1.2 and 1.6 meq/ 100 g soil of potassium and 0.11 and 0.12 meq /100 g soil of zinc, respectively (Table 2). This indicated that grapevines could produce better shoot growth in Sonoita soil than Mohall and Casa Grande soils; however, Mohall soil had shoot growth means of 108.3 cm (Table 4) that was bigger than Sonoita and Casa Grande soils with 100.4 and 85.6 cm of shoot growth means, respectively. This suggest that other elements may have some influence in the shoot growth that interact with potassium and zinc uptake.

Shoot growth was statistically different between treatments in every soil; therefore, in Mohall and Casa Grande soils, 5 BB had the highest shooth growth in comparision with the rest of the treatments, and in Sonoita soil, Dogridge had the highest shoot growth in relation with the other treatments.

In relationship with the treatment means of the three soils, the roostocks 41 B, 5 BB, and Dogridge showed (Table 4) bigger shoot growth means with 117.3, 149.6, and 108.0 cm, respectively, than the rest of the treatments. The 5 BB rootstock had the highest shooth growth means of the seven treatments with 149.6 cm. Mohall soil had the highest shoot growth means with 108.3 cm of the three soils.

Potassium

Potassium is found in most soils as a component of various rocks and minerals and it is mostly found in unavailable forms (Follet et al., 1981). Arizona soils are usually calcareous soils with high pH, low precipitation and organic matter; and according to this study, the three Arizona soils Mohall, Sonoita, and Casa Grande show the same characteristics with low exchangeable potassium content with 1.2, 1.8 and 1.6 meq/100 g soil respectively (Table 2).

Plants usually contain from 1 to 2 percent of foliar potassium; according to data from Kearney Agricultural Center of University of California Davis, less than 1 percent is deficient, 1.0 to 1.5 percent is questionable and more than 1.5 percent is adequate for grape petioles (Table 1., Christensen, 1972).

In this study, no treatment had less than 1.0 percent of foliar potassium (Table 5). In Mohall soil, Cabernet savignon grafted to 5 BB had a significant difference of potassium content with 2.95 percent, in comparision with other treatments. Cabernet savignon grafted to 41 B was the highest in Sonoita soil with 3.33 percent of foliar potassium. In Casa Grande soil, Cabernet savignon grafted to 5 BB, and grafted to Dogridge had the highest potassium content, each one with 2.8 percent.

Table 5. Potassium content of a variety, rootstocks, and grafted materials in the three Arizona soils.

Variety and rootstocks	SOILS MOHALL	SONOITA	CASA GRANDE	Treatment Means
	%			
Cabernet Savignon	2.66 c*	2.89 b	2.50 bc	2.68
41-B	1.34 f	2.08 f	1.80 d	1.74
5-BB	1.84 d	2.46 e	2.44 c	2.25
Dogridge	1.76 e	2.60 d	2.55 bc	2.30
Cab.Sav./41-B	2.67 c	3.33 a	2.70 ab	2.90
Cab.Sav./5-BB	2.95 a	2.74 c	2.80 a	2.83
Cab.Sav./Dogridge	2.88 b	2.97 c	2.80 a	2.88
Soil Means	2.30	2.72	2.51	

*Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

One of the objectives in this study is to understand about the relationship of nutritional uptake for rootstocks, and grafted plants in comparision with nongrafted varieties. Actually, most of the comercial vineyards use grafted plants for many purposes; therefore, the idea is to increase soil disease resistance and to increase elemental uptake for the scions. In Table 5, potassium content for grafted plants, cabernet savignon grafted to 41 B, to 5 BB, and to Dogridge show bigger treatment means with 2.90, 2.83, and 2.88 percent, respectively, than the rest of the treatments. In Figure 1, the last three treatments are grafted plants, and they have a higher potassium content than the rest of the treatments.

In the other hand, Sonoita soil had the highest soil means of the three evaluated soils with 2.72 percent of foliar potassium (Table 5); this confirms in average that Sonoita soil contained more potassium content in the soil as is showed in Table 2.

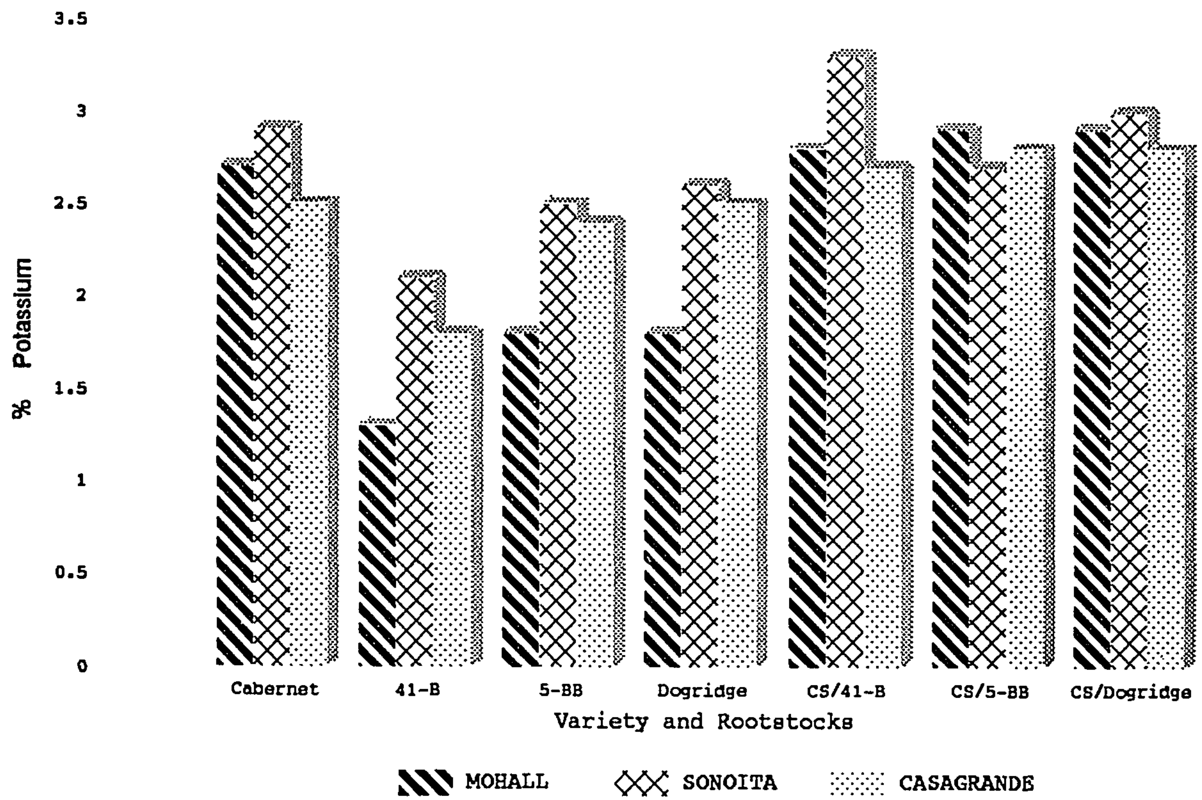

Figure 1. Potassium content of grapevines grown in Arizona soils.

<u>Calcium</u>

Calcium tends to make cells more selective in their absorption of nutrients; it is a constituent of the middle lamella of each cell wall. Rapidly growing root tips are especially high in calcium, indicating that calcium is needed in large quantities for cell division (Donahue et al., 1983)

Calcium is supplied to the plant from the exchangeable form and from moderately soluble minerals; in this study, Mohall, Sonoita, and Casa Grande soils show 18.8, 14.0, and 16.9 meq/100 g soil of exchangeable calcium; and 21, 6, and 6 percent of calcium carbonate respectively (Table 2). In relationship with foliar calcium content, California reports that tissue petioles calcium content of grape varieties, 1.2 percent is deficient, from 1.2 to 2.5 percent is questionable, and over 2.5 percent is adequate (Table 1., Christensen, 1972). In this study, no grapevine had more than 1.2 percent of calcium content in petioles; therefore, every plant had a deficient calcium level.

Calcium data are given in Table 6. Cabernet savignon had significant difference with 0.81 percent in Mohall soil; Cabernet savignon grafted to 41 B was the highest with 0.84 percent in Sonoita soil, and with 0.80 in Casa Grande soil. In soil means, Sonoita was the highest with 0.56 percent; and in treatment means Cabernet savignon grafted to 41 B was the highest with 0.81 percent.

Table 6. Calcium content of a variety, rootstocks, and grafted materials in the three Arizona soils.

Variety and rootstocks	SOILS MOHALL	SONOITA	CASA GRANDE	Treatment Means
	------------ % ------------			
Cabernet Savignon	0.81 a*	0.58 d	0.30 e	0.56
41-B	0.49 d	0.21 g	0.46 d	0.39
5-BB	0.34 f	0.66 c	0.49 c	0.50
Dogridge	0.46 e	0.74 b	0.23 f	0.48
Cab.Sav./41-B	0.78 b	0.84 a	0.80 a	0.81
Cab.Sav./5-BB	0.26 c	0.40 f	0.60 b	0.42
Cab.Sav./Dogridge	0.67 c	0.53 e	0.50 c	0.57
Soil Means	0.54	0.56	0.48	

*Means not followed by the same letter are ststistically different at the 5 % level of significance according to the LSD procedure.

Growing grapevines in calcareous soils with high pH, low precipitation, and low organic matter, calcium tends to form calcium carbonate and to maintain low soluble calcium in soil solution. This evaluation included two lime tolerant rootstocks, 5 BB and 41 B; 41 B was reported to grow in soils with 40 percent of lime (Galet, 1979); consequently, Cabernet savignon grafted to 41 B shows the highest calcium uptake (Table 6). Also, Cabernet savignon grafted to 41 B showed the best calcium uptake according Figure 2, in which the three evaluated soils are high in comparision with the rest of the treatments.

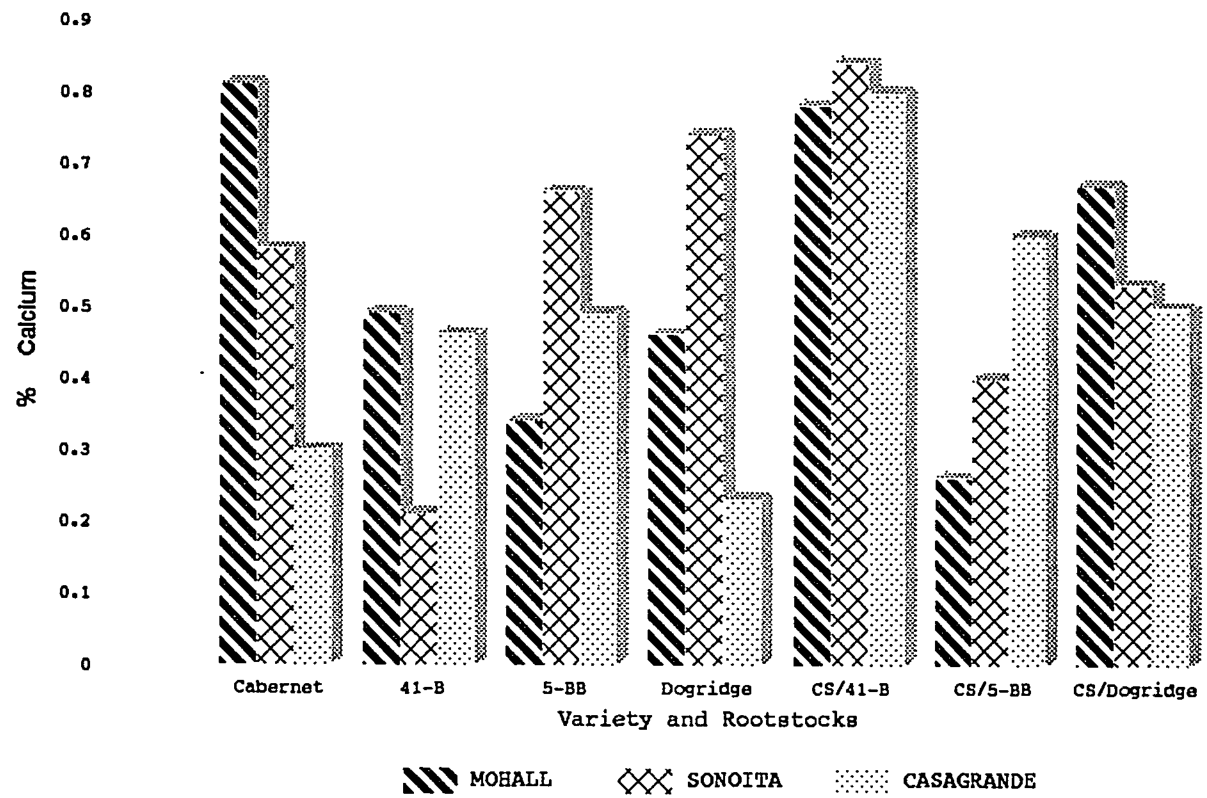

Figure 2. Calcium content of grapevines grown in Arizona soils.

<u>Magnesium</u>

Soils have many mineral sources of magnesium that may supply important quantities; however, exchangeable and soluble magnesium are the major sources for plants (Donahue et al, 1983). In this study, Mohall, Sonoita, and Casa Grande soils contain 1.1, 0.7, and 2.7 meq/100 g soil of magnesium, respectively (Table 2). The magnesium foliar content in grape petioles for deficiency is less than 0.2 percent, and from 0.2 to 0.3 as questionable, and more than 0.3 percent as adequate according California (Table 1, Christensen, 1972).

In this evaluation, Cabernet savignon treatment was highly significant in magnesium content in the three soils with 0.24 percent in Mohall soil, 0.23 percent in Sonoita soil, and 0.29 in Casa Grande soil in comparision with the rest of the treatments (Figure 3). In relationship with soil means, Casa Grande soil had the highest magnesium content with 0.20 percent. Cabernet savignon had the highest treatment means with 0.25 percent (Table 7).

Table 7. Magnesium content of a variety, rootstocks, and grafted materials in the three Arizona soils.

Variety and rootstocks	----------SOILS------------ MOHALL	SONOITA	CASA GRANDE	Treatment Means
	----------	%	------------	
Cabernet Savignon	0.24 a*	0.23 a	0.29 a	0.25
41-B	0.10 e	0.11 b	0.16 d	0.12
5-BB	0.15 cd	0.14 b	0.24 b	0.18
Dogridge	0.16 c	0.17 b	0.22 b	0.18
Cab.Sav./41-B	0.19 b	0.18 b	0.19 c	0.19
Cab.Sav./5-BB	0.16 c	0.15 b	0.16 d	0.15
Cab.Sav./Dogridge	0.14 d	0.13 b	0.14 d	0.14
Soil Means	0.16	0.16	0.20	

*Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

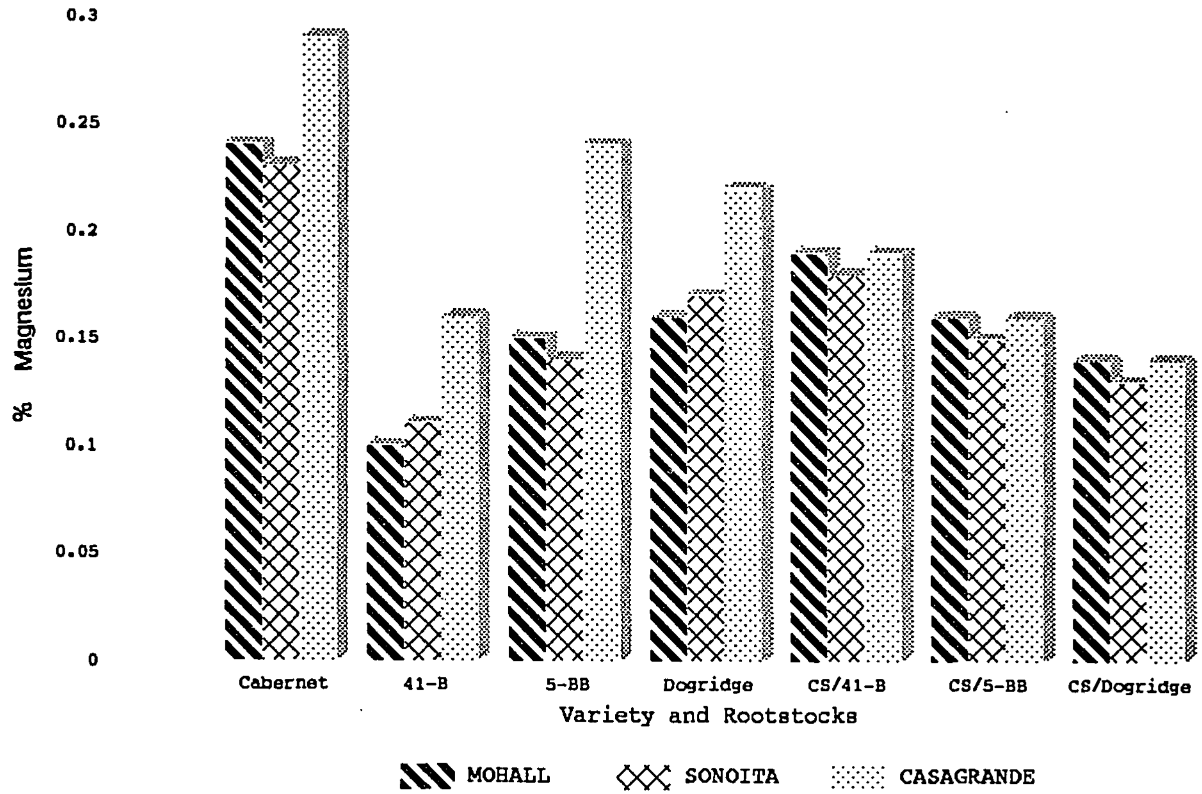

Figure 3. Magnesium content of grapevines grown in Arizona soils.

Sodium

The elemental content of sodium is measured with the minimum and maximum uptake as good genetic characteristic to get significative differences in the evaluated materials; therefore, the sodium content is sometimes related to interaction of the cation balance. The foliar amount of sodium percent in petiole grape varieties may be a problem over 0.5 (Christensen, 1972).

In this evaluation Cabernet savignon and Cabernet savignon grafted on Dogridge were the lowest in sodium content with 0.10 and 0.11 percent in Mohall soil respectively.

41 B, Dogridge, and Cabernet savignon grafted to 5 BB, and grafted to Dogridge were highly significant with the lowest sodium content in Sonoita soil. 5 BB had the lowest sodium content in Casa Grande soil (Table 8).

All treatments had lower sodium content (Figure 4) than the minimum critical level of 0.5 percent that is reported by California with possible problem (Table 1).

In soil means, Sonoita had lower soil sodium content with 0.07 than the rest of the soils. Cabernet savignon grafted to Dogridge had the lower content of sodium with 0.08 percent than the other treatments in the treatment means (Table 8).

Table 8. Sodium content of variety, rootstocks, and grafted materials in the three Arizona soils

Variety and rootstocks	SOILS MOHALL	SONOITA	GRANDE	Treatment Means
	%			
Cabernet savignon	0.10 a*	0.21 d	0.12 e	0.14
41-B	0.18 b	0.01 a	0.09 bc	0.09
5-BB	0.16 b	0.14 c	0.03 a	0.11
Dogridge	0.17 b	0.03 a	0.17 f	0.12
Cab.sav/41-B	0.29 c	0.08 b	0.08 b	0.15
Cab.Sav./5-BB	0.36 d	0.02 a	0.10 cd	0.16
Cab.Sav./Dogridge	0.11 a	0.03 a	0.11 d	0.08
Soil Means	0.19	0.07	0.10	

*Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

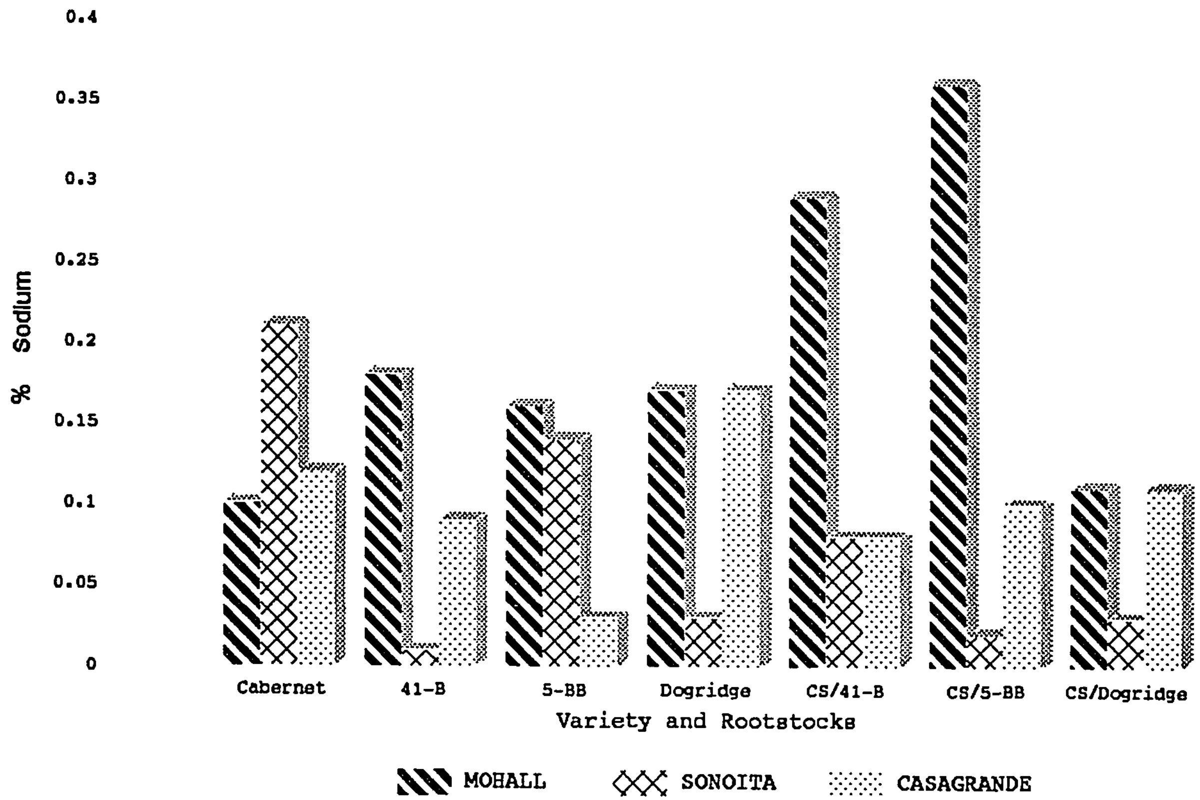

Figure 4. Sodium content of grapevines grown in Arizona soils.

<u>Cation Balance</u>

One important parameter to measure the nutritional uptake for evaluating differences in varieties and rootstocks is cation balance (absorbed cations). In this study, cation balance was the sum of the plant cations such as potassium, calcium, magnesium, and sodium from every soil; also, there were obtained the soil means and treatment means from the evaluated materials and the three Arizona soils (Table 9).

No significative difference in cation balance was found between treatments in Mohall and Casa Grande soils. In Sonoita soil, only 41-B was the lowest one with significative difference in cation balance (Table 9).

Sonoita soil provided the highest cation uptake with means of the three soils with 114.6 meq/100 g.

Plant roots have direct influence in the elemental concentrations in soil solution; therefore, roostocks have usually more biological activities than direct varieties that are used as rooting plants (Shuman, 1991). Then, Cabernet savignon to 41 B, 5 BB, and Dogridge had more cation uptake in the treatment means with 136.8, 113.5, and 117.3 meq/100 g than nongrafted materials (Table 9); consequently, the total treatments average shows in this study that rootstocks influence the cation uptake.

Table 9. Absorbed cations in grapevines grown in the three Arizona soils.

Variety and rootstocks	MOHALL	SONOITA	CASA GRANDE	Treatment Means
	--- meq / 100 g dry tissue --			
Cabernet Savignon	112.8 a*	131.4 a	108.5 a	117.5
41-B	75.2 a	73.4 b	86.4 a	78.3
5-BB	83.6 a	113.9 ab	114.4 a	104.0
Dogridge	88.8 a	119.2 ab	102.6 a	103.5
Cab.Sav./41-B	135.9 a	145.9 a	128.5 a	136.8
Cab.Sav./5-BB	117.5 a	103.7 ab	119.4 a	113.5
Cab.Sav./Dogridge	123.8 a	114.8 ab	113.3 a	117.3
Soil Means	105.4	114.6	110.4	

(MOHALL, SONOITA and CASA GRANDE are headed "soils".)

*Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

Manganese

Manganese is least soluble in basic soils, also calcareous soils precipitate insoluble managanese dioxide (Donahue et al., 1983). The soils in this study are calcareous and the foliar grapevine data obtained do not observe any deficient level according grape variety levels in California with less than 20 mg kg-1 in petioles (Christensen, 1972).

Cabernet savignon had the highest manganese content with 89 mg kg-1 in Mohall soil, Dogridge had the highest manganese content with 94 mg kg-1 in Sonoita soil, and Cabernet savignon grafted to 5 BB had the highest manganese content with 60 mg kg-1 in Casa Grande soil (Table 10).

In relationship with soil means Mohall soil had the highest manganese content with 56 mg kg-1; and in treatment means Cabernet savignon had the highest manganese content with 65.6 mg kg-1 (Table 10). In manganese content, there is observed that the three types of evaluated materials had similar manganese content such as Cabernet savignon, Dogridge, and Cabernet savignon grafted to 5 BB, with 65.6, 60.6, and 63.0 mg kg-1. They were the three highest manganese contents in the treatments indicating that in this study no problem was observed with manganese (Figure 5).

Table 10. Manganese content of a variety, rootstocks, and grafted materials in the three Arizona soils.

Variety and rootstocks	MOHALL	SONOITA	CASA GRANDE	Treatment Means
	-------- SOILS	----------		
	------- mg kg-1	--------		
Cabernet Savignon	89 a*	60 b	48 b	65.6
41-B	49 d	31 e	26 e	35.3
5-BB	45 e	16 f	35 d	32.0
Dogridge	64 c	94 a	24 e	60.6
Cab.Sav./41-B	21 f	59 b	50 b	43.3
Cab.Sav./5-BB	82 b	47 c	60 a	63.0
Cab.Sav./Dogridge	42 e	38 d	40 c	40.0
Soil Means	56.0	49.3	40.4	

* Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

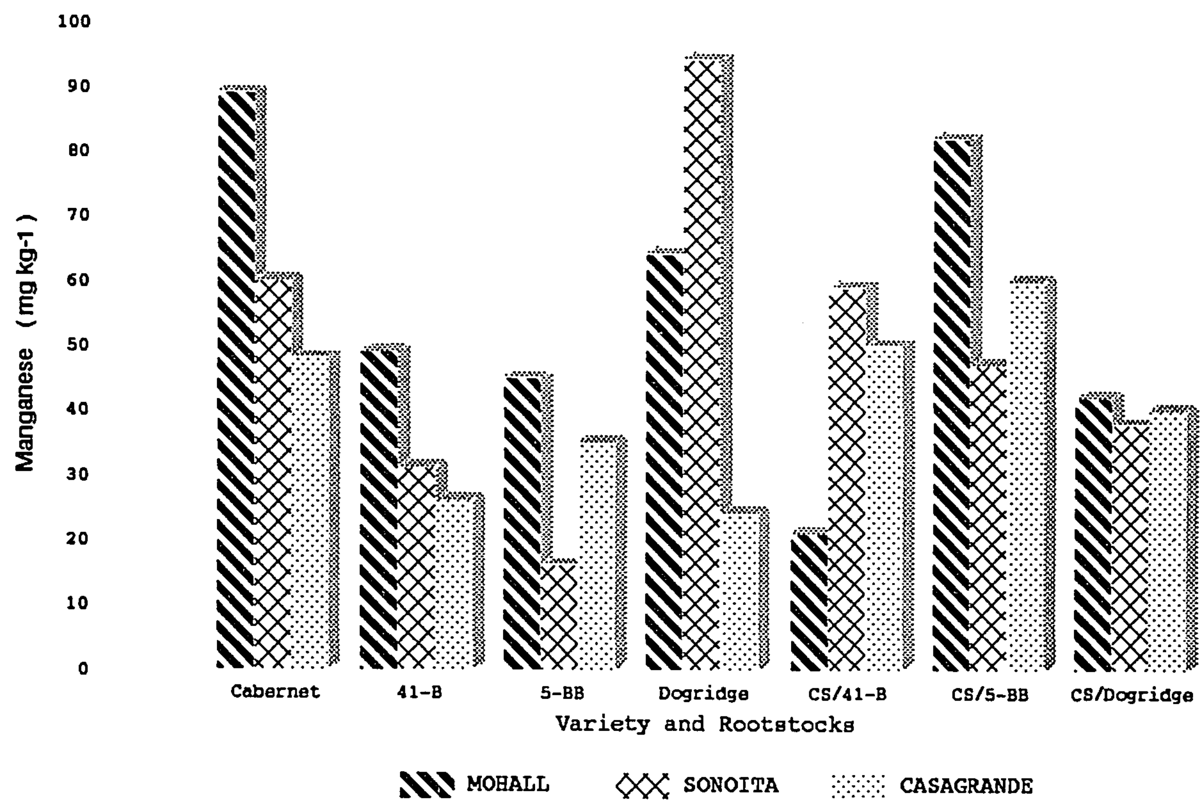

Figure 5. Manganese content of grapevines grown in Arizona soils.

Iron

According critical levels of California, iron content in petioles ranges from 70 to 200 mg kg-1 (Table 1). In this evaluation only two treatment had higher iron content than 70 mg kg-1; therefore, we had deficient levels in some treatments that we studied (Table 11). Iron is very important in the synthesis of chlorophyll (Winkler et al., 1974) and leaves in grapevines show chlorosis with iron deficiency; however, in this evaluation no leaves showed chlorosis during the course of the experiments.

This evaluation shows significat differences between treatments, so Cabernet savignon grafted to 41 B had the highest iron content with 80 mg kg-1, and 60 mg kg-1 in Mohall and Casa Grande soil, respectively. Dogridge had the highest iron content with 80 mg kg-1 with Sonoita soil. In soil means, Sonoita soil provided the highest iron content with 58 mg kg-1, and in treatment means Cabernet savignon grafted to 41 B had the highest iron content with 67.3 mg kg-1 (Table 11).

Only two treatments were greater than the minimum amount than 70 mg kg-1; these two treatments were Dogridge and Cabernet savignon grafted to 41 B, one in Sonoita soil and the other in Mohall soil; however, the other soils show lesser iron content than 70 mg kg-1 (Figure 6).

Table 11. Iron content of a variety, rootstocks, and grafted materials in the three Arizona soils.

Variety and rootstocks	SOILS MOHALL	SONOITA	GRANDE	Treatment Means
	------	mg kg-1	-------	
Cabernet Savignon	43 d*	65 b	18 c	42.0
41-B	45 d	50 c	17 c	23.6
5-BB	54 b	45 c	15 c	38.0
Dogridge	51 c	80 a	13 c	48.0
Cab.Sav./41-B	80 a	62 b	60 a	67.3
Cab.Sav./5-BB	15 e	60 b	50 b	41.6
Cab.Sav./Dogridge	13 e	44 c	23 c	26.6
Soil Means	43.0	58.0	28.0	

*Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

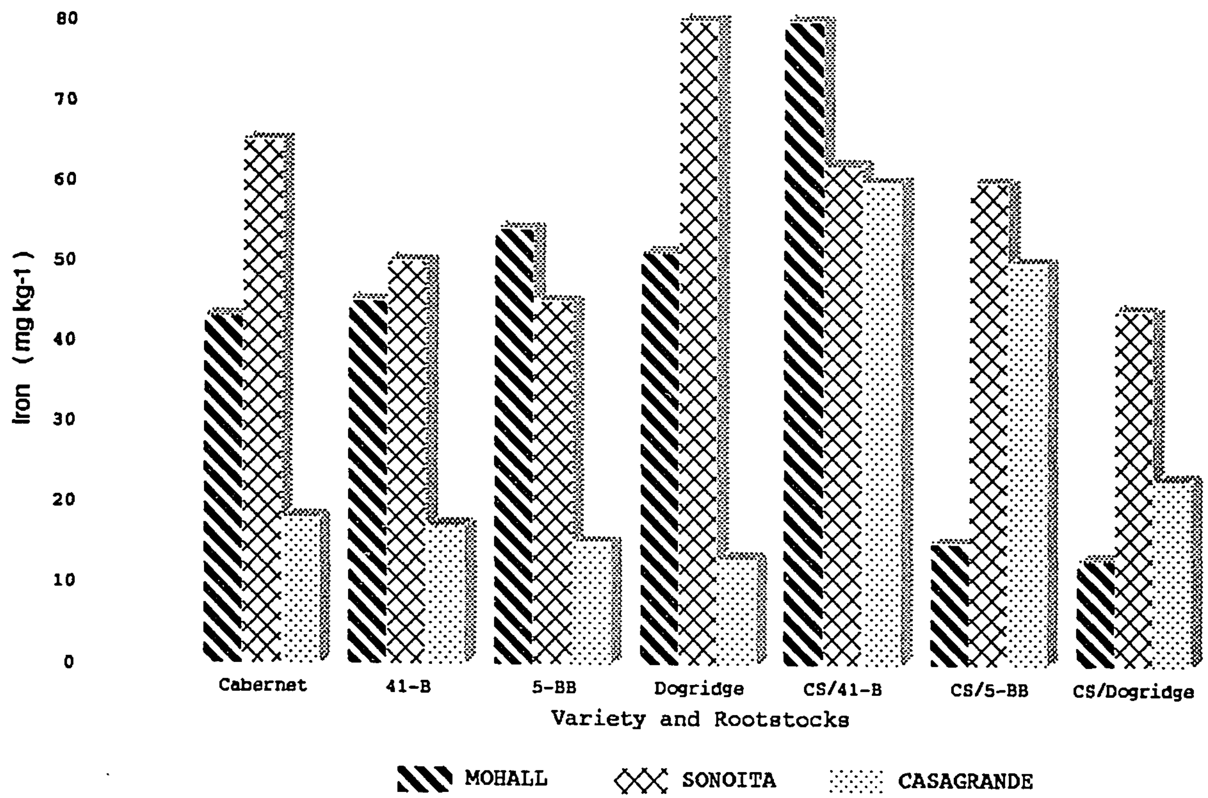

Figure 6. Iron content of grapevines grown in Arizona soils.

This situation shows that plants from Casa Grande soil with 6.0 mg kg-1 of iron contained more iron than Sonoita and Mohall soils with 3.1 and 3.8 mg kg-1, respectively (Table 2); and some materials such as Dogridge and Cabernet savignon grafted to 41 B had more iron content in grape petioles in Sonoita and Mohall soil than the rest of the treatments, suggesting that roots of the roostocks could be of some influence in the iron uptake from the soil solution.

Zinc

Zinc is essential for plants, it catalyses of certain processes such as the system of producing auxins; then a deficiency of zinc results in a deficiency of auxin and a failure of the shoot to grow normally (Winkler et al., 1971). Also, in this study, no one of the treatments showed less than the deficient petiol level of 15 mg kg-1 of zinc content (Christensen, 1972).

Normal shoot growth in grapevines was observed in every treatment; however in the three soils some statistically significant differences were observed; in this form, in Mohall soil, Cabernet savignon grafted to 5 BB and grafted to Dogridge had the highest zinc content with 48 and 49 mg kg-1, respectively; in Sonoita soil, Cabernet savignon grafted to 41 B had the highest zinc content with 80 mg kg-1; and in Casa Grande soil no differences had between Cabernet savignon, 41 B, and Cabernet savignon grafted to 41 B, and grafted to Dogridge; and the rest of treatment a minimum difference was observed (Table 12).

Sonoita soil provided more zinc uptake with means of 58.0 mg kg-1 zinc content in comparision with Mohall and Casa Grande soils with means of 35.4 and 48.6 mg kg-1 of zinc content. In the treatment means, Cabernet savignon grafted to 41 B had the highest zinc content with 58.3 mg kg-1 (Table 12, Figure 7).

Table 12. Zinc content of a variety, rootstocks, and grafted materials in the three Arizona soils.

Variety and rootstocks	MOHALL	SONOITA	CASA GRANDE	Treatment Means
	-------- SOILS	---------		
	----- mg kg-1	--------		
Cabernet savignon	38 c*	65 b	53 a	52.0
41-B	19 d	50 c	53 a	40.6
5-BB	18 e	45 c	35 d	32.6
Dogridge	33 d	60 b	45 c	46.0
Cab.sav./41-B	43 b	80 a	52 a	58.3
Cab.sav./5-BB	48 a	62 b	50 b	53.3
Cab.Sav./Dogridge	49 a	44 c	52 a	48.3
Soil Means	35.4	58.0	48.6	

*Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

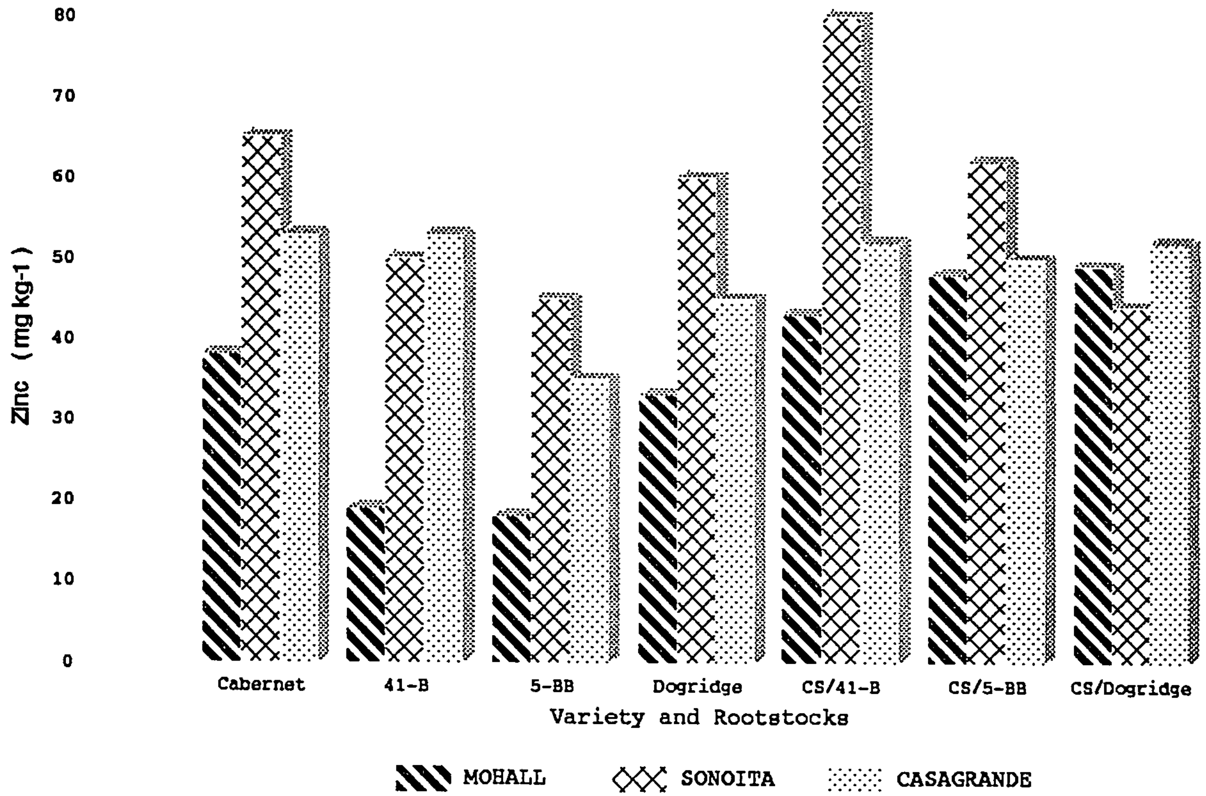

Figure 7. Zinc content of grapevines grown in Arizona soils.

<u>Copper</u>

In California, grapevine copper content for adequate level is more than 6 mg kg-1; in this study every treatment showed higher copper content than the minimum level reported for California (Christensen, 1972). In the three soils, Dogridge was highly significant in copper content; therefore, in the treatment means Dogridge had a 40.3 mg kg-1 of copper content in comparision with the rest of the treatments (Table 13).

In relationship with soil differences in soil means Sonoita soil had the highest copper content with 20.7 mg kg-1; also, Dogridge shows in the three soil a big peack in comparision with the other treatments (Figure 8).

Table 13. Copper content of a variety, rootstocks, and grafted materials in the three Arizona soils.

Variety and rootstocks	MOHALL	SONOITA	CASA GRANDE	Treatment Means
	------	mg kg-1	-------	
Cabernet Savignon	15 c*	16 d	10 d	13.6
41-B	10 e	13 e	14 c	12.3
5-BB	13 cd	20 c	13 cd	15.3
Dogridge	42 a	39 a	39 a	40.3
Cab.Sav./41-B	21 b	16 d	18 b	18.3
Cab.Sav./5-BB	14 c	28 b	20 b	20.6
Cab.Sav./Dogridge	11 de	13 e	12 cd	12.0
Soil Means	18.0	20.7	18.0	

*Means not followed by the same letter are statistically different at the 5 % level of significance according to the LSD procedure.

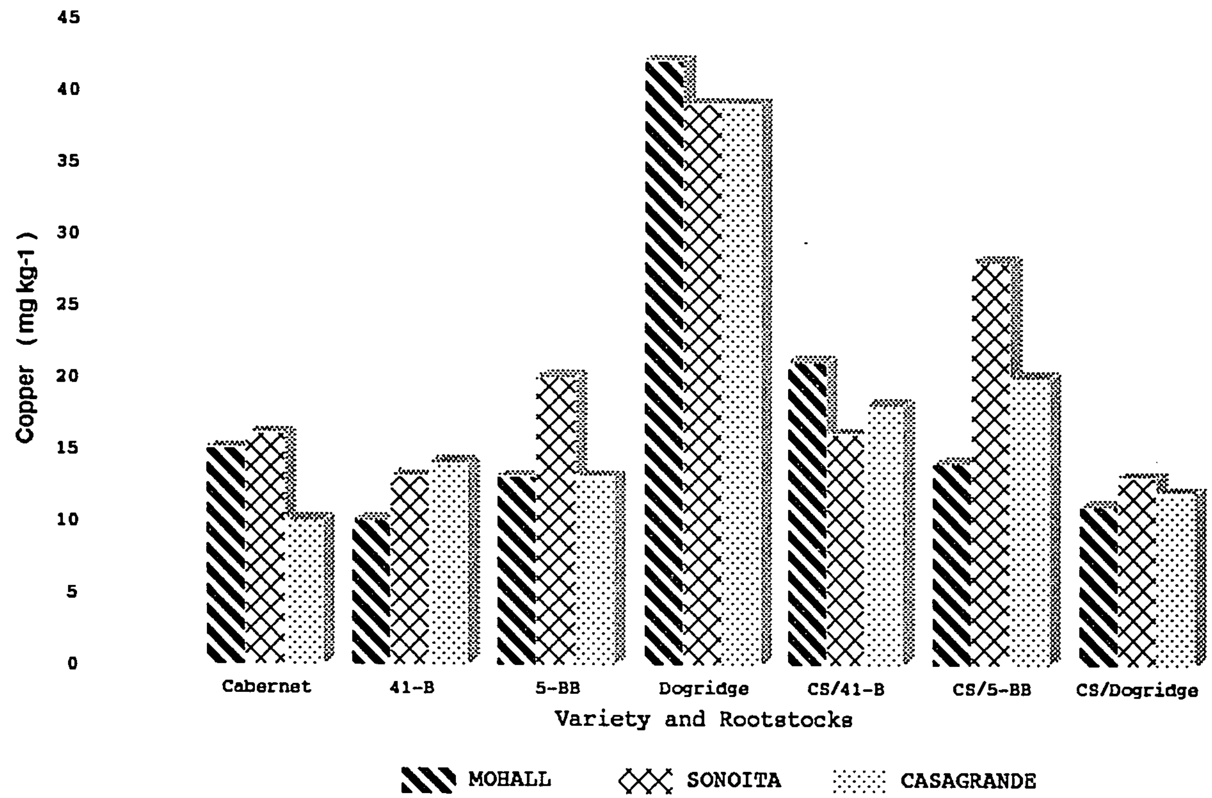

Figure 8. Copper content of grapevines grown in Arizona soils.

CHAPTER 5

SUMMARY AND CONCLUSIONS

A greenhouse study was conducted during 1989 and 1990, to determine the effect of grape variety Cabernet savignon, three common rootstocks, and the variety grafted to the three rootstocks in the nutritional uptake from three soils collected from Maricopa, Tucson, and Sonoita, Arizona areas. Two rootstocks, 41 B and 5 BB were reported to be lime resistant and Dogridge which is vigorous.

The selected Arizona soils are calcareous located in low precipitation areas with high sand content and high calcium carbonate which causes in many cultivated plants nutritional deficiencies, especially iron and zinc, the greenhouse water used in this study had good quality.

The evaluation of the greenhouse experimental results was accomplished through the consideration of shoot growth and chemical composition of grape leaf petioles. The statistical analyses of the results were made on elemental content and cation balance for every soil separately.

The results can be summarized as follows.

1. The chemical properties of the used soils showed similar properties and the greenhouse water was of good quality.

2. Good compatibility was obserbed between the rootstocks and scions and all grafted vines grew very well.
3. Rootstocks showed bigger shoot growth in grapevines than the rest of the treatments.
4. Grafted grapevines contained higher foliar potassium than nongrafted plants.
5. In this study every treatment contained lower foliar calcium than the minimum critical reported for California.
6. Cabernet savignon was highly significant in magnesium content when grown in the three soils as compared to the other combinations.
7. All treatments had lower sodium content than the critical possible problem level of 0.5 reported by California.
8. Grafted plants had more cation uptake than nongrafted plants.
9. No problem was observed with the manganese content, every treatment was higher than the deficient level of 20 mg kg-1 reported by California.
10. Cabernet savignon grafted to 41 B showed the highest iron content in comparision with the rest of the treatments.
11. Cabernet savignon grafted to 41 B showed the highest zinc content in relation with the other treatments.

12. Dogridge was highly significant in copper content in the three soils, compared with the other plants.

APPENDIX I

Average Monthly Maximum and Minimum Temperatures and Humidity of the Greenhouse during the Course of the Experiment.

Month	Max. Temp.	Min. Temp.	Max. R.H.	Min. R.H.
	--- C ----	--- C ----	--- % ---	--- % ---
Feb.	28.4	11.6	70.0	28.4
March	33.9	13.8	67.4	26.7
April	31.9	16.3	66.5	25.4
May	35.9	18.0	58.8	31.8
June	38.1	20.5	62.3	26.3
July	33.6	22.6	59.4	30.5
August	33.8	22.9	68.4	32.4
Sept.	30.8	20.5	67.8	33.5

REFERENCES

Amberg, H. O. 1983. Rootstocks in the northeast. Eastern Grape Grower and Winery News.

Arbabzadeh, F. and G. Dutt. 1987. Salt tolerance of grape rootstocks under greenhouse conditions. Am. J. Enol. Vitic., Vol. 38:95-99.

Arslan, A. 1990. Modeling water quality for soils containing gypsic horizons. Ph.D. Dissertation. University of Arizona.

Ayers, R.S. and D.W. Westcot. 1976. Water quality for agriculture. FAO Irrigation and Drainage paper 29, Rome.

Bar-tal, A.B. Bar-Yosef, and Y. Chen. 1988. Effect of fulvic acid and pH on zinc sorption on monmorillonite. Soil Sci. 146:367-372.

Bohn, H.L., B.L. McNeal, and G.A. O'Connor. 1985. Soil Chemistry. John Wiley and Sons., Inc. New York.

Brown, J.C. 1968. Metal chelation in Soils, Soil Science of America, Washington, D.C.

Brown, J.C., J.E. Ambler, R.L. Chaney, and C.D. Foy. 1972. Differential responses of plant genotypes to micronutrients. (p. 389-418). in J.J. Mortvedt (ed.), Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

Christensen, P. 1972. Vineyard tissue sampling guide for plant analysis. Fresno County Farm Advisors Office. April 5, 1972.

Christensen, P. 1984. Nutrient level comparisons of leaf petioles and blades in twenty-six grape cultivars over three years. Am. J. Enol. Vitic. 35:124-133.

Cummins, G.A. and P. Lilly. 1984. Soil pH rate for fruit yield and elemental concentration of muscadine grapes. Hortscience 19: 831-832.

Cunningham, H.G. 1972. Trends in the use of micronutrients. (p.419-429). in. J.J. Mortvedt (ed.), Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

Donahue, R.L., R.W. Miller, J.C. Shickluna. 1983. An introduction to Soils and Plant Growth. Prentice-Hall, Inc., Englewood Cliff, New Jersey 07632.

Follet, R. H., L.S. Murphy, R.L. Donahue. 1981. Fertilizers and Soil Amendments. Prentice-Hall, Inc., Englewood Cliff, New Jersey 07632.

Galet, P. 1979. A practical Ampelography. Comstock Publishing Associates. Cornell University Press. Ithaca and London.

Greweling, T. 1976. Chemical Analysis of Plant Tissue. Search Agriculture vol. 6. Cornell University Agricultural Experiment Station. Ithaca, New York.

Harmon, F.N. 1955. A modified procedure for green-wood grafting Vinifera grapes. Proc. Amer. Soc. Hort. Sci. 64: 255-258.

Harmon, F.N. and E. Snyder. 1948. Some factors affecting the success of green-wood grafting of grapes. Proc. Amer. Soc. Hort. Sci. 52: 294-298.

Harter, R.D. 1991. Micronutrient adsorption-desorption reactions in soils. (p. 59-87). in. J.J. Mortvedt (ed.), Micronutrients in agriculture. Soil Sci. Soc. Am.,Madison, WI.

Hollerith, J. 1982. Nutritional Requirements of Vinifera wine grapes. Wine Growers J. 9: 29 - 32.

Howell, G.S. 1987. Vitis Rootstocks. Michigan State University. "Rootstocks for fruit crops". John Wiley and Sons.

Howell, G.S. 1989. Factors to consider in rootstock selection Phylloxera, other soil borne problems. Michigan State University.

Hunter, R.F., L.S. Murphy, and R.L. Donahue. 1981. Fertilizers and Soil Amendments. Prentice-Hall, Inc., Englewood Cliff, New Jersey 07632.

Islam, A.K.M.S.,D.G. Edwards, and C.J. Asher. 1980. pH optima for crop growth. Plant Soil. 54: 339-357.

Jones, J.B. 1984. Mixed blessing. Be careful with acid fertilizers. Solutions 3:42.

Jones, J.B. 1991. Plant tissue analysis micronutrients. (p. 477-520), in. J.J. Mortvedt (ed.), Soil Sci. Soc. Am., Mdison, WI.

Kasimatis, A.N. and L. Lider. 1972. Grape rootstock varieties. University of California. AXT-47.

Knox, C. 1982. Correcting nutrient deficiencies in a Minnesota vineyard. Wine Grower J. 9: 34-36.

Kochian, L.V., 1991. Mechanisms of micronutrient uptake and traslocation in plants. (p. 229-295), in. J.J. Mortvedt (ed.), Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

Lehr, J.R. 1972. Chemical reactions of micronutrients in fertilizers. (p. 459-503). in. J.J. Mortvedt (ed.), Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

Lindsay, W.L. 1991. Inorganic equilibria affecting micronutrients in soils. (p. 89-111), in. J.J. Mortvedt (ed.), Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

Lindsay, W.L., and W.A. Norvell. 1978. Development of DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am. J. 42: 421-428.

Martens, D.C., and D.T. Westermann. 1991. Fertilizers Applications for correcting micronutrients deficiencies. (p. 548-592)., in. J.J. Mortvedt (ed.), Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

McLean, E.O. 1982. Soil pH and lime requirements. in, A.L. Page (ed.)., Methods of soil analysis (2dn. ed.) (p. 199-224). Agron. Mono. No. 9 (part 2). Am. Soc. Agron., Madison, WI.

Mortvedt, J.J. 1991. Micronutrient fertilizer technology. (p. 523-548), in. J.J. Mortvedt (ed.). Micronutrients in Agriculture., Soil Sci. Soc. Am., Madison, WI.

Norvell, W.A. 1991. Reaction of metal chelates in soils and nutrient solutions. (p. 187-227), in. J.J. Mortvedt (ed.). Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

Olsen, S.R. 1972. Micronutrient Interactions. (p. 243-263). in. J.J. Mortvedt (ed.), Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

Page, A.L. (ed.) 1982. Methods of soil analysis (2nd ed.). Agron. Mono No. 9 (Part 2) Am. Soc. of Agron., Inc., Madison, WI.

Perry, R.L. and H. Escamilla. 1985. Rootstocks vs. cotton root rot. Michigan State University., East Lansing.

Reuter, D.J. and J.B. Robinson. 1986. Plant Analysis. An Interpretation Manual. Northfield Research Laboratories. South Australian Department of Agriculture, Adelaide.

Roberts, S., and M. Ahmedullah. 1987. The effect of soil applied macro-and micronutrients on results of diagnostic soil and tissue test for 'Concord' grapes. Commun. Soil Sci. Plant Anal. 18:221-234.

Römheld, V. and H. Marschner. 1991. Function of micronutrients in plants. (p. 297-327), in. J.J. Mortvedt (ed.). Micronutrients in Agriculture. Soil Sci. Soc. Am. Madison, WI.

Shuman, L.M. 1988a. Effect of removal of organic matter and iron or manganese-oxides on zinc adsortion by soils. Soil Sci. 146: 248-254.

Shuman, L.M. 1988b. Effect of organic matter on the distribution of manganese, copper, iron, and zinc in soil fractions. Soil Sci. 146: 192-197.

Shuman, L.M. 1991. Chemical forms of micronutrients in soils. (p.113-144) in J.J. Mortvedt (ed). Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI.

Singh, J.P.., S.P.S. Karwasra, and M. Singh. 1988. Distribution and forms of copper, iron, manganese, and zinc in calcareous soils of India. Soil Sci. 146: 359-365.

Stroehlein, J.L., S. Miyamoto, and J. Ryan. 1978. Sulfuric acid for improving irrigation waters and reclaiming sodic soils. Agric. Eng. Soil Sci. Series 78-5, University of Arizona.

Viets, F.G. and W.L. Lindsay. 1973. Testing soil for zinc, copper, manganese, and iron. p. 153-172. In L.M. Walsh and J.D. Beaton (ed) Soil testing and plant analysis.SSSA. Madison, WI.

Wallace, A. and A.M. Abou-Zamzam. 1989. Calcium-zinc interactions and growth of bush beans in solutions culture. Soil Sci. 147: 442-443.

Welch, J.E. and L.J. Lund. 1989. Zinc movement in sewage-sludge-treated soils as influenced by soil properties, irrigation water quality and soil moisture level. Soil Sci. 147: 209-214.

Wiemann, S. (ed.). 1991. The paker, producing availability and merchandising guide. (special 20 TH edition). Central California.

Wilkinson, H.F. 1972. Movement of micronutrients to plant roots. (p.139-169). in. J.J. Mortvedt (ed.). Micronutrients in Agriculture. Soil Sci. Soc. Am. Madison, WI.

Winkler, A.J., J.A. Cook, W.M. Kliewer, and L.A. Lider. 1974. General Viticulture. University of California. Press., Berkeley and Los Angeles California.

Yahya, I. 1990. Toxic levels of aluminum and manganese and variation of nitrogen in grape leaves. Ph.D. Dissertation, University of Arizona.