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THE EFFECTS OF CALCIUM ON AVOCADO GROWTH AND ROOT HEALTH

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INTRODUCTION

Many avocado growers are debating the question of whether or not to apply calcium to their groves. Some advocates say calcium is a necessary soil additive, creating almost magical improvements in soil chemical balance and tree growth. Others maintain that, since calcium is common in California soils, it serves only to improve soil structure in sodic soils or soils with permeability problems due to high sodium levels. Still others assert that, under most conditions, calcium additives do little to affect avocado growth and yield.

This article will provide you with the most current information on the effects of calcium applications on

- the nutrition of avocados in California,
- the chemistry and structure of avocado soils,
- the growth and reproduction of *Phytophthora cinnamomi,* the cause of avocado root rot,
- the resistance of avocado roots to root rot, and
- levels of soil microorganisms.

SOURCES OF CALCIUM

Several forms of calcium are commonly used as soil amendments with varied effects on soil nutrients and soil pH. In general, soluble calcium will bring the soil pH to neutral, either by raising the pH of an acidic soil or lowering the pH of a sodic soil. Gypsum ($CaSO_4.2H_2O$) can also lower the pH of an alkaline soil by precipitating bicarbonate and supplies calcium and sulfur, necessary plant nutrients. Gypsum is often used to increase soil permeability, reduce crusting, and loosen hard soils. Calcium nitrate ($Ca(N0_3)_2$) stabilizes soil pH to approximately pH 7 (neutral) and is an important source of the nitrate form of nitrogen. It is used as a cold-weather fertilizer, since the nitrogen is readily available in this compound. Calcium carbonate (calcite, calcitic limestone) is frequently applied to raise the pH of an acidic soil; however, since many California soils contain large amounts of naturally occurring limestone, further amendments may not be needed. In cases where the soil is decomposed granite and long—term fertilization with ammonium salts, urea, or anhydrous ammonia has acidified the soil, calcium carbonate may be used to raise pH. Dolomite, or dolomitic limestone, (carbonates of calcium and magnesium), occurs widely in nature and is also used to raise the pH of acidic soil. Calcium hydroxide (slaked or hydrated or builder's lime) or calcium oxide (unslaked or burned or quick lime) will raise soil pH drastically and requires careful handling; consequently these amendments are seldom used in California.

EFFECTS OF CALCIUM ON THE NUTRITION OF AVOCADOS IN CALIFORNIA

Calcium is a required element for avocado growth and is an important component of the cell wall and the exterior surface of cell membranes. In the plant cell wall, calcium controls growth, ion exchange properties, and enzyme activity. It also stabilizes cell wall structure by cross-linking with cell wall components. In avocados, calcium levels affect fruit yield, size, and postharvest quality. Fruit ripening is slowed by high internal levels of calcium and cold-induced disorders are decreased. In soils low in available calcium, calcium amendments to the soil have enhanced plant growth and fruit yield when used in conjunction with high levels of other plant nutrients such as phosphorus and nitrogen. For instance, in an acidic Australian soil, fruit yield in avocado was increased by gypsum amendments when used with manure and a cover crop. Different calcium compounds have varying effects on fruit yield in avocados. In an acidic soil (pH 4.8), moderate levels (two tons/ha year) of dolomitic lime or gypsum increased avocado fruit yield substantially, despite the fact that the trees appeared to be at optimal nutritional status. However, most avocado soils in California are not highly acidic, and these dramatic effects on growth and yield would not be expected. Furthermore, since much of our California avocado soil and irrigation water contain high levels of calcium, it is thought that additional applications of calcium are not required to achieve optimal calcium levels in avocados. In both greenhouse and field studies at the University of California, avocado growth and yield were not increased by gypsum amendments to typical, Phytophthora-free California avocado soils. However, when the soil was infested with the root rot fungus, avocado shoot and root growth and fruit yields were increased by gypsum soil amendments.

EFFECTS OF CALCIUM ON CHEMISTRY AND STRUCTURE OF AVOCADO SOILS

EFFECT ON NITROGEN. The effect of calcium on nitrogen in the soil may be a significant factor in the fertilization of crops, since an important pathway for nitrogen loss from the agrosystem is ammonia volatilization. Ammonia volatilization from soils after surface application of urea or inorganic nitrogen has been reported to be reduced by the addition of calcium nitrate in Texas. This effect, however, apparently requires large amounts of calcium nitrate. Ammonia volatilization is normally increased in calcareous soils and decreased in acidic soils; thus, it is an effect of soil pH. Addition of a calcium amendment to calcareous, high pH soils might have a small effect on lowering soil pH, thereby decreasing the amount of ammonia volatilized. This may increase the availability of nitrogen to avocados and therefore increase growth and yield under some conditions.

EFFECT ON CARBON DIOXIDE PRODUCTION. The soil carbon dioxide level (CO_2) is usually controlled by the activity of microorganisms, water content, soil texture, temperature, and root respiration. In calcareous soils, high CO_2 levels increase the concentrations of soluble calcium and bicarbonate in the soil water. In California avocado soils, the water content is the single most important factor controlling CO_2 concentration. Wet soils favor high levels of CO_2 which in turn can affect soil ecology. A high concentration of carbon dioxide can inhibit many types of soil microorganisms. Calcium amendments can improve permeability and increase aeration which leads to lower soil CO_2.

EFFECT ON MICRONUTRIENTS. The form of calcium in the soil, through its effect on pH, can influence the availability of micronutrients to avocado groves in California. Iron, manganese, copper, and zinc are all less available to plants in alkaline soil conditions. Moist calcareous soils, such as those found in many irrigated avocado groves in California, are too alkaline to allow iron and other micronutrients to stay in an available form. In California soils, adding calcium amendments that raise the soil pH above 8.0 is not advised *(e.g.,* slaked or burned lime), due to problems with micronutrient deficiency. Amending soil with a calcium compound that does not excessively raise soil pH, such as gypsum, should not affect availability of these micronutrients.

EFFECTS OF CALCIUM ON SOIL DRAINAGE. Calcium amendments can greatly increase soil permeability and improve drainage under specific conditions. Calcium in the soil stabilizes humus compounds and flocculates the clay portion of the soil. The addition of gypsum to soil has been shown to improve drainage when the soil is fine—textured and high in sodium. Calcium displaces the sodium on the surfaces of the clay particles, causing the soil particles to shrink. This decreases clay dispersion and increases the soil's porosity. If a high sodium soil is restricting water flow and gypsum is recommended, the gypsum ideally should be incorporated by breaking up the impermeable layer and mixing the gypsum into the soil. In the case of an avocado grove where soil incorporation is difficult, commercial grade (bulk) gypsum can be used by broadcasting around the base of trees, which will help infiltration. Gypsum can also increase soil drainage by increasing the mineral concentration of soil water low in dissolved minerals, such as snow melt, and thereby preventing surface sealing. Finely ground gypsum can be dissolved and added with the irrigation water to increase permeability. However, in soil columns in the greenhouse, this type of gypsum has been shown to actually plug the soil pores when mixed into the soil, so only the bulk gypsum should be broadcast around the base of trees. When poor drainage is caused by soil compaction, gypsum alone is unlikely to have an effect on improving drainage, and tillage may be required for improvement of drainage. In an established grove, deep tillage is usually not an option.

EFFECTS OF CALCIUM ON GROWTH AND REPRODUCTION OF *P. CINNAMOMI*

Calcium appears to inhibit *P. cinnamomi* and reduce avocado root rot. High levels of exchangeable calcium in soil have been linked to Phytophthora root rot suppressiveness in an Australian rain forest soil. Losses from Phytophthora root rot were minimal in Australian avocado groves where the soils had high levels of available calcium and nitrogen in combination with organic matter. This inhibition of fungal growth does not seem to be pH-based since $CaSO_4$ often reduces root rot, while having a minimal effect on pH.

The effects of calcium compounds on root rot are complex and interrelated with other factors: under some conditions, the application of calcium did not affect root rot caused by *P. cinnamomi.* In Australia, avocado root rot was significantly lower in gypsum—amended trees than in unamended trees, although the benefits were decreased by the combination of a very susceptible host *(Persea americana)* and favorable conditions for Phytophthora growth (periodically flooded soil). The type of calcium compound added greatly affects disease control. In Australian avocado groves, applications of dolomite or phosphogypsum did not reliably decrease disease incidence in avocados, although the pH and levels of exchangeable calcium rose. The application of gypsum to avocados in California often has a suppressive effect on root rot caused by *P. cinnamomi.*

ZOOSPORE MOTILITY. Calcium may reduce the ability of *Phytophthora cinnamomi* zoospores to reach avocado roots. Zoospores are the swimming spores *of Phytophthora* that move through water to reach avocado roots and induce root rot. Calcium is pivotal in the zoospore's ability to swim, and is required for normal functioning of the flagella, the propulsive organs. If the calcium concentration is greater than 1mM (0.5meq/l), the flagella malfunction, disrupting the normal swimming patterns. The zoospore is unable to swim in a straight line and instead swims in circles. Zoospores influenced by calcium in this manner would be unable to reach the roots of the host plant.

ZOOSPORE ENCYSTMENT. Calcium may induce premature encystment of zoospores and so prevent them from reaching avocado roots. Zoospores encyst, that is they stop swimming, and prepare to infect the host, usually after reaching the host roots. If zoospores encyst before reaching the roots of the host, they are unable to infect and will die. Encystment of zoospores is caused by a variety of factors including extremes of pH and temperature, nutrients, and high concentrations of root exudates. Varying levels of calcium in sterile solutions *of Phytophthora* zoospores have been used to study the mechanism of encystment by several researchers. Some calcium is necessary for normal zoospore physiology, but high levels of calcium (5 meq/1 and higher) in solution cause the zoospores to encyst and germinate immediately. Fine-textured soil has been shown to cause rapid encystment of swimming zoospores, perhaps due to the decrease in motility associated with small pores in the soil. These effects of premature encystment and germination in the presence of high calcium levels could result in fewer zoospores reaching the host.

ZOOSPORE ADHESION. Calcium may increase the probability that zoospores stick to soil particles rather than the roots. In order to successfully infect the host root, zoospores must adhere to the host tissue after they encyst. Zoospores that do reach the host root under high calcium (5meq/1) conditions have a better chance of infection, due to a calcium requirement for adhesion. However, the zoospore is more likely to encyst prematurely away from the host under high calcium conditions and stick to soil particles or organic matter in the soil, instead of being moved passively by water movement through the soil to the host roots. This decreases the likelihood of zoospores infecting the host roots when the roots are growing in soil amended with calcium. The lowest level of calcium in solution needed to affect *Phytophthora cinnamomi* under field conditions is 0.5 meq/1, while a solution saturated with gypsum is 7.5 meq/1 calcium, and irrigation water from the Colorado river has about 1 meq/1 calcium.

SPORANGIAL PRODUCTION. Gypsum appears to reduce sporangial production of *P. cinnamomi.* Zoospores of the fungus *Phytophthora* are formed inside structures called sporangia, and are released when conditions are favorable. Addition of gypsum has been shown to reduce sporangial production and zoospore release in both soil and in a sterile solution. However, the addition of another calcium compound, calcium nitrate, stimulates production of sporangia, although the numbers of zoospores released are fewer. The combination of nitrogen and calcium in this case seems to stimulate both *Phytophthora* and bacteria antagonistic to *Phytophthora,* which have been observed attached to the sporangial walls. This bacterial antagonism may kill the sporangia and explain the poor release of zoospores observed. In our studies at UC Riverside, we have observed that in soil amended with gypsum, there is a decrease in both the number and size of the sporangia produced. Fewer zoospores are then available to infect avocado roots. Addition of gypsum could reduce avocado root rot by interfering directly with sporulation of the pathogen.

EFFECTS OF CALCIUM ON RESISTANCE OF AVOCADOS TO ROOT ROT

Calcium amendments can reduce avocado root rot by creating a favorable environment for the growth of the tree. Calcium amendments (such as gypsum) can increase permeability, allowing water to drain freely through the soil, which allows more oxygen to reach the roots. Root rot decreases in a soil with high levels of oxygen, because root growth is inhibited more by low oxygen than is *Phytophthora.* Vigorous root growth is important in disease resistance, and since low oxygen inhibits root growth this is another possible reason that soils low in oxygen are conducive to root rot.

Higher calcium concentrations have been observed in avocado roots grown at neutral pHs than in those roots grown in more acidic soils (pH 5.2). Increased calcium in avocado roots correlates with a decrease in root rot incidence. The increased availability of calcium at higher soil pHs may allow the plants to be more resistant to fungal attack. *Persea indica* grown in a California soil with calcium amendments (calcium nitrate, calcium chloride, and calcium sulfate) in a UCR greenhouse showed increased resistance of the roots to infection by zoospores. The role that calcium might play in this root rot resistance has not been well defined. The presence of calcium has been shown to reduce damage to the avocado cell wall by the *Phytophthora* enzyme polygalacturonase. Avocado root cell walls exposed to this enzyme become more permeable, creating openings through which the pathogen can enter the plant. Calcium strengthens cell walls, making them less permeable and more resistant to *P. cinnamomi.*

Calcium also stabilizes membranes, leading to less root exudation of amino acids, sugars, and other cell metabolites. *Phytophthora cinnamomi* zoospores, when released from the sporangium, are attracted to these nutrients exuded from the host roots and swim toward the roots. Increased root exudation has been linked to both low calcium levels (0.13 meq/1) and compacted soil. High levels of calcium have also been shown to affect adversely the zoospore's ability to detect host exudates. Calcium could affect the disease by reducing the number of zoospores attracted to the roots. However, most of our California soils have adequate calcium levels to meet the nutritional needs of avocados; in our studies, increasing the level of calcium in the soil with gypsum amendments did not increase the disease resistance of bare avocado roots. Amending the soil with gypsum did decrease the disease incidence, probably by directly affecting the fungus.

EFFECTS OF CALCIUM ON LEVELS OF SOIL MICROORGANISMS

Varying degrees of inhibition of *Phytophthora cinnamomi* by soil microorganisms, such as *Rhizobium, Epicoccum,* and *Penicillium,* have been observed in culture and in soil. In natural situations, microorganisms have been shown to be instrumental in control of root rot. Soils suppressive to avocado root rot are present in Australia as well as in California. These soils have high levels of organic matter, high levels of available calcium, available nitrogen, and high microbial activity. High levels of nutrients available for both plants and microorganisms in a soil may affect avocado root rot in two ways: 1) by increasing plant growth and root regeneration, and 2) by nourishing microorganisms antagonistic to *Phytophthora.* Calcium nitrate added to soil in which avocados are grown can increase the populations of beneficial soil fungi. Calcium compounds, such as calcium carbonate, that raise the pH of acid soil can also stimulate microbial activity. The problem with adding calcium or other amendments to soil to increase beneficial microorganisms is that these beneficial microorganisms must be present. It may be an erroneous supposition that these beneficial organisms are present in all avocado soil. In our studies with California avocado soils, the number and types of beneficial microorganisms were not increased by the addition of gypsum, suggesting that gypsum suppressed the pathogen directly, rather than by stimulating other microorganisms.

SUMMARY

Calcium amendments to the soil of an avocado grove can improve soil permeability, root growth, fruit yield, and disease resistance when the soil is poorly drained and infested *with Phytophthora cinnamomi.* Factors such as the calcium compound used, the amount of exchangeable sodium in the soil, and the pH of the soil can drastically affect such improvements. Much of the research on fruit yield and disease resistance was done in acidic soils that were low in calcium and may not always apply to alkaline or neutral soils. Many California soils are already high in calcium carbonate, so the addition of more calcium may have little effect on avocado nutrition. Furthermore, in California, calcium compounds that drastically raise pH, such as calcium hydroxide, are usually not recommended due to problems with micronutrient availability.

Gypsum, a commonly used calcium amendment, can increase soil permeability, but only when the permeability problem is caused by the presence of exchangeable sodium or irrigation water low in dissolved minerals. However, gypsum can have a suppressive effect on avocado root rot in southern California soils. It may inhibit *P. cinnamomi* by causing premature encystment and adhesion of zoospores, reduced sporangial production and zoospore numbers, and improved soil drainage. We recommend gypsum application to avocado soils that are infested with *Phytophthora cinnamomi* and drain poorly due to high exchangeable sodium or irrigation water low in dissolved minerals. Gypsum applications for calcareous, well drained, disease-free soils are not likely to improve yields. Calcium is not a cure-all for avocado problems, but prudent, informed applications can, in some cases, improve the health and productivity of an avocado grove.