MANAGEMENT AND CONTROL PLAN FOR ZINFANDEL VINES IN SOUTH PASO ROBLES, CA.

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ABSTRACT

Zinfandel, also known as Zin, is a red skinned variety of wine grape very popular in California. The wines produced from Zinfandel grapes have an intense fruitiness and luscious texture. Production is extremely variable throughout California and is dependent upon, climate, soil fertility, crop level management practices, and irrigation. This study was conducted to determine the on site soil physical and chemical properties as a means to obtain optimal yields and fruit quality. The A & L Western Agriculture Laboratories performed comprehensive fertility analysis to determine the concentrations of the plant essential nutrients, organic matter, electrical conductivity, cation exchange capacity, and pH in the soils. This site has experienced considerable soil disturbance during the rainy seasons due to the erosion of the Salinas River bank bordering the eastern side of the site as well as the non-vegetative ground to the north. Unfortunately, bare soil is highly susceptible to erosive losses. Valuable topsoil can be lost and areas can be deeply cut by gully erosion during the rainy season. The best erosion treatment is to take prevention measures. Therefore, it is recommended that any areas with bare soil be vegetated before next winter’s rainy season. Irrigation rates should be adjusted throughout the year in accordance with annual precipitation, average wind speeds, average temperature, and the evapotranspiration rate. Special considerations should be made where irrigation water

could run off a steep slope. On these sites vegetation must be established, and measures taken to offset sediment loss due to erosion. Zinfandel vines appear to be sensitive to a variation in soil classifications and the effect of the loss of topsoil. With an improvement in land use management this specific site shows considerable potential to be a long term winemaking site.

ACKNOWLEDGEMENTS

On site soil samples, collected from the horizons of identified soils, were sent to A&L Western Agricultural Laboratories of Modesto, CA for chemical analysis. Further thanks goes out to those who helped guide me through this project.

Kimberly R. Hudson
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INTRODUCTION

In the Paso Robles area there are a number of family-owned wineries, all of which are producing high end wines. Many tourists find the area of interest due to its small town atmosphere and openness expressed by the local community, not to mention the country feel. As more and more visitors are being directed to Paso Robles, most leave with a sense of enjoyment and their pallet intrigued by the overwhelming variety of wines to be offered.

Paso Robles stretches from Monterey County to south of a town known as Santa Margarita, encompassing 650,000 acres, with the appellation extending just to its west. Most people view the area of the Paso Robles appellation as a new and upcoming wine region, although the winegrowing in the area dates back to the 1700's. As time has progressed the number of acreage consumed by vineyards has flourished. An increase in winegrowing acreage from 40 acres to over 200 acres was seen from 1873 to 1953, and reached well over 20,000 acres in 2002. In 1882 the region officially began commercial winemaking. As the popularity of wines grew, so did the Paso Robles wine region. By the early 1920's, many other wineries started to appear.

Today, Paso Robles is home to more than 170 wineries and about 26,000 vineyard acres focusing on premium wine production. The distinct microclimates and diverse soils, combined with warm days and cool nights, make growing conditions ideal for producing more than 40 wine varietals from Cabernet Sauvignon and Merlot, to Syrah, Viognier and Roussanne, to Zinfandel, the area's heritage wine variety. Cabernet Sauvignon, Chardonnay, Merlot, and Zinfandel represent approximately 76% of the planted acreage within the Paso Robles. Paso Robles winemakers are pursuing new innovative wine techniques (e.g., blends) to complement the distinct soils, topography, and the coastal regional climate to create a unique and successful terroir (Paso Robles Wine County Alliance, 2006).

Paso Robles' climate is considered semi-arid, with low humidity and low rainfall. Perhaps the most significant climate factor of Paso Robles is the unique combination of hot days and cool nights. Located just over 20 miles inland from the Pacific Ocean, the daily high temperatures are contrasted by cooling, coastal breezes that flow over the Coastal Range in the evenings, leading to temperature variations of up to 50 degrees in a single day. This variation results in very ripe fruit, without any loss of acidity. Coupled with soil and topographic variations, the climate creates an ideal growing environment, especially for hardier red grape varieties, as it brings out the large fruit component and ripe characters that dominate Paso Robles' wines.

The topography is rolling and the soil is generally decomposed shale of shallow thickness. The soils of the Paso Robles region are very diverse, ranging from sedimentary soils and a mixture of clay, sand and silt on the east side, to igneous and metamorphic soils on the western side. The soils are typically limiting to the grapes, which is ideal for developing smaller, more intense fruit. The richer soils of the region are often made limiting by restricting water and nutrient quantities.

The objectives of the experiment are to analyze and assess the physical and chemical properties of the soil as they relate to zinfandel grapevines, soil fertility, and the overall soil health. Upon obtaining data a plan that outlines management strategies will be produced in order to develop a healthy and productive vineyard site that can be maintained for both the short and long term.

LITERATURE REVIEW

Zinfandel Varietal

Zinfandel grapes can produce a wide range of wine styles including white zinfandel, light-bodied red wines, full-bodied dry red wines and sweet late harvest wines. Zinfandel grapes have been grown in California for over a hundred years and Zinfandel wines are one of California's most popular and successful varieties of wine. Zinfandel grapes grow in tight bunches and its thin skins can be susceptible to rot. The best Zinfandel grapes are grown from old vines. This is loosely defined as vines that have been active for a minimum of 40 years (Baldy, 2007). Although old Zinfandel vines tend to produce smaller crops, the berries have greater intensity and depth of flavor.

Wine Grape Overview

The vast majority of the world's wine producing regions have a mean annual temperature of 58^{o}F. The presence of large bodies of water and mountain ranges can have a positive effect on the climate and vines. Nearby lakes and rivers can serve as protection against drastic temperature changes at night by releasing the heat it has stored during the day to the vines. The vine needs roughly 1300-1500 hours of sunlight during the growing season and about 27 inches of rainfall throughout the year in order to produce grapes suitable for winemaking (Baldy, 2007). In ideal circumstances the vine will receive the majority of its rainfall during the winter and spring months. Rainfall during harvest time can cause many hazards such as fungal disease and berry splitting. The optimum weather during the growing season is a long, warm summer that allows the grapes the opportunity to fully ripen and develop a balance between the acid and sugar levels in the grape. Matching the varietal selection with the best possible rootstock for the soil type is key to a healthy, disease-free vineyard that produces at its peak quantity at the desired fruit quality. Soil properties must be balanced with the potential vigor of the rootstock and to extract the most out of each site, whether it is quantity or quality.

Climate Suitability

The climate that affects the vine is the mesoclimate, which contain factors such as temperature, wind, and humidity. Differences in the climate between two vineyards of the same variety often lead to significant wine differences. Many grape varieties have different levels of sensitivity to temperature. Premium wine grapes produce more intense pigments and flavors if they ripen under cool, fall temperatures rather than warm conditions. Wind affects grape growing whereas a slight breeze is helpful in reducing humidity and controlling grape rots. A steady wind is harmful because it can stimulate leaf pores to close (Baldy, 2007). This can result in delayed sugar accumulation in the grapes.

Production

Production is extremely variable throughout California and is dependent upon climate, soil fertility, crop level management practices, and irrigation. Berry size is affected by water availability and irrigation strategy. Head-trained, spur-pruned vineyards will yield 3 to 6 tons per acre. In coastal or foothill Zinfandel vineyards farmed for red wine production, cluster thinning is common to maximize crop uniformity for color and ripeness. Yields for trellised vineyards could range from 5 to 6 tons per acre, with 4 tons not being uncommon. In these regions, typical yields for head-trained, spur-pruned vineyards would be 3 to 5 tons (Ribereau-Gayon et al., 2006).

Zinfandel's compact clusters are susceptible to physical damage, insect damage, or disease. Bunch rot is hard to avoid. Because the grapes grow in such tight bunches, bunch rot and black rot can be a real problem and you must constantly monitor for this or you can lose your entire crop. Training the vines along the trellis so the bunches don't touch will help this problem as well as help the uneven ripening. Water management is very important for these vines since without sufficient water you may be growing raisins. Older vineyards are often infected with virus's that may delay ripening.

Winemakers produce a single varietal Zinfandel wine or may prefer to add small amounts of other varieties, commonly found in old, mixed plantings, to enhance complexity (Ribereau-Gayon et al., 2006). In cooler areas, the fruit will produce wines that have berry and spice flavors while in warm areas the character is less obvious. Zinfandel can reach high sugar levels allowing them to produce a high-alcohol table wine or port-style dessert wine as well.

Management

Irrigation rates should be adjusted throughout the year in accordance with annual precipitation, average wind speeds, average temperature, and the evapotranspiration rate. Special considerations should be made for drip irrigation on steep slopes or where irrigation water could run off a steep slope. On these sites vegetation must be established, and measures taken to offset sediment loss due to erosion.

Soil Physical Properties

Much time and effort is spent selecting the type of wine to grow in a particular area or the steps to follow in order to compensate for fluctuations in the particular soil. Soil physical properties such as texture, drainage, effective rooting depth, compaction and erosion are all factors that need to be considered when assessing a potential vineyard site.

Texture

Different parent materials yield various soil characteristics. As most vineyards are located on a slope of some degree, the soils will be a mixture of the bedrock material. Whatever the parent material is, the quality of life for the vine highly depends on the texture of the soil. Optimal conditions for vine-plants develops when a mix of about 25 percent sandy or coarse material is present, helping to break up the tendency of soils to compact (Wilson, 1998). Naturally existing soils in the environment are composed of varying sizes of soil particles called soil separates. These soil separates are known as sand (largest), silt and clay (smallest) which determine the soil texture depending on the relative proportions. Texture is a crucial characteristic of soil due to its role in water infiltration rates, water storage within the soil, the overall ease of tilling, the amount of aeration, and soil fertility. As particle size increases so does the relative pore space which is why soil texture is closely related to the surface area.

Sand being the larger of the three soil separates means a larger space between each of the existing particles which promotes free drainage of water and entry of air into the soil. Sand feels gritty to the touch and the particles are generally visible. Due to the large size of sand particles, they can hold little water and are considered non-cohesive.

Silt on the other hand contains particles that are not visible to the naked eye and have no particular gritty feel to them; in fact silt feels smooth or silky. Silts are composed of weathered minerals with a larger surface area than that of sand allowing the particles to undergo the weathering process more rapidly to release plant nutrients. With increased surface area silts also contain smaller pore spaces but with a more abundant amount of pore spaces, allowing silt to retain more water and drains at a slower rate.

Clays have a very large surface area, giving them a very high capacity to adsorb water and other substances. The pore space between clay particles is very small, causing movement of both water and air to be slowed. Very few varietals like a large percentage of clay because it makes the soil harder to plow as well as aerate which in turn causes difficulty for root systems to penetrate and expand. Although high clay content causes a root restrictive medium for vine growth, clays contain lots of minerals that grapevines need to survive. Dominance of the kind of clay in the soil is why some vineyard plots may be better than others mere paces apart (Wilson, 1998). In general, between 5 - 10% clay is the desired range for optimal grape growing.

Structure

Structure is the arrangement of primary soil particles into formations known as aggregates. Soil structure is another important aspect of the quality of vine life. A granular structure is best for vines to adequately flourish (Wilson, 1998). Where the bedrock is shallow and the soil is thin, the vines roots will typically be shallow as well, making the vine susceptible to drought. The variations of soil aggregates greatly influence water movement, heat transfer, aeration, and the porosity in the soil. Agricultural practices such as harvesting, grazing, tillage and the addition of constituents have a large impact on soil structure. One important aspect of soil structure is particle density which is the mass per unit volume of soil solids. Particle density varies with the type of soil minerals present as well as the amount of organic matter. The particle density of most mineral soils is in the range of 2.60 to 2.75 g/cm^3. Particle density is used in the calculation of pore space and bulk density. When unknown, particle density of mineral soils is assumed to be 2.65 g/cm^3. Soil particle density is a measure of the mass per unit volume of the soil solids only. Texture and structure do not affect particle density. However, organic matter, which is a soil solid, readily influences particle density. Organic matter weighs much less per unit volume than soil minerals. Soils high in organic matter have lower particle densities than soils similar in texture that are low in organic matter. Soil particle density generally increases with soil depth because of the decrease in organic matter.

Soil bulk density, like all density measurements, is an expression of the mass to volume relationship for a given material. Soil bulk density measures total soil volume. Thus, bulk density takes into account solid space as well as pore space. Soils that are loose, porous, or well-aggregated will have lower bulk densities than soils that are compacted or non-aggregated. This is because pore space (or air) weighs less than solid space (soil particles). Sandy soils have less total pore than clayey soils, so generally they have higher bulk densities. Bulk density is an indirect measure of pore space and is affected primarily by texture and structure. As aggregation and clay content increase, bulk density decreases. Tillage operations do not affect texture, but they do alter structure (soil particle aggregation).

Farmers talk about “heavy” and “light” soils in relation to the ease of tillage.

“Heavy” soils are clayey and difficult to till, while “light” soils are sandy and easy to till (Bishop and Lark, 2007). These terms are misnomers in the technical sense because sandy soils are heavier per unit volume than clayey soils (Bishop and Lark, 2007). Since sandy soils have less pore space than clayey soils, the sandy soil has less air (more solid soil particles) and is therefore heavier. High bulk densities can occur naturally or from human-induced soil compaction by cultivation; root growth is directly affected by high density soils.

Effective Rooting Depth

Effective rooting depth is the depth of the soil profile in which the plant can obtain the necessary plant available water (PAW). Factors such as the soils resistance to penetration, pore aeration, slow movement of nutrients and water, and the buildup of gases all play a role in the rooting depth. Grapevines by preference are deep-rooted and in favorable conditions their roots may go as deep as 20 feet or more (Wilson, 1998). Roots penetrate the soil by forcing and manipulating their way into and through pores. When pores become too small for any particular root the pore must be enlarged by the root pushing soil particles aside. As pore space and size decreases bulk density along with soil strength increase, restricting the root growth. Increased clay content, compaction, and the drying of soils all play a role in decreasing pore size which in turn increases the resistance to root penetration. With this, a sandy soil will be more easily penetrated by a plants root system than that of a clayey one.

Soil type affects wine quality by providing vines with the nutrients and water that influence shoot growth, which gives soil the potential to indirectly exert important effects on wine quality. However, drainage of excess soil water, irrigation, and growth management practices can help counterbalance the effects of the particular soil. Many growers' plant zinfandel vines in a range of soil types, each soil type can produce premium wine grapes. A number of individuals are under the notion that irrigation can take away from the fruit quality, however both crop yield and quality can increase together. Vines can extract one to two inches of soil water for each foot of rooting depth; if uninhibited, roots will grow to a depth of eight or more feet. As the vines use the soil water, the remaining moisture becomes hard to get. Growing season temperatures, humidity and rainfall determine the need for irrigation in a vineyard.

Soil Hydrology

Soil water storage is the water retained by the soil. Once water has penetrated or infiltrated the soil some will eventually be lost from the root zone by drainage. When drainage water moves downward it will reach a point where all the soil pores are saturated. This boundary is known as the water table while the zone as a whole is named the ground water. Most of the groundwater travels downward until discharged into a larger body of water such as a river or stream. The water table will vary depending on the amount of drainage water coming through the soil and the naturally seeping bodies of water in the surrounding area. Some of this stored water will be lost by evaporation. Although precipitation is lost, in some dry areas with deep soils water can move back up into the root zone by capillary rise or capillary action. Humid areas and some desert landscapes with mild irrigation can lose up to 50% of the precipitation below the root zone. The majority of the remaining water will be absorbed by the roots and eventually cycled through the plants and lost through the leaves via transpiration. The water lost to the atmosphere can be returned to the soil as precipitation and renew the cycle.

Erosion

During rainfall, mechanical breakdown, swelling, dispersion and slaking detach soil fragments from crumbs formed by tillage or from crusted soil surfaces, providing sediment for interrill erosion (Warrington, 2008). The destruction of the aggregates and subsequent erosion can change the size distribution of sediment significantly compared to the original soil. Knowing the size distribution of the detached soil fragments is essential for understanding the amount and temporal and spatial patterns of interrill erosion, as well as the potential off-site effects on the water quality of streams and lakes receiving the sediment. Methods developed to quantify aggregate stability have evolved around the application of disruptive forces that are comparable with those observed in the field, such as erosion, slaking and tillage (Warrington, 2008). The destruction of soil aggregate structure in the field can lead to increased rates of erosion and decreased soil fertility. The size-stability distribution in addition to estimating aggregate-size distribution distinguishes between amounts of stable and unstable macro-aggregates (>250 µm).

Soil Chemical Properties

An essential aspect of plant growth and development is the availability of mineral elements. These elements are involved in plant metabolic functions and the plant cannot complete its life cycle without the element. Plants typically show visual symptoms indicating a deficiency of a specific nutrient, which can usually be corrected or prevented by providing that nutrient. Visual symptoms can be due to a variety of plant stresses other than that of nutrients as well and should be carefully analyzed. Balance in the nutrient diet is undoubtedly one of the factors in the mystery of why the vines of one vineyard plot may be judged superior to its look-alike neighbor (Wilson, 1998).

Cation Exchange Capacity

Cation exchange capacity (CEC) is the measure of the soil's ability to hold onto cations by a type of electrical attraction. This cation exchange capability is as vital to the life functioning of the vine plant as oxygen is to the human bloodstream (Wilson, 1998). This is how plants get their nutrients and neutralize toxic chemicals. Although there are a number of exchangeable cations in the soil the most abundant are calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), and aluminum (Al^{3+}). Soil particles known as colloids are what hold the cations in place due to their negative charge. Colloids have a large specific surface area allowing them to hold extremely high quantities of cations and play the role of storing nutrients. Colloids are typically thin, flat plates within the clay and humus fragments of the soil. The replacement of cations on the colloid occurs when cations are taken up by plant roots causing other cations in the soil water to move into place (Miller, 2001). When high concentrations of a specific cation are present, that cation tends to drive off the existing cations on the colloid, taking their place. As the strength of a colloids negative charge increases the colloids ability to hold and exchange cations increases.

The units used to express the concentration of cations are centimoles of charge per kilogram of soil (cmolc / kg). The soil pH plays an important role for CEC because as the soil becomes less acidic (pH increases), the number of negative charges on the colloids increase causing the CEC to increase as well.

CEC is a function of the type of soil present. Decomposed organic matter known as humus contains the highest CEC due to the organic matter colloids having large quantities of negative charge. Humus contains CEC values much greater than those of both montmorillonite and kaolinite clay, making it extremely important for improving the soils overall fertility.

Both aluminum and sodium are not considered plant nutrients, and are actually unwanted by the plant (Miller, 2001). Maintaining a certain soil pH level is important in order to control the uptake of these cations. If the pH level of the soil is greater than five then aluminum forms a precipitate and falls out of solution. However at a pH below five, aluminum could become available as a cation and eventually leading to toxic levels.

CEC in a weathered soil environment can be improved by the addition of lime and or raising of the pH; although the addition of organic matter is typically the most effective method when attempting to increase the CEC of the soil. For every 1% of soil organic matter there is 200 cmolc, which is much higher than that of any other soil colloids (Table 1).

Soil Colloid	**Colloid Type**	**Charge Dependence**	**Avg. CEC (cmolc/kg)**
Humus/Organic matter	2 to 1	pH	200
Vermiculite	2 to 1	isomorphous substitution	115
Smectites (montmorillonite)	2 to 1	pH	80
Illite	2 to 1	isomorphous substitution	20
Kaolinite	1 to 1	pH	5
Sesquioxides	0 to 1	pH	2

Table 1. Average CEC values for important soil colloids and their charge dependence

Nitrogen

Nitrogen is a very important component of a number of plant essential compounds. It plays a key role in all amino acids, which are the building blocks of all proteins. Nitrogen also affects enzymes which regulate almost all of the biological activity within a plant. Other components include nucleic acids and chlorophyll which is an important aspect of photosynthesis. Sufficient nitrogen supplied to the particular crop helps to stimulate root growth and development as well as the uptake of other plant essential nutrients.

Nitrogen is taken up by plant roots from the soil solution as nitrates (NO_3^-) and ammonium (NH_4^+) ions. The majority of plants usually either take up one form or the other; however a well balanced mixture of the two can ultimately yield the healthiest plant. Nitrate anions (negatively charged ions) are able to move easily to the root system with the flow of soil water and tend to cause a rise in the pH. On the other hand ammonium cations (positively charged ions) exchange at the root surface with hydrogen ions causing an overall lowering of the pH around the roots.

Nitrogen deficiency and oversupply are problems that can occur when applying or not applying fertilizers. Plants with a nitrogen deficiency develop a pale yellowish green color known as chlorosis, along with stunted growth and thin stems (Havlin et al., 2005). Nitrogen is an overall mobile nutrient, so when a deficiency is present the signs are first seen in the older foliage leaving the newest leaves with a more healthy appearance. When an abundance of nitrogen is applied an excessive amount of vegetative growth occurs. High nitrogen can delay plant maturity and cause the plants to be more easily invaded by disease and insects. Many of these problems are present when other essential nutrients such as potassium are deficient while nitrogen is abundant. With unnecessary amounts of nitrogen present the crop quality is also degraded, color and flavor of fruits along with sugar and vitamin levels are poor.

Phosphorus

Phosphorus is an essential component; plants cannot grow without it. Phosphorus is part of adenosine triphosphate (ATP), which drives biochemical processes, including the uptake of nutrients and their transport within the plant (Havlin et al., 2005). Phosphorus is also an essential component of deoxyribonucleic acid (DNA), the seat of genetic inheritance, and of ribonucleic acid (RNA), which directs protein synthesis (Havlin et al., 2005). In order to maintain a healthy phosphorus content, usually only 0.2 -0.4% within the leaf tissue is needed (Brady and Weil, 2000).

With correct phosphorus availability it will enhance photosynthesis, nitrogen fixation, flowering, fruiting, and maturation. Root growth is also encouraged by phosphorus allowing for an improvement in crop quality.

Potassium

Potassium (K^+) plays a role in water relations, charge balance, osmotic pressure in cells across membranes, which explains its high mobility in the plant (Brady and Weil, 2000). Potassium is involved in synthesis and transportation for plant reproduction and storage organs. It helps to convert compounds into carbohydrates, proteins, oils, and other products. In a fruit crop such as grapes, sufficient potassium can enhance fruit size, color, taste and skin thickness. Potassium provides the majority of the osmotic pressure needed to draw water into the plant roots. It is especially important in aiding plants to adapt to environmental stresses. Optimal potassium health increases drought tolerance and promotes resistance to some fungal diseases as well as insects. With a potassium deficiency both plant growth and fruit quality can be reduced. When potassium is lacking in the soil system plants have a decreased ability to withstand water stress.

Other Plant Essential Nutrients

Secondary macronutrients needed for healthy fruit growth are sulfur (S), calcium (Ca), and magnesium (Mg). Both sulfur and magnesium are needed in similar amounts to that of phosphorous while calcium tends to be required in higher amounts. A typical calcium to magnesium ratio in a healthy soil medium is around 5:1.

Sulfur is absorbed by plant roots as sulfate (SO_4^{-2}) and is the primary form in the soil. Typical concentrations in plants range from 0.1 to 0.5% (Havlin et al., 2005). Atmospheric sulfur (SO_2) is released into the air, oxidizes to SO_4^{-2}, and is deposited in the soil through precipitation (Sparks, 2003). Sulfate reaches the roots by diffusion and mass flow; however can be readily leached through the soil profile due to its mobility. Most irrigation water contains SO_4^{-2} and should be analyzed before applying any additional fertilizers.

Calcium is absorbed from the soil solution in the form of Ca^{2+}. Its main form of transportation through the soil system is by that of mass flow. A deficiency of calcium is typically uncommon however can be seen in excessively leached as well as unlimed soils. When an abundance of calcium is present it tends to build up near the plant room system. Calcium plays a key role in the plants cell wall structure, when calcium is low problems such as increased permeability and abnormal nutrient uptake can occur. With low calcium uptake grape discoloration and softness can occur as a few of the distinct symptoms. On the other hand calcium is important due to its role in increasing NO_3^- uptake and its help in the regulation of cation uptake. Some of the main factors determining the availability of calcium are soil pH, cation exchange capacity, and the soil type.

Similar to that of calcium, magnesium is mainly seen in the soil system as Mg^{2+} and again is supplied to plant roots by mass flow and diffusion. Total soil magnesium content ranges from 0.1% in coarse, humid-region soils to 4% in fine-textured, arid, or semiarid soils formed from high-Mg minerals (Brady and Weil, 2000). Typical soil conditions when magnesium is likely to be deficient are acidic soils, sandy, highly leached and calcareous soils. Very few standard fertilizers supply a sufficient amount of magnesium; however some can be supplied via animal and water waste.

Micronutrients

Micronutrients are often overlooked as essential elements required for a healthy soil system, but are equally important to that of macronutrients. Micronutrients are present in the soil in much smaller quantities but when deficiencies occur plant growth and overall productivity is decreased. There are nine different micronutrients all of which vary according to the specific region. These nutrients consist of iron(Fe), manganese(Mn), zinc(Zn), copper(Cu), nickel(Ni), boron(B), molybdenum(Mo), chlorine(Cl), and cobalt(Co). These micronutrients in the soil are elements in primary and secondary minerals, adsorbed to mineral and organic matter surfaces, incorporated in organic matter and microorganisms, and in solution (Sparks, 2003). In order to optimize plant productivity the understanding of the relationship between each of these nutrients in the soil is essential.

All of these micronutrients have been found in varying quantities in igneous rocks (Miller and Gardiner, 2001). Iron and manganese play a primary role in the structure of minerals such as biotite and hornblende. Zinc and cobalt also play a role in structure of minerals, including clays. Anions such as borate and molybdate in soils may undergo adsorption or reactions similar to those of phosphates. The most soluble of the nine nutrients is chlorine, and is incorporated into the soil system in relatively high amounts by rainwater. Although the majority of these nutrients are not always readily available to the plant, their uptake is a crucial aspect of a healthy plant. A good source of micronutrients can be found in animal manures.

pH

Soil pH is an important factor in plant essential nutrient availability. The pH scale is logarithmic. A pH of 4.0 is 10 times more acidic than a pH of 5.0 and 100 times more acidic than a pH of 6.0. While most essential nutrients have the greatest plant availability at a pH of about 6.5, some may be most available at an alkaline or acidic pH. At pH values less than 6.0, the basic cations (Ca, Mg, K, Na, Mo) become less available due to reduced solubility in the soil solution. Phosphorus becomes less available at pH values less than 6.0 due to precipitation with Fe. At pH values above 6.5, the metal micronutrients (Fe, Mn, Cu, Zn, Co) become less available due to precipitation as carbonates from the soil solution. Soil pH influences plant growth and is easily determined as well as provides a number of hints about other soil properties.

Salinity

A saline soil has salt within the root zone which interferes with plant growth. The cause of soil salinity can be unleached products of mineral weathering, salty irrigation water, or the migration of salty groundwater by capillary action. Ions in the soil water can be estimated by electrical conductivity (EC), which is a method to help estimate the amount of total soluble salts in the soil. The traditionally accepted threshold value for salinity is reached when the EC of a saturation paste extract equals 4 dS/m (Miller and Gardiner, 2001).

Vine decline due to salinity frequently occurs at the end of the irrigation system where water tends to pond. The symptoms noticed in vines declining because of excess soil salinity include decreases in vegetative growth, leaf burn, reductions in yield, fruit size and quality, and in extreme cases, death of the vines (Wilson, 1998).

MATERIALS AND METHODS

Site Description

Soil samples were collected in Atascadero, California (Figure 1).

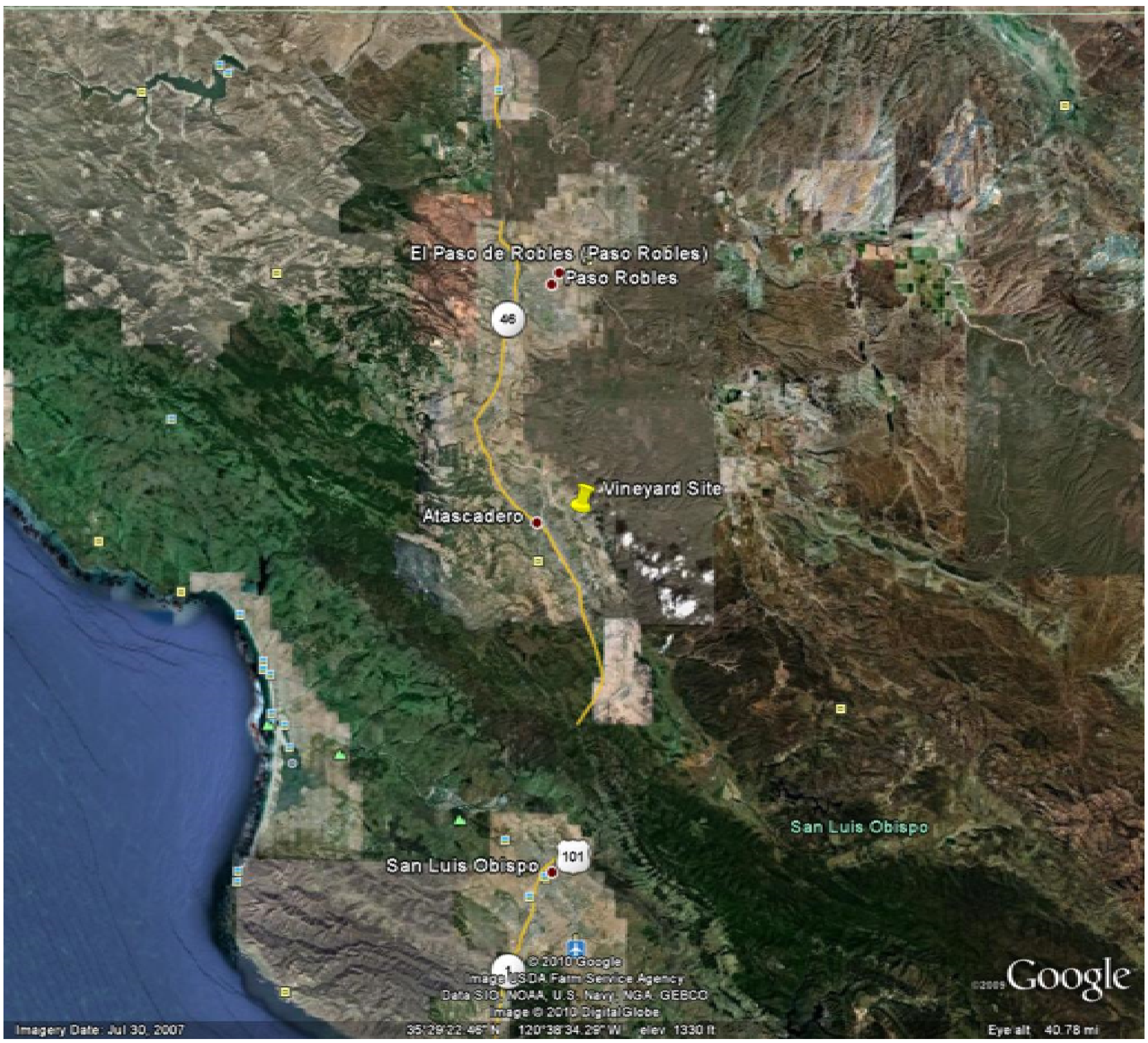

Figure 1. Map of the vineyard site, located south of Paso Robles, CA in San Luis Obispo County. Source: Google Earth, 2010

Two soil pits were dug with three samples being taken from each pit for a total of six samples. The vineyard site is located at N35°29'23.51" W120°38'33.82" and at approximately 855 ft. above sea level. The zinfandel vines are located on the five acre site and consist of roughly 60 vines total (Figure 2).

Figure 2. The vineyard site along with pit locations and surrounding property of the vineyard owner.
Source: Google Earth, 2010

Materials

Prior to obtaining the soil samples the vineyard site was assessed for landscape variations in order to portray an accurate description of the site as a whole. Two soil pits were dug with three samples being taken from each pit for a total of six samples.

- Rounded shovel (used for digging pits/obtaining samples)
- Sharpshooter shovel (used in transect confirmation)
- Poly-D reagent pH kit (used to test field pH)
- 150 cm cloth tape (used to measure soil and horizon depths)
- Munsell color book (used to classify soil dry and moist color)
- Hand-held clinometer (used to measure slope)
- Water bottle (used to moisten soil for hand texturing)
- Soil knife (used to chip away at surfaces and obtain samples)
- Garmin GPS receiver (used to document latitude and longitude on location)

Standard Methods

Both physical and chemical analysis were performed on the vineyard site in order to get a more accurate description of soil properties.

Physical Analysis

Physical analyses were performed both in the field and in the laboratory by the author. The vineyard site was investigated using two (2) soil pits to document soil morphological properties including soil structure, depth, presence of carbonates, and soil chemical characteristics. Soil classification and soil land use interpretations followed those discussed in the Soil Survey Manual (Soil Survey Staff, 2000), Keys to Soil Taxonomy, 10th edition (Soil

Survey Staff, 2006). Digital maps were produced from data collected for the study site using GoogleEarth software.

The soil structure was evaluated by the size, shape, and degree of ped distinctness. The soil texture was determined using the "by feel" method.

Chemical Analysis

Pits were also used to obtain soil samples that were delivered to A & L Western Agriculture Laboratories and to California Polytechnic State University, San Luis Obispo for further soil chemical analysis and to classify the soils. The A & L Western Agriculture Laboratories, Modesto, CA performed comprehensive fertility assay analyses to determine the concentrations of the plant essential nutrients (N,P,K; measured in ppm) in the soils, soil organic matter (as a percentage), electrical conductivity (E.C. measured in dS m^{-1}), cation exchange capacity (CEC as meq $100g^{-1}$ soil), and soil pH. For a more complete analysis a S3C comprehensive soil test was also ran to test for magnesium, calcium, sodium, sulfate-sulfur, zinc, manganese, iron, copper, boron, lime, and salinity.

RESULTS

Soil Physical Properties

Soil Map Unit Description

The dominant soil map unit at the vineyard site is the Metz sandy loam, 0 to 5 % slope (map unit 166). Metz sandy loams are formed on a flood plain with alluvial parent material derived from mixed rocks. They exist on toeslopes and fall under the drainage class of somewhat excessively drained. The depth to a restrictive root layer is typically more than 80 inches. Flooding is rare and the tendency to pond is not yet seen. Its available water holding capacity is low at about 5.3 inches. The soil series typical profile consists of 0 to 9 inches of a loamy sand with 9 to 60 inches of stratified sand to very fine sandy loam underlying.

Soil Pedon Description

The Metz series consists of very deep, somewhat excessively drained soils that formed in alluvial material from mixed, but dominantly sedimentary rocks. Metz soils are on floodplains and alluvial fans and have slopes of 0 to 15 percent. The mean annual precipitation is about 15 inches and the mean annual air temperature is about 59 degrees.

Taxonomic Class: Sandy, mixed, thermic Typic Xerofluvents

Typical Pedon: Metz fine sandy loam, cultivated.

Ap--0 to 12 inches; light brownish gray (2.5Y 6/2) fine sandy loam, dark grayish brown (2.5Y 4/2) moist; massive; hard, friable, slightly sticky and slightly plastic; common very fine roots in upper 2 inches, few very fine roots in rest of horizon; many very fine interstitial and few fine tubular pores; compacted due to tillage; noncalcareous; moderately alkaline (pH 8.0); abrupt wavy boundary.

C1--12 to 29 inches; light brownish gray (2.5Y 6/2) fine sand, dark grayish brown (2.5Y 4/2) moist; massive; soft, very friable; few very fine roots; many very fine interstitial pores; near top of horizon, a discontinuous streak of sand lenses 1 to 2 inches thick; slightly effervescent; moderately alkaline (pH 8.0); clear smooth boundary.

C2--29 to 38 inches; light brownish gray (2.5Y 6/2) sand, grayish brown (2.5Y 5/2) moist; single grain; loose; few very fine roots; horizon has 1 percent gravel and 1 to 2 percent mud balls 2 to 5 inches in diameter of very dark gray (N 3/) mottled silty clay; many very fine and few fine roots; many very fine interstitial pores; slightly effervescent; moderately alkaline (pH 8.0); gradual smooth boundary.

C3--38 to 52 inches; light brownish gray (2.5Y 6/2) very fine sandy loam, olive brown (2.5Y 4/4) moist; strong brown (7.5YR 5/6 dry and moist) mottles; weak coarse prismatic structure; slightly hard, very friable, slightly sticky and slightly plastic; common very fine roots; many very fine interstitial and common very fine tubular pores; indistinct strata of silt loam in middle of horizon; strongly effervescent with disseminated lime; moderately alkaline (pH 8.0); abrupt smooth boundary.

C4--52 to 118 inches; light brownish gray (2.5Y 6/2) fine sand, dark grayish brown (2.5Y 4/2) moist; single grain; loose;many very fine interstitial pores; slightly effervescent; moderately alkaline (USDA, 1999).

Texture

The textures at the vineyard site from the surface to fifty four inches consisted of a sandy loam for both sampling locations. Clay content varied slightly as depth increased; however the overall texture seemed to be very similar throughout the profile.

Structure

The structure in the topsoil was overall weak. The aggregates were barely observable in place. When gently disturbed, the soil material broke into a mixture of whole and broken aggregates. The structure in the subsoil horizons (H2, H3) for both pit locations fell under the grade structureless. The soil material in the subsoil horizons separated as individual primary particles and did not form aggregates, this is considered single grained. All of the horizons were granular with somewhat rounded and smaller aggregates than most other structures.

Effective Rooting Depth

Neither of the soil pit locations showed any evidence of a hard soil layer up to 54 inches in depth. Presence of few fine to very fine roots were evident in the surface horizons mainly due to the annual grasses between rows.

Soil Chemical Properties

Organic Matter

Soil organic matter was generally low throughout the vineyard site. Pit number one ranged from 0.8 to 1.1 % while pit number two ranged from 0.8 to 1.4 %.

Nitrogen

Nitrate-nitrogen ranged from 9 to 13 ppm in pit number one and from 9 to 10 ppm in pit number two. The average concentration of the site was 10 ppm (Figure 3).

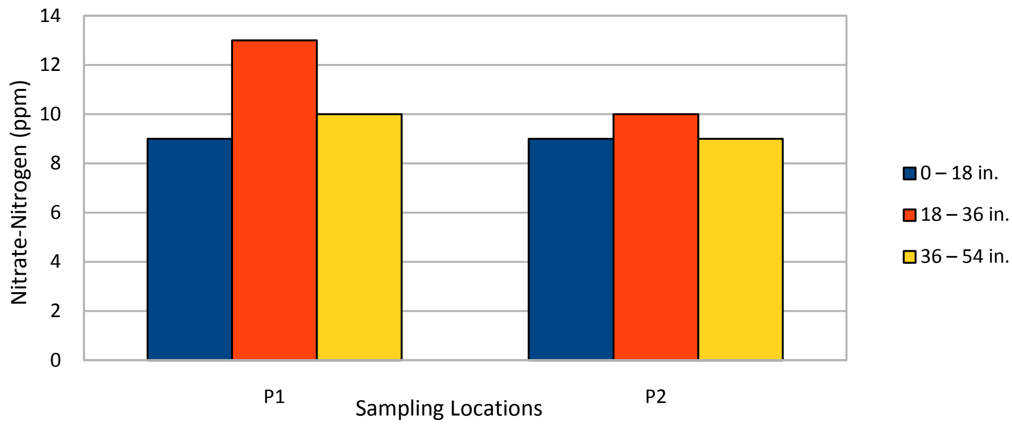

Figure 3. Concentration of nitrate-nitrogen in the soil pit sampling locations at various depths.

Phosphorous

The phosphorous ranged from high to very high in pit number one with concentrations ranging form 25 to 45 ppm. In pit number two the phosphorous concentration was medium to very high ranging from 15 to 53 ppm (Figure 4).

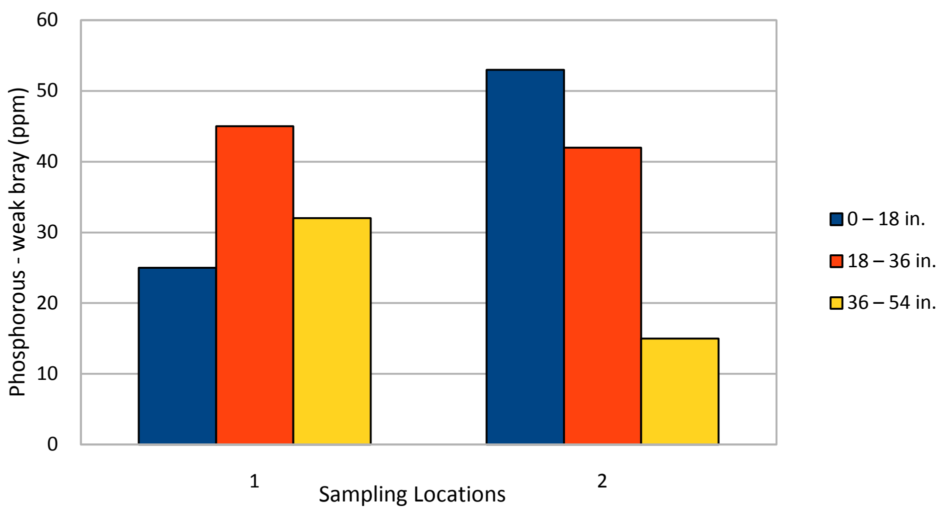

Figure 4. Phosphorous concentrations of the soil sampling pits at various depths of the vineyard site.

Potassium

Potassium ranged from 105 to 236 ppm in pit number one with the concentration decreasing with increased depth. In pit number two the potassium ranged from 109 to 289 and also decreased in concentration as depth increased (Figure 5).

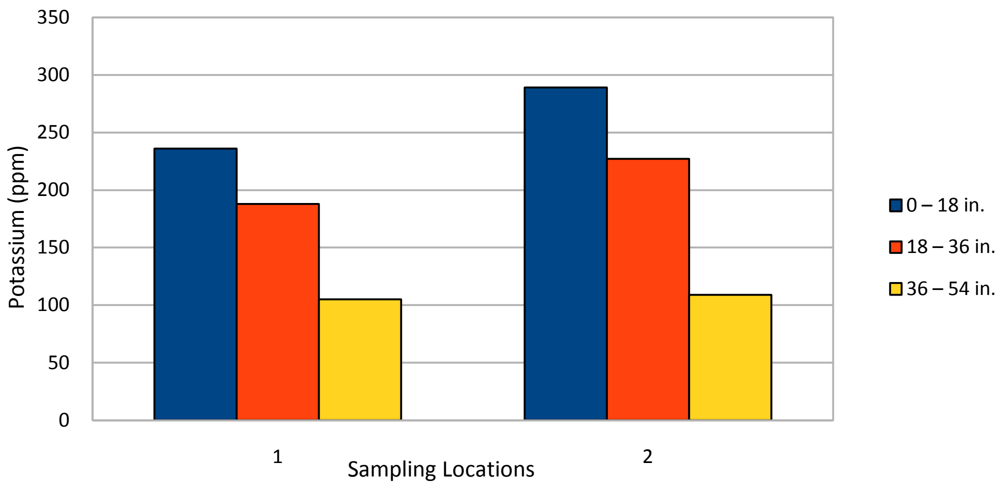

Figure 5. Potassium concentrations of the soil sampling pits at various depths.

Calcium and Magnesium

Calcium was generally present in high concentrations and was higher in the upper horizons except for in pit number two where the concentration in the third horizon (36 – 54 in.) exceeded the second horizon (18 – 36 in.). The average concentration of both soil pits was 909 ppm putting it in a relatively higher concentration class (Figure 6).

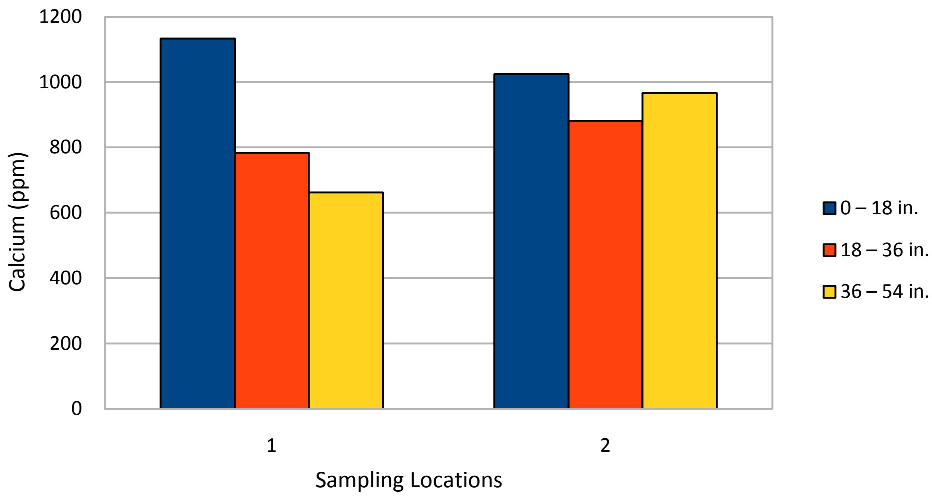

Figure 6. Calcium concentrations of the two pit locations at the vineyard site with increasing depth.

Magnesium concentrations in the first soil pit ranged from 164 to 301 ppm with the upper horizon containing the highest amount. In pit number two the concentration of magnesium ranged from 213 to 280 ppm which showed less fluctuation, however the uppermost horizon still containing the highest amount (Figure 7).

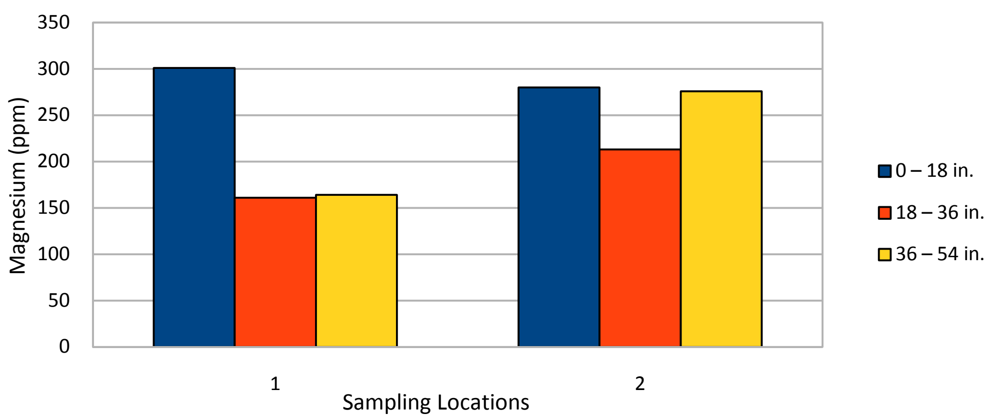

Figure 7. Magnesium concentrations of the soil pits at the vineyard site with varying depths.

The calcium to magnesium ratios at the vineyard site ranged from 3.5 to 4.9 respectively with the majority of the samples around a ratio of 4:1 (Figure 8).

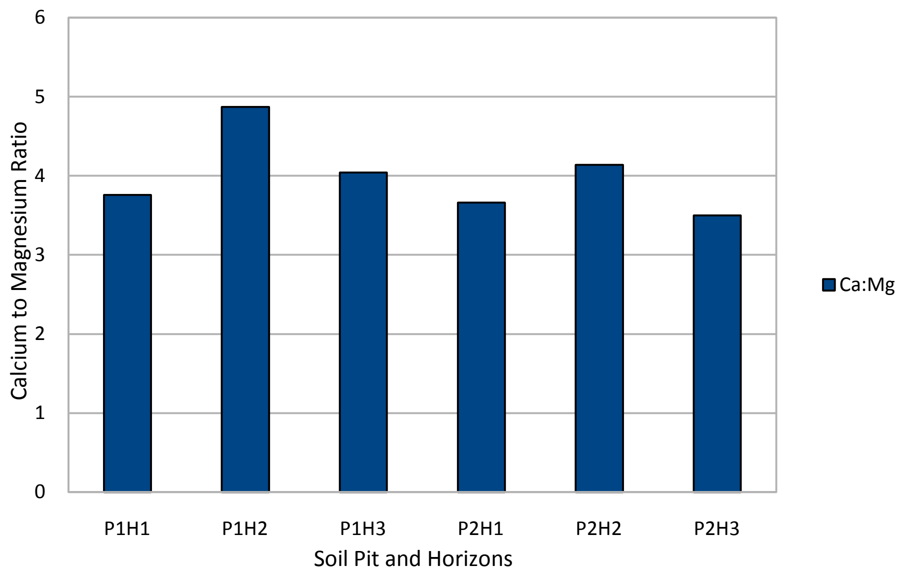

Figure 8. Variation of calcium to magnesium ratios with various depths and location.

Micronutrients

Zinc concentrations ranged from 0.4 to 1 ppm in pit number one and 0.4 to 0.8 ppm in pit number two, with an average concentration of 0.6 ppm. Manganese ranged from 1 to 2 ppm in both pits number one and two. The iron concentrations fell between 8 and 15 ppm in pit number one and 9 to 15 ppm in pit number two. The copper concentrations fluctuated between 0.3 and 0.4 throughout both soil pits. Boron had a concentration of 0.7 ppm in the uppermost horizon of pit number one and decreased to 0.1 ppm in the lower two horizons. Pit number two had boron concentrations ranging from 0.3 to 0.6 ppm (Figure 9).

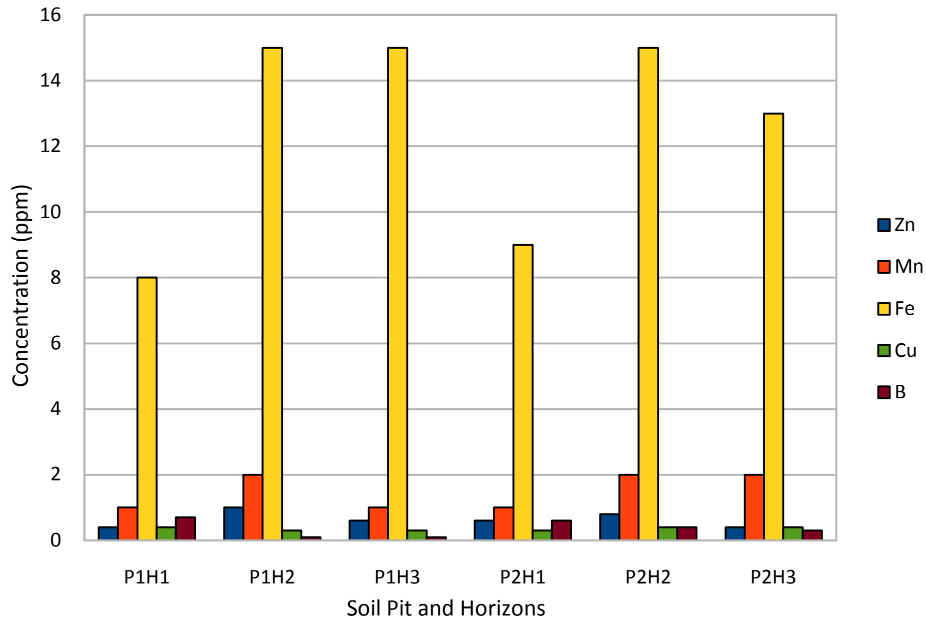

Figure 9. Concentrations of zinc, manganese, iron, copper, and boron at the vineyard site.

Sodium

The sodium concentration in pit number one ranged from 18 to 138 ppm with its presence being most prominent in the uppermost horizon. In pit number two the concentration ranged from 21 to 32 ppm showing a much smaller fluctuation in the sodium levels (Figure 10).

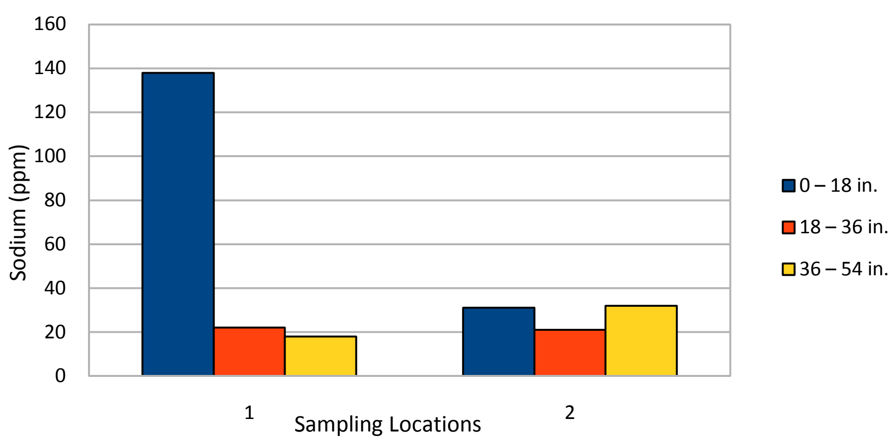

Figure 10. Sodium concentrations for both soil pits at the vineyard site with varying depths.

pH

The soil pH values were between 6.7 and 8.4 throughout both soil pit sampling locations (Figure 11.)

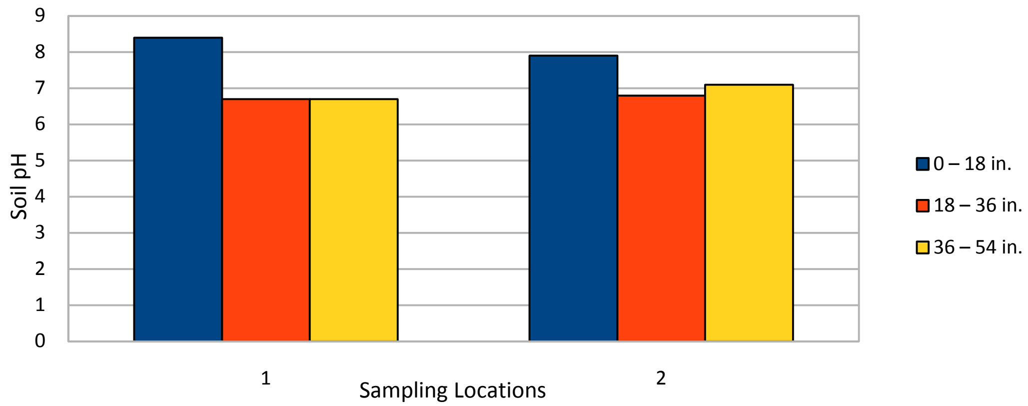

Figure 11. Variation of soil pH throughout the sampling locations at the vineyard site.

Cation Exchange Capacity

Cation exchange capacity (CEC) ranged from 5.2 to 9.3 meq/100g in the soil samples from both pit locations at the vineyard site. The average CEC was 7.2 meq/100g (Figure 12).

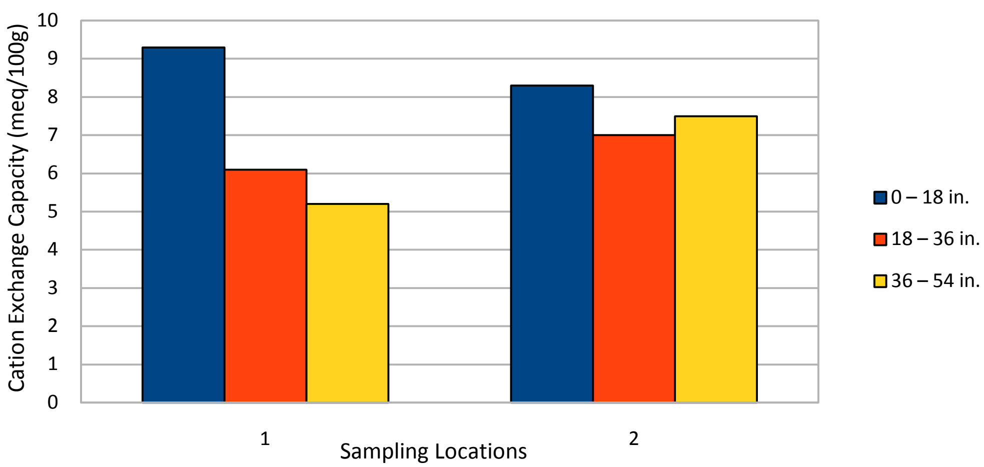

Figure 12. Cation exchange capacity with varying depth at the vineyard site.

Cation Saturation

The cation saturation for both pits combined showed that calcium had the highest percentage at 60.6 percent saturation. Magnesium followed that of calcium at 26.5 percent saturation with potassium and sodium showing the smallest amount of saturation

(Figure 13).

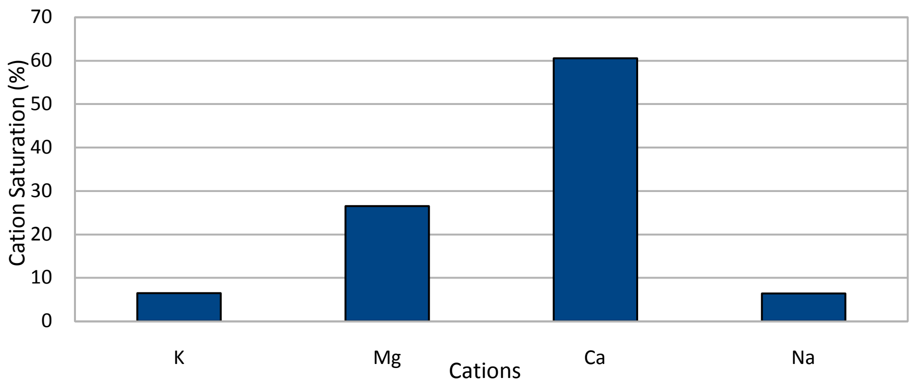

Figure 13. Percent cation saturation of the vineyard site as a whole.

Soluble Salts

The soluble salts in the soil had little fluctuation with it ranging from 0.2 to 0.3 dS/m (0.2 to 0.3 mmhos/cm) (Figure 14).

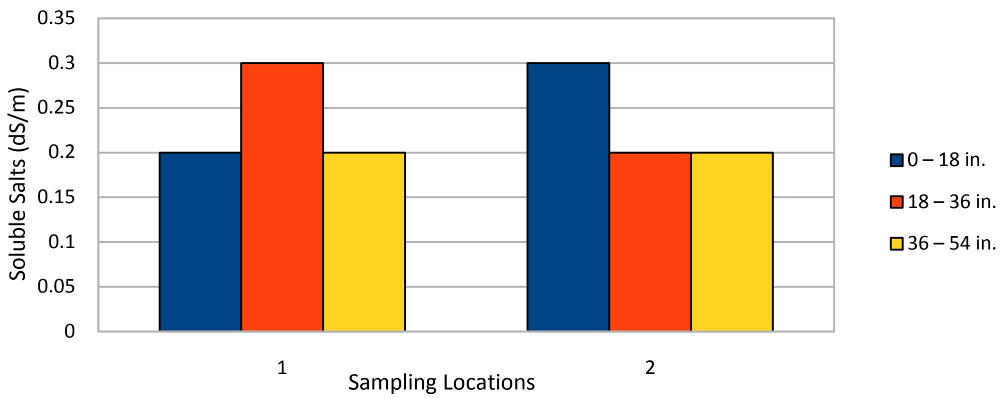

Figure 14. Electrical conductivity (EC) of the soil pits at the vineyard site.

Excess Lime

A & L Western Laboratories provided an excess lime rating for each of the soil horizons. The excess lime rating for all of the samples that were analyzed were reported of having low rating.

DISCUSSION

Soil Physical Properties

Texture

The sandy loam texture existing throughout the vineyard site has both advantages and disadvantages when assessing Zinfandel health. The lack of clay content and the abundance of sand causes the soil to drain quickly and also contains a low nutrient holding ability along with a low capacity for plant available water. Conversely, it is beneficial if the soil does contain some fraction of sand or a coarser material in order to reduce any tendencies for the soil to compact. Although water infiltration may be high and the plant available water decreased with a more sandy textured soil it does however allow for adequate root growth and development.

Due to the high macro-porosity of a sandy loam, soil water can pass through quickly. Subsequently, it can dry out quickly as well. Soils containing more sand and less clay require more frequent watering. However, it takes less water to reach the deeper roots of the vine; thus an irrigation plan incorporating more irrigating cycles with less water being distributed per watering would be ideal.

Structure

All of the horizons analyzed had a granular structure which is best for vines to adequately flourish. The planting of cover crops and or perennial grasses between rows can help to alleviate the erosion of loose soil material. With the lack of structure both water infiltration as well as air and water permeability will be rapid.

Erosion

This site has experienced considerable soil disturbance during the rainy seasons due to the erosion of the Salinas River bank bordering the eastern side of the site as well as the non-vegetative ground to the north. Unfortunately, bare soil is highly susceptible to erosive losses. Valuable topsoil can be lost and areas can be deeply cut by gully erosion during the rainy season. The best erosion treatment is to take prevention measures. Therefore, it is recommended that any areas with bare soil, especially those with slopes greater than ten percent, be vegetated before next winter's rainy season.

Effective Rooting Depth

The effective rooting depth on site is not a threat due to the low density soil and relatively high pore space and size are present. Grapevines tend to be deep rooted, sometimes up to 20 feet or more which this particular soil provides the luxury.

Soil Chemical Properties

The reliability of chemical nutrient testing should be monitored and does not always provide an adequate description of the soils ability to deliver nutrients to the plant. Annual soil fertility should be monitored in order to keep both plant health and management efficiency at an optimal level. The results and interpretations provided by A & L Western Agricultural Laboratories are based on a general soil-plant relationship and typical vineyard conditions. In addition to soil monitoring, leaf blade and petiole sampling is recommended in order to provide complete soil-plant fertility relationship at the site.

Organic Matter and Cation Exchange Capacity

The relatively low soil organic matter content at the vineyard site is directly related to the ability of the soil and plant to provide important nutrients including nitrogen, phosphorous, potassium, calcium, magnesium, and sulfur. Organic matter, also known as humus in its decomposed form, contains the highest cation exchange capacity, making it extremely important for improving the soils overall fertility.

The addition of organic matter is typically the most effective method when attempting to increase the CEC of the soil. For every 1% of soil organic matter there is 200 cmol/kg soil, which is much higher than that of any other soil colloids. Benefits of increasing the organic matter content include increased plant available water holding capacity, improved soil structure, more efficient water infiltration and gas exchange, more available micronutrients, pH buffering, improved cation exchange capacity, and an overall greater nutrient availability. While consistent low levels of organic matter may restrict beneficial microbial activity and lead to both soil compaction as well as erosion.

Nitrogen

The overall nitrogen concentrations in the samples were under the optimal amount. Nitrate levels between both pits ranged between 18 and 26 lbs/ac-furrow slice. It is recommended that roughly 10 to 20 pounds/acre be additionally supplied to the vineyard site. The site itself is not equivalent to an acre thus local conditions and experience along with variety to determine rates and timing. Nitrates in your irrigation source should also be allowed (ppm NO_3^- x 0.61 = lb N/ac-ft of water). Plant-tissue nitrogen should also be monitored as previously mentioned on an annual basis. Nitrate applications should be minimized prior to bloom, then applied through berry-set, and again immediately post-harvest. Any later applications are not recommended.

In order to increase nitrogen levels applying either inorganic or organic fertilizer and/or organic matter would help to increase nitrogen levels in the soil to increase vine health.

Phosphorous

No significant phosphorous issues seem to be present, most of the samples contained adequate phosphorous in order to maintain a health vineyard. Some horizons did contain higher concentrations however this can be due to the highly limited mobility of phosphorous. The soil pH and phosphorous availability go hand in hand. Phosphorous tends to be most available to vines when the soil pH is close to neutral or slightly lower. No extreme fluctuations in soil pH were evident creating no real threat of a deficiency or toxicity, rather the particular concentrations in phosphorous were once again due to its low mobility.

Potassium

Similar to that of phosphorous, their does not seem to be any deficiency or excess potassium on the vineyard site. The potassium levels throughout both soil profiles tend to stay in the medium to slightly higher range. Sufficient potassium is a positive trend due to its significant role in the drought tolerance of plants and their ability to withstand water stress.

Sulfur

Most irrigation water contains some amount of sulfur and should be analyzed before applying any additional fertilizer. Sulfur as a whole is typically a difficult nutrient to predict without the help of a plant analysis. Sulfur deficiencies are rare especially here in California. The sulfur concentrations for both soil pits ranged from one to two ppm while maintaining a level of 15 to 20 ppm will guard against any deficiencies; however irrigation water does in face supply a significant amount. Although the sulfur concentrations seem relatively low the sulfates may have leached below the sampling depth. Low amounts of sulfur within the soil medium may cause yellowing or the lack of vigor and should be monitored. Sulfur deficiencies often develop over long periods of time and should be monitored along with all other plant essential nutrients.

Calcium and Magnesium

Both calcium and magnesium are present in all the samples that were analyzed. In order to maintain a healthy soil environment a good calcium to magnesium ratio is essential. A typically healthy soil medium contains a calcium to magnesium ratio or 5:1. All the soil samples analyzed at various depths fall between 3:1 and 5:1 showing a good ratio. Magnesium deficiencies do not tend to occur until the ratio between it and calcium are up around 10 or 15:1 (Havlin et al., 2005). Overall both calcium and magnesium do not seem to be posing any real problem. If the ratio needs to be adjusted due to any alterations in the soil the addition of gypsum as a calcium supplement can be applied to increase the ratio.

Micronutrients

Zinc concentrations varied from low to very low in concentration ranging from 0.4 to 1 ppm. In order to maintain an adequate supply of zinc the soil levels should be kept above 1 ppm. A plant-tissue analysis at the appropriate time will more accurately determine the zinc availability to the plant. Zinc deficiency may be corrected with zinc sulfate trenching or solution injection or by broadcasting zinc chelate. Zinc sulfate may also be introduced through a foliar spray (Brown and Uriu, 1998).

Manganese, iron, and copper all seem to be present in sufficient amounts. The vines may respond to the application of manganese if the concentration is below 2 ppm. If copper levels fall below 0.3 ppm the vines could have a response with copper addition. Overall manganese, iron, and copper all seem to be at adequate concentrations.

Boron in some horizons seemed to be slightly low. Aiming for concentrations above 0.5 ppm will help to avoid any deficiency problems. A tissue analysis at the appropriate time will more accurately determine the plant availability. When applying boron be extremely cautious; thus the tissue analysis is key to avoid any detrimental effects from boron toxicity.

pH

The soil pH plays a key role in determining the availability of many nutrients. The topsoils have alkaline pH values (7.9 and 8.4), which implies the past addition of lime. These additions could have been intentional due to a specific amendment and or fertilizer used or through the irrigation water supply if the source is being distributed from a well. The uppermost horizons of both soil pits seemed to have pH levels slightly higher than ideal, while the remaining subsoil horizons in both pits were right around neutral to slightly acidic. All sampling depths were within a normal pH range and generally not of any real concern. The acidification of the high pH soils could improve the soil environment. Various sources of acidifying materials should be compared, but be aware that sulfate-sulfur has no acidifying power.

Soluble Salts

The soil salinity report does not indicate any severely sodic or saline problems in the soil samples analyzed. If sodium is a concern, broadcast/water-run amendment and incorporate if possible. Approximately 1.5 lb of elemental sulfur or 10 lbs of gypsum is required to replace 1 ppm of “exchangeable” sodium from six inches of soil.

Excess Lime

Lime was not a concern at the vineyard site, all levels of excess lime came back with results showing low concentrations.

Management Recommendations

The soil fertility could differ greatly with depth and should be taken into consideration. Concentrate on amending and fertilizing the topsoil zone only. However, take note of trends deeper in the soil profile that may need attention. Light frequent applications of fertilizer through the irrigation water will provide the most efficient uptake of most nutrients. Foliar additions of zinc are recommended. Limit fertilizer applications to active growth periods. An erosion control plan should be established along the eastern side of the vines due to the presence of the Salinas River. The river bank should be vegetated before next year's rainy season to help prevent increased sediment loss and an eventual vine threat.

CONCLUSION

The objectives of this project were to analyze the soil chemical and physical properties and the relationship of these to vine health, soil fertility, and the overall health of the soil. Upon assessing the properties, a plan that outlines the management strategies for the vineyard site were determined.

A total of two soils were analyzed that showed little variation in both physical and chemical aspects. The site as a whole is to be treated as one management unit due to the similar properties noted. Soil physical testing showed that the soil texture was adequate as a sandy loam for an established vineyard. The soil chemical properties for both sampling locations seemed to be sufficient to support a healthy vineyard with a few outliers to be monitored. A high sodium concentration in soil pit number one in the uppermost horizon is of some concern however with the presence of plenty calcium in the horizon no real threat is at hand. However, in both soil pits the topsoils contained alkaline pH's which implied some sort of lime being added in the past. This lime source could be from a potential well as a water source or from a past amendment being incorporated. The relatively low sulfate-sulfur concentrations could cause slight yellowing and reduced vigor and should also be monitored, but overall was not a major concern.

The information in this report should serve as a general guideline for the growers at the site when making management decisions for the vineyard. As recommended earlier in the report, a leaf blade and petiole sampling should be performed in order to gain a more accurate depiction of the soil-plant fertility relationship. Such analysis could cut down on future costs for maintaining the vineyards health and longevity. Furthermore, the erosion recommendations are general and a more advanced structural approach may be needed to keep the site maintained over time.

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APPENDIX