Compost
Demonstration Project,
Southern California:

Use of Yard Trimmings and Compost on Citrus and Avocado

September 1999

California Environmental Protection Agency
Integrated Waste Management Board

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EXECUTIVE SUMMARY

A two-year project designed to investigate the value of using raw yard trimmings or composted yard trimmings as mulch on citrus and avocado groves was initiated in January 1997. Cooperators included the California Integrated Waste Management Board (CIWMB), the City of San Diego, the City of Los Angeles, the County of Santa Barbara, personnel from the University of California Department of Plant Pathology and Department of Environmental Sciences and Soils, farm advisors from San Diego County, Riverside County, and Ventura County, and citrus and avocado growers.

Composted yard trimmings and/or raw yard trimmings were applied to trees in three commercial citrus groves and four commercial avocado groves in randomized, well-replicated experiments. Two of the citrus groves were in Ventura County and the third was in the Coachella Valley of Riverside County. Two of the avocado groves were in Ventura County, one was in San Diego County and another was in Santa Barbara County.

All of the commercial groves examined were infested with *Phytophthora* root rot. While *Phytophthora* infestations are normal for citrus groves and cause only a chronic yield loss, about 60 percent of the avocado groves in California suffer from root rot. *Phytophthora* root rot in avocado is much more serious and will kill the trees if the disease is not controlled. Trees mulched with raw or composted yard trimmings were contrasted with unmulched trees with respect to the following factors: growth, yield, appearance, leaf nutrients, root growth, *Phytophthora* populations, nematode populations, rodent damage, soil characteristics, microbial numbers, microbial activity, soil enzymes, soil water, nitrate in ground water, and weed suppression.

Because application of mulch to citrus and avocado trees was viewed as a major impediment to its use, a pneumatic mulch spreader was purchased. It featured a unit in which the mulch was fed into a blower, which in turn deposited the mulch onto the trees through a 30-meter flexible hose. The mulch spreader was used to apply mulch to a number of the trials. It worked reasonably well, and for some of the avocado orchards that were on steep hillsides, it was the only practical method of applying the mulch. Deficiencies in the spreader were the small 1-cu-meter hopper size, which required constant refilling and the relatively slow speeds at which the mulch could be applied. On flat ground, the mulch could be spread faster with more conventional mulch spreaders. The mulch spreader was featured in a number of field days. Local commercial mulch applicators developed similar mulch spreaders with larger hoppers and greater application speeds.

Results indicated that avocado trees benefited from the mulch and compost treatments. Avocado trees exhibited striking increases in root growth associated with mulch applications. Two of the four groves exhibited improved growth, yield, or appearance associated with mulch application. These results were attributed to a reduction in avocado root rot provided by the mulch and compost treatments. It was shown that microbial numbers and activity were greatly increased in the vicinity of the mulches. Wood decay fungi, which proliferated in the mulches, produce two enzymes, cellulase and laminarinase. These enzymes dissolve the hyphae of the avocado root rotting fungus, *Phytophthora cinnamomi*. The enzymes were found to be abundant in the mulch. As a result, root infections due to *P. cinnamomi* as well as populations of *P. cinnamomi* were very low in the vicinity of the mulch.

Unfortunately, neither the effects of the microorganisms or the enzymes they produced extended deep into the soil, and the beneficial effects of the mulch on avocado root rot was restricted to the soil surface layers. Root rot and *P. cinnamomi* existed unabated in the soil underneath the mulches. However, avocado trees have very shallow roots, which proliferated

abundantly in the mulch and the soil-mulch interface, where they were relatively free of avocado root rot.

Citrus, on the other hand, did not benefit as much from mulching. Only one of the three trials exhibited improved growth, yield or appearance due to mulching. This effect was shown to be the result of a nitrogen deficiency, which was remedied by the addition of mulch and compost. Because citrus roots generally reside deeper in the soil, mulching apparently had little effect on *Phytophthora* populations in citrus groves.

Both citrus and avocado trees benefited from improved nutrition, water savings, and weed suppression associated with mulching. However, these benefits are not unique. Growers can achieve the same results via more traditional farming methods such as fertilization, irrigation and herbicide treatments. While these benefits of mulching may pay for mulch application costs, there are few other compelling reasons to use mulch in citrus. In avocado, these benefits are supplemented by the unique root rot-inhibiting properties of mulch, which make mulching in avocados a very attractive cultural practice.

When mulches are used on either citrus or avocado, irrigation must be closely monitored. Mulch keeps the soil moist for longer periods of time. There is a potential danger of growers overwatering their trees and exacerbating root rot, which is favored under moist conditions. This could have a disastrous effect on citrus, while on avocados, overwatering would prevent the trees from realizing the full benefits of mulching for growth and root rot suppression. Under these conditions, avocado trees may be stunted or killed by *Phytophthora,* especially if the overwatering occurs on young trees before they initiate roots into the mulch layer.

No damaging effects of prudent mulching of avocados and citrus with raw or composted yard trimmings were detected. However, rodents such as gophers and voles seemed to prefer trees with mulch. During this project, these rodents killed a significant number of trees. Ground water contamination with nitrate from mulch was found to be negligible. Heavy metals and other toxic compounds were occasionally found in mulches or composts, but these levels did not greatly differ from levels found in natural California soils and were far less than the levels of those compounds permitted in sewage sludge. *Sporothrix* and *Aspergillus* are two genera of fungi, which were found to be particularly prevalent in the yard trimming mulch. These genera have been associated with allergies and other diseases of humans.

Mulches were found to be an effective weed suppressant in citrus and avocado orchards. A 7.5-cm layer will completely control weeds. A 15-cm layer will last for three years.

An estimated 1700 acres of the 68,000 acres of avocados grown in California are replanted every year. If half of the replanted acreage receives a minimum of two mulch applications of 1 cu yd/tree before reaching maturity, this would result in a very conservative annual market for mulch of about 170,000 cu yd/yr.

INTRODUCTION

Citrus with a value of more than $600 million and avocados with a value of more than $240 million annually are among the top 10 most valuable agronomic commodities in California. Citrus is grown on 275,000 acres, with 109,000 of these acres in southern California. Avocados are grown on 68,000 acres, principally in southern California.

Although the effects of yard trimmings used as mulches on citrus and avocado have not been adequately tested, mulches in general have been shown to be highly beneficial to growth and production of many crops. The use of mulches has been reported to result in water conservation, reduced weed growth, increased soil organic matter, reduced ground water contamination, reduced fluctuations in soil temperature, increased soil fertility, increased water penetration into the soil, and control of soil-borne diseases. If mulches are compatible with citrus and avocado production, we believe that the use of mulches and compost on avocado and citrus groves would be a wonderful marriage of technology and agriculture that would benefit growers and the public alike.

Much of the citrus and avocado production is in Southern California. There is also an abundance of high-quality yard trimmings in Southern California to use as mulch.

If these yard trimmings were to be used as mulch for citrus and avocado groves in Southern California, the shipping cost to these local agricultural markets would be relatively low compared to the cost for shipping to more distant agricultural markets.

An estimated 1700 acres of the 68,000 acres of avocados grown in California are replanted every year. If half of the replanted acreage receives a minimum of two mulch applications of 1 cu yd/tree before reaching maturity, this would result in a very conservative annual market for mulch of about 170,000 cu yd/yr. At these rates of application, there is a potential market for mulch application of about 10 million cu yd/yr. If rates and demand were to increase, it is feasible that demand could be as high as 41 million cu yd/yr.

Avocado trees in particular are thought to benefit from the use of organic mulches. The limiting factor in avocado production is *Phytophthora* root rot caused by *Phytophthora cinnamomi*. Despite intensive efforts to control the disease by resistant rootstocks, irrigation management, soil sterilization and fungicides, *Phytophthora* root rot now affects 60-75 percent of California groves and the 1988 losses to *Phytophthora* root rot were estimated to be $30 million.

Successful control of *Phytophthora* root rot has been difficult to achieve. Increasing restrictions on the use of chemical fungicides are imposing additional constraints on disease control. The most reasonable approach to managing *Phytophthora* root rot is a combination of resistant rootstocks, chemical control, biocontrol and cultural methods.

The use of mulches to control *Phytophthora* and enhance growth of avocado could be a major weapon in our effort to control avocado root rot. There is a great deal of evidence that mulches suppress *Phytophthora* root rot throughout the world. A technique known as the Ashburner method uses mulches to suppress *Phytophthora* root rot in Australia. It is thought that mulches provide a food base for biocontrol agents and therefore allow for the distribution and survival of biocontrol agents, which suppress *Phytophthora* root rot.

The use of some mulches on citrus, however, has resulted in an increase of *Phytophthora* root rot and damage to the tree. Alfalfa hay and sewage sludge used as mulches have both resulted in increased root damage to citrus. To date there is no evidence that yard trimmings used as mulch will damage citrus.

Composted yard trimmings have several advantages over raw yard trimmings. Most importantly, it is free of pathogens, which is very important to many growers who fear the introduction of *Phytophthora* into their groves. However, there are questions about whether abundant nutrients are available to support the growth of natural biocontrol agents after composting. Raw yard trimmings are cheaper and if they support growth of biocontrol organisms, they may be a more economical product for growers.

The purpose of this project is to provide the necessary research that will demonstrate to citrus and avocado growers the value of using raw yard trimmings or compost as mulch. Data were gathered on the effects of yard trimmings and compost on growth and yield of citrus and avocado as well as on their effects on root rot caused by *Phytophthora* in 1997 and 1998. In order to accomplish the project goal, a cooperative team consisting of members from the University of California, private industry, state, county and city governments and agriculture were assembled. Cooperators in this project are listed below:

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MATERIALS AND METHODS

In order to assess the effects of mulch and compost on citrus and avocado production, seven field trials (three citrus and four avocado) were established throughout southern California at sites representative of the industries. The sites, locations and treatments are described below.

Debonne Management Citrus Trial

The Debonne trial consisted of 8-yr-old Oroblanco grapefruit on Troyer rootstock, which were planted into soil infested with *Phytophthora* root rot. The trial was located in Thermal, California, in Riverside County. The trees were treated annually in 1997 and 1998 with either composted or raw yard trimming mulch received from California Bio-Mass in Thermal, California (see Tables 37, 38). Mulch was spread under the tree canopy out to the drip line but was kept away from the trunk.

Twenty replicate trees were treated annually with 1/3 cu yd of composted yard trimming mulch. Twenty replicate trees were treated annually with 1/3 cu yd of raw yard trimming mulch. Twenty replicate trees received no mulch. The trial was irrigated via mini-sprinklers. The plot was designed as a randomized block design with 20 blocks (one tree/treatment/block).

Pommer Ranch Citrus Trial

The Pommer trial consisted of 3-yr-old Eureka lemon on Macrophylla rootstock, which were planted into soil infested with *Phytophthora* root rot. The trial was located in Oxnard, California in Ventura County. The trees were treated annually, in the spring from1994-1998, with raw yard trimming mulch obtained from the Bureau of Sanitation, Dept. of Public Works, in the City of Los Angeles (see Tables 37, 38). Mulch was spread under the tree canopy out to the drip line and also down the rows as a strip, but not between rows of trees. Mulch was kept away from the trunks.

Twenty replicate trees annually received a 2.5-cm layer of mulch (1 cu yd/tree). Twenty trees annually received a 7.5-cm layer of mulch (2.9 cu yd/tree). Twenty trees annually received a 15-cm layer of mulch (5.7 cu yd/tree). Finally, twenty trees received no mulch. The trial was irrigated via drip irrigation. The plot was designed as a randomized block with five blocks (four trees/treatment/block) for a total of 80 trees.

Essick Ranch Citrus Trial

The Essick trial consisted of 3-yr-old navel oranges on Troyer rootstock, which were planted into soil infested with *Phytophthora* root rot. The trial was located in Ojai, California in Ventura County. The trees were treated annually, in the spring from1994-1998, with raw yard trimming mulch obtained from the Bureau of Sanitation, Dept. of Public Works, in the City of Los Angeles and from the Solid Waste Management Dept. of Ventura County (see Tables 37, 38). Mulch was spread under the tree canopy out to the drip line and also down the rows as a strip, but not between rows of trees. Mulch was kept away from the trunks.

Twenty replicate trees annually received a 2.5-cm layer of mulch (1 cu yd/tree). Twenty trees annually received a 7.5-cm layer of mulch (2.9 cu yd/tree). Twenty trees annually received a 15-cm layer of mulch (5.7 cu yd/tree). Finally, twenty trees received no mulch. The trial was irrigated via mini-sprinklers. The plot was a randomized design with five replications (four trees/replication/treatment) for a total of 80 trees.

Vedder Ranch Avocado Trial

The Vedder trial consisted of mature, 12-year-old Hass avocados on seedling rootstocks with severe avocado root rot in Carpinteria, California in Santa Barbara County. Trees were treated annually, in the spring of 1997 and 1998, with either composted or raw yard trimming mulch. Mulch was spread under the tree canopy out to the drip line but was kept away from the trunk.

Twenty replicate trees were treated with composted yard trimmings obtained from Community Recycling and Resource Recovery, Sun Valley, California (see Tables 37, 38). Twenty replicate trees were treated with raw yard trimmings obtained from Solid Waste Management, Santa Barbara County (see Tables 37, 38). Rates for the treatments were 1.5 cu yd/tree. Twenty replicate trees received no mulch. The trial was irrigated via mini-sprinklers. The plot was designed as a randomized block design with five blocks (four trees/treatment/block) for a total of 60 trees.

Powell Ranch Avocado Trial

The Powell trial consisted of young Hass seedlings on Spenser rootstock planted into a soil infested with *Phytophthora* root rot. The trees were planted in November of 1997. The trial was located in Escondido, California in San Diego County. Trees were treated annually in the winter of 1997 and 1998 with either composted or raw yard trimmings received from the City of San Diego Environmental Services Dept. (see Tables 37, 38). Mulch was spread under the tree canopy out to the drip line but was kept away from the trunk.

Twenty trees received 1/3 cu yd of raw yard trimmings. Twenty trees received 1/3 cu yd of composted yard trimmings. Twenty trees received 1 cu yd of raw yard trimmings. Finally, twenty trees received no mulches. The trial was irrigated via mini-sprinklers. The plot was designed as a randomized block design with 20 blocks (one tree/treatment/block) for a total of 80 trees.

Vanoni Ranch Avocado Trial

The Vanoni trial consisted of 3-year-old Hass avocado on three types of rootstocks (Duke 7, Thomas and Toro Canyon) which were planted into soil infested with *Phytophthora* root rot. The trial was located in Somis, California in Ventura County. The trees were treated annually during the summers from 1994-1998 with a mulch derived by processing the wood, bark, leaves and fruit of *Eucalyptus globulus* through a commercial brush chipper (see Tables 37, 38). Mulch was spread under the tree canopy out to the drip line but was kept away from the trunk.

Sixteen trees of each rootstock received 1/3 cu yd of the raw mulch annually. Sixteen trees of each rootstock received no mulch. Sixteen trees of each rootstock received a yearly commercial application of Aliette fungicide (3.8 L, 100 ppm active ingredient), which is used for control of *Phytophthora* root rot. Sixteen trees of each rootstock received both the raw mulch and the Aliette fungicide. The trial was irrigated via mini-sprinklers. The plot was designed as a completely randomized factorial with rootstock, fungicide and mulch being the three factors. There were 16 replications per treatment for a total of 192 trees.

Sprinkling Ranch Avocado Trial

The Sprinkling trial consisted of 3-year-old Hass avocado on three rootstocks (Duke 7, Thomas, and UC2011) which were planted into soil infested with *Phytophthora* root rot. The trial was located in Somis, California in Ventura County (see Tables 37, 38). The trees were treated annually, during the spring from 1994-1998, with raw yard trimmings obtained from Agromin in Ventura County. Mulch was spread under the tree canopy out to the drip line but was kept away from the trunk.

Twenty trees of each rootstock received 1/3 cu yd of mulch annually. Twenty trees of each rootstock received no mulch. Twenty trees of each rootstock received a yearly commercial application of Aliette fungicide (3.8 L, 100 ppm active ingredient), which is used for control of *Phytophthora* root rot. Twenty trees of each rootstock received both the yard trimming mulch and the Aliette fungicide. The trial was irrigated via mini-sprinklers. The plot was designed as a randomized block factorial with rootstock, fungicide and mulch being the three factors. There were 20 blocks with one replicate per block for a total of 240 trees.

Mulch and Compost Application

Mulch was applied, by hand, by commercial mulch applicators or with a FINN AEM Spreader (Model 2000), which was purchased with the help of the City of San Diego, Environmental Services Dept. This pneumatic mulch spreader featured a unit in which the mulch was fed into a blower, which in turn deposited the mulch onto the trees through a 30-meter flexible hose. For plots on steep hillsides, this was the only practical way of applying the mulch.

Data Acquisition

Plots were evaluated for crop growth (canopy volume and stem diameter), foliage appearance, fruit yield, leaf nutrients (N, P, K, Ca, Mg, Na, Zn, Mn, Cu, Fe, Cl, and B), root growth, *Phytophthora* populations, nematode populations, rodent damage, soil characteristics (N, P, K, Ca, Mg, Na, Zn Mn total carbon, pH, conductivity, and percent organic matter), microbial numbers, microbial activity, soil enzymes, soil water, nitrate in ground water and weed suppression. Mulches were analyzed for bulk density, cation exchange capacity, conductivity (mmhos/cm), pH, total carbon, ash content, N, P, K, As, Cd, Cu, Pb, Mo, and Zn.

FINDINGS

Growth and Yield of Citrus and Avocado

Mulching increased tree canopy volume in only one of the three citrus trials. In the Debonne trial, canopy size was increased 17 percent by composted yard trimmings and 15 percent by raw yard trimmings (Table 1). Visual tree ratings based on color and health of the canopy were also significantly higher in both the raw composted yard trimming treatments than in the untreated trees in the Debonne trial (Table 1). This effect was thought to be the result of a nitrogen deficiency which was, in part, remedied by the addition of raw mulch or compost (see leaf nutrient section). In the other two citrus trials, mulch had no affect on canopy size or visual rating (Tables 2, 3).

Trunk diameters were significantly reduced by raw yard trimmings applied to any depth in the Pommer trial (Table 2). This effect may be due to gophers, which killed several trees in this trial (dead trees were excluded from the analysis). In the other two trials, mulch had no significant effects on trunk diameters (Tables 1, 3). Mulch had no significant effect on citrus yields in any of the three trials (Tables 4,5,6). Mulch had no effect on fruit size in the Essick trial (Table 6). Mulch also had no effect on granulation of fruit, which was a prevalent disorder, in the Debonne trial (Table 4).

Mulching increased tree canopy volume in only one of the four avocado trials. In the Sprinkling trial, raw yard trimmings increased the canopy volume of trees on Duke 7 rootstock by 89 percent (Table 10). In this same trial, raw yard trimmings did not significantly increase the canopy size of avocados on the more *Phytophthora* resistant rootstocks UC2011 and Thomas (Table 10). In the Vedder trial, raw yard trimmings reduced canopy volume by 27 percent. However, in this same trial, composted yard trimmings did not reduce canopy size (Table 7). In the other two trials, mulch had no significant affect on canopy volume (Tables 8, 9), although in earlier years, raw yard trimmings appeared to reduce canopy volume in the Vanoni trial.

Mulching increased trunk diameters in only one of the four avocado trials. In the Sprinkling trial, raw yard trimmings increased the trunk diameters of trees on Duke 7 rootstock by 38 percent and the diameters of trees on UC 2011 by 15 percent (Table 10). The diameters of trees on the more *Phytophthora*-resistant Thomas rootstock were not affected by mulch applications (Table 10). In the other three trials, mulch had no effect on trunk diameters (Tables 7, 8, 9).

Mulching improved visual tree ratings in two of the four avocado trials. In the Vedder trial in 1998, composted yard trimmings but not raw yard trimmings significantly improved visual appearance of the trees (Table 7). In the Sprinkling trial, mulch significantly improved the visual appearance of trees on Duke 7 and UC 2011 rootstocks, but not on the more resistant Thomas rootstock (Table 10).

In the two avocado plots in which yield was taken, mulch increased yield in one and decreased yield in the other. In the Vanoni trial, raw yard trimmings reduced yield by 25 percent (Table 11). In the Sprinkling trial, raw yard trimmings significantly increased yield of trees by 61 percent when all rootstocks were combined. Yield was increased more on Duke 7 rootstock than the other more resistant rootstocks, but was not significantly increased by raw yard trimmings for any of the rootstocks alone (Table 12).

Mulch did not affect overall fruit size in the Vanoni trial. However, in 1996 the mulched trees had smaller fruit, while in 1998 the mulched trees had significantly larger fruit (Table 11). In the Sprinkling trial, mulch did not affect fruit size (Table 12).

Where mulches increased the growth, appearance or yield of avocado, it is believed that mulches reduced avocado root rot and improved the ability of avocado to grow in the presence of avocado root rot (see root growth and *Phytophthora* sections). The rootstocks less tolerant to root rot responded more favorably to mulching than did the more resistant rootstocks (Table 12). In the Sprinkling trial, the mulches compared favorably to applications of the fungicide Aliette, which is used to control avocado root rot, and the best treatments were mulches combined with Aliette (Tables 10, 12).

Where mulches reduced growth and yields of avocado it is believed that the mulches prevented the soil from drying out (see section on soil moisture). Avocado root rot is favored by wet soils. At the Sprinkling ranch, irrigation was monitored by tensiometer so that the trees were only watered when the soil became dry. In the Vanoni trial, trees were watered every two weeks by the calendar, and this apparently kept the soil too wet and the inhibitory effects of the mulch on avocado root rot was decreased. As the trees got older and used more water, the trees were no longer too wet and the mulches no longer inhibited growth or yield.

Mulch Application

Because labor costs associated with application of mulch to citrus and avocado trees was viewed as a major impediment to its use, a pneumatic mulch spreader was purchased. It featured a unit in which the mulch was fed into a blower, which in turn deposited the mulch onto the trees through a 30-meter flexible hose. The mulch spreader was used to apply mulch to a number of the trials. It worked reasonably well, and for some of the avocado orchards, which were on steep hillsides, it was the only practical method of applying the mulch. Deficiencies in the spreader were the small 1-cu-meter hopper size, which required constant refilling and the relatively slow speeds at which the mulch could be applied. On flat ground, the mulch could be spread faster with more conventional mulch spreaders. The mulch spreader was featured in a number of field days, and local mulch applicators developed similar mulch spreaders with larger hoppers and greater application speeds.

Leaf Nutrients of Citrus and Avocado

Mulch significantly increased nitrogen concentrations in citrus leaves in all of the three citrus trials (Tables 13, 14, 15). In the Debonne trial, composted yard trimmings significantly increased nitrogen in the citrus leaves when compared to either raw yard trimmings or no mulch (Table 13). The increased absorption of nitrogen by mulched trees in the Debonne trial is thought to be the reason these trees exhibited increased growth and improved color and appearance (see section on growth and yield).

Phosphorus concentrations in citrus leaves was increased by raw yard trimmings or composted yard trimmings in one of the three citrus trials and unaffected by mulch or compost in the other two trials (Tables 13, 14, 15). Calcium concentrations in citrus leaves was reduced by either yard trimmings or composted yard trimmings in two of the three citrus trials (Tables 13, 14, 15). Magnesium concentrations in citrus leaves were reduced by raw or composted yard trimmings in one of the three citrus trials and unaffected in two trials (Tables 13, 14, 15). Potassium concentrations in leaves of citrus were increased by raw or composted yard trimmings in one of three trials and unaffected in the other two trials (Tables 13, 14, 15). Sodium concentrations in leaves of citrus were unaffected by raw or composted yard trimmings in all three citrus trials (Tables 13, 14, 15). Zinc concentrations in citrus leaves were increased by raw or composted yard trimmings in two of the three citrus trials and unaffected in one trial (Table 13, 14, 15). Manganese concentrations in citrus leaves was unaffected by raw or composted yard trimmings in all three of the trials (Table 13, 14, 15). Copper concentrations in citrus leaves were increased by composted yard trimmings in the Debonne trial, but unaffected by the raw yard trimmings in all three of the citrus trials (Tables 13, 14, 15). Iron concentrations in the leaves of citrus were unaffected by raw yard trimmings or composted yard trimmings in all three citrus trials.

The Pommer trial was the only trial in which boron was measured in leaf tissue, because it was the only trial where boron was suspected of being present in damaging amounts. Raw or composted yard trimmings significantly reduced boron concentrations in the leaves of citrus in that trial (Table 14).

Raw yard trimmings significantly increased nitrogen concentrations in avocado leaves in one of the three avocado trials tested (Tables 17, 18). In the remaining two avocado trials tested, concentrations of nitrogen in avocado leaves were unaffected by raw or composted yard trimmings (Tables 16, 20).

Phosphorus concentrations in avocado leaves were unaffected by raw or composted yard trimmings in the three avocado trials tested (Tables 16, 17, 18, 19). Potassium concentrations in avocado leaves were increased by raw or composted yard trimmings in two of the three avocado trials tested (Tables 16, 17, 18, 19). In the remaining trial, potassium concentrations were unaffected by raw yard trimmings (Tables 17, 18). Calcium concentrations in avocado leaves were unaffected by mulches in the three avocado trials tested (Tables 16, 17, 18, 19). Magnesium concentrations in avocado leaves were reduced by both raw and composted yard trimmings in one of the three avocado trials tested (Table 16). In the other two avocado trials tested, magnesium concentrations in the avocado leaves were unaffected by raw yard trimmings (Tables 17, 18, 19).

Zinc concentrations in avocado leaves were increased by raw yard trimmings in one of the three avocado trials tested (Tables 17, 18). In the other two avocado trials tested, zinc concentrations in the avocado leaves were unaffected by raw or composted yard trimmings (Tables 16, 19). Manganese concentrations in avocado leaves were unaffected by mulch applications in all three of the avocado trials tested (Tables 16, 17, 18, 19). Copper concentrations in avocado leaves were unaffected by mulch applications in all three of the avocado trials tested (Tables 16, 17, 18, 19).

Iron concentrations in avocado leaves were unaffected by mulch applications in all three of the avocado trials tested (Tables 16, 17, 18, 19).

It appears that many soil nutrients are available to citrus and avocado from the mulches. Whether they are increased or decreased in plant tissue depends upon whether the nutrients are abundant or deficient in any given soil and also upon the normal soil chemistry and competition among nutrients that is present in all soils. The nutrients which are most deficient in California avocado and citrus soils, and therefore need to be supplied, are nitrogen, zinc, manganese and copper. All of these nutrients, but particularly nitrogen and zinc, can be supplied by mulch to citrus and avocados. No toxic nutrients like sodium or boron were increased in citrus and avocado tissues by the application of mulch. In fact, boron was reduced by mulch application in the only trial where it was measured.

Root Lengths in Citrus and Avocado

Root length in citrus in the top 23 cm of soil was unaffected by mulch applications in all three of the trials in which it was measured (Table 21).

Root length of avocado in the top 15 cm of soil was significantly increased by mulch applications in both of the trials where it was measured (Table 21). Root length was increased 184 percent in the Sprinkling avocado trial and 43 percent in the Vanoni avocado trial (Table 21).

Root length was measured at several depths under mulched and unmulched trees at the Vanoni trial (Table 22). Mulches were found to change the depth of rooting in avocado trees. Roots were found to grow into the mulch, and significantly fewer avocado roots were found at 7.5 and 15 cm in the soil below the mulch than at the interface with the mulch (Table 22). In unmulched trees, the greatest number of roots formed at 7.5 cm in the soil (Table 22). When soil was taken from beneath mulched and unmulched trees in the Sprinkling trial and used as potting soil for Topa Topa avocado seedlings in the greenhouse, soil from mulched trees resulted in nearly a 7-fold increase in healthy roots and 98 percent increase in root length compared to soil from unmulched trees (Table 23).

These large growth increases of avocado roots in mulched soil are attributed to the fact that avocado roots will grow prolifically in the mulched layers of the soil and that these layers are inhibitory to avocado root rot (see sections on *Phytophthora* populations and on soil enzymes). Citrus roots, on the other hand, do not grow as readily into mulched layers and therefore are not as effectively positioned to receive the benefits of mulch.

Phytophthora Populations

Phytophthora populations in all three of the citrus trials were unaffected by mulch applications (Table 24). However, both the Pommer and Essick trials had such low initial populations of *Phytophthora* that one might not expect to see differences.

Phytophthora populations in soil under the mulch were also unaffected by mulch applications in the two avocado trials tested (Table 24). However, when soil from underneath mulched and unmulched trees in the Sprinkling trial were used as potting soil for Topa Topa avocado seedlings in the greenhouse, the soil from mulched trees had no significant effect on the amount of root infection, despite the fact that there were many more roots produced in the mulched soil (Table 23).

When root infections were measured at different depths under mulched and unmulched trees in the Vanoni trial, it was found that root infections caused by *Phytophthora* were very low in the mulch and at the mulch-soil interface, but significantly higher in the soil under the mulch (Table 22). Similarly, *Phytophthora* populations were found to be low in the mulch and at the mulch-soil interface, but significantly higher in the soil, whether it was mulched or unmulched soil (Table 25).

Finally, when mycelium of *Phytophthora cinnamomi* was buried at different levels in the mulch, it could be shown that zoospore production at the mulch-soil interface was lower than at greater depths in the soil (Table 26). Hyphal lysis, or death of *Phytophthora* hyphae, was at a maximum at the mulch-soil interface, and it was significantly higher than lysis in the unmulched soil (Table 26). Parasitism of *Phytophthora* hyphae also reached its maximum at the mulch-soil interface (Table 26).

Nematode Populations

Mulch had no significant effect on the population of the citrus nematode in the Pommer trial. In the Essick trial, however, mulches at the 2.5-cm and 7.5-cm depths significantly reduced nematode populations (Table 27). Avocados in California have no known pathogenic nematodes so no data were gathered for avocados.

Rodent Damage

A significant number of trees were damaged by rodents such as voles and gophers during the course of these experiments. While the numbers were not large enough to obtain statistical confirmation, it appears from the field observations that the rodents preferred mulched trees over unmulched trees. Growers wishing to use mulches on their groves should practice sound rodent control.

Soil Characteristics

Soil characteristics were examined in four of the trials. Data from the Vanoni trial was far superior to data from the other three plots because of its large size and large number of replications. Soil pH was slightly but significantly reduced by mulches at the Vanoni trial (Table 31) and at the Essick trial (Table 29), but not at the other two trials (Tables 28, 30). This slight reduction in pH could cause a solubilization of many nutrients and make them more available to the citrus or avocado trees (see section on leaf nutrients of citrus and avocado). Soil organic matter and total carbon in the soil obviously were significantly increased by mulching (Tables 31, 32).

Electrical conductivity (Ece) is a measure of total salinity in the soil. Ece was unaffected by mulches in any of the trials (Tables 28, 29, 30, 31). Nitrogen levels in the soil were elevated significantly by mulch in the Vanoni Trial (Tables 31, 32). Even though soil nitrogen levels in the other trials appeared to be increased dramatically by both raw and composted yard trimmings, the values were not statistically different from unmulched plots (Tables 28, 29, 30). Soil levels of 25 ppm or higher of nitrogen are thought to be adequate to support growth of avocado and citrus. All mulched soils exceeded this level.

Soil phosphorus was significantly increased by mulch in all four trials tested (Tables 28, 29, 30, 31, 32). Soil potassium was significantly increased by raw yard trimming application in the Vanoni (Tables 31, 32) and Pommer (Table 28) trials. In the other two trials tested, potassium concentrations were far greater in the mulched soils than they were in the unmulched soils although the values were not statistically different (Tables 29, 30). Soil calcium was measured only at the Vanoni trial and it was not significantly affected by mulching (Table 31). Soil magnesium was measured only at the Vanoni trial and it was significantly increased by mulching (Table 31). Soil sodium was significantly increased by mulching at the Vanoni trial (Table 31), but not at the other three trials tested (Tables 28, 29, 30).

Soil boron was significantly increased by mulching in both of the trials where it was measured (Tables 28, 29). Boron is damaging to avocado and citrus trees and the organic matter in the mulch appears to be fixing the boron so that it is not absorbed by the trees (see section on leaf nutrients of citrus and avocado).

Soil chloride was only measured in three of the trials. It was significantly reduced by raw yard trimmings in the Pommer trial (Table 28), but not by raw or composted yard trimmings in the other two trials (Tables 29, 30). Soil zinc and manganese concentrations were measured only in the Vanoni trial and were significantly increased by mulching (Table 32). It appears that mulching can considerably improve soil characteristics especially when certain soil characteristics were poor prior to mulching.

Microbial Numbers

Fungal populations were measured at the Vanoni trial as an indicator of total microbial populations. Table 33 shows that total fungal populations were increased 4- to 10-fold in the vicinity of the mulches. However, populations of fungi decreased rapidly away from the mulch deeper in the soil. Populations of fungi 15 cm under mulches were not significantly different from populations of fungi in unmulched soils (Table 33). Two wood decay fungi, *Ceraceomyces* or *Phanaerochete*, were visually observed associated with 100 percent of the mulched soils but were not found on any unmulched soils. These fungi were very conspicuous, and their hyphae could be seen totally innervating the mulches under some trees. *Aspergillus* and *Sporothrix* are two genera of fungi, which were found to be particularly prevalent in the raw yard trimming mulch. These fungi have been associated with allergies and other human diseases.

Microbial Activity

Microbial activity, as measured by the hydrolysis of fluorescein diacetate in the Vanoni trial, closely paralleled the microbial population data. It was significantly higher in the areas closely associated with the mulch. However, the effect was quickly lost deeper in the soil. Microbial activities 7.5 and 15 cm under mulches were not significantly different from microbial activities in unmulched soils (Table 34).

Soil Enzymes

Soil enzymes were measured in the Vanoni trial. Cellulase and laminarinase are two enzymes that are thought to break down the wall structure of the root rot fungus *P. cinnamomi.* They are known to be produced by wood decomposing fungi. Both enzymes were found to be abundant in the mulches and at the soil-mulch interface, but disappeared very rapidly away from the mulch deeper in the soil. Soil enzyme values at

7.5 and 15 cm below the mulch were not significantly different than values in unmulched soil (Table 35). Furthermore, one or more enzymes were shown to be present which actually decomposed the cell walls of *P. cinnamomi*. This enzyme, called "P. cinnase", was measured and it closely paralleled the occurrence of cellulase and laminarinase. It was found in the mulches, but not 7.5 and 15 cm below the mulches or in unmulched soil. This enzyme was found in the same areas as the locations with high microbial populations and high microbial activity (see above). It was also found in areas where root infection by *P. cinnamomi* was low, populations of *P. cinnamomi* were low and where lysis and parasitism of *P. cinnamomi* hyphae were high (see section on *Phytophthora* populations).

Soil Water

Soil water was carefully monitored at the Vanoni trial. Figure 1. Indicates that the mulches keep the soil consistently wetter than unmulched soil. Many growers will irrigate when the soil matric potential reaches 30 kPa. It appears from this data that mulching young avocado trees may lengthen the time between irrigations from 10 days to 15-17 days. That translates to a savings in water of about 40 percent. The water savings are in line with values noted from other plots with young trees, and the mulch in these plots is thought to restrict surface evaporation. This is verified by observations that water savings are far less in mature orchards when the canopy shades the soil and prevents surface evaporation and most water is lost as evapotranspiration. However, the higher soil matric potentials under the mulch may enhance avocado root rot, since it flourishes in wet soil. This may negate any positive, inhibitory effects of the mulch on *P. cinnamomi*. The somewhat negative effect of the mulch on growth of avocados in the Vanoni trial is attributed to the mulch keeping the soil too wet (see section on growth and yield). Care must be taken to irrigate mulched trees only as needed to obtain the full benefit of the mulch on growth and root rot suppression.

Nitrate in the Ground Water

Nitrate in the soil water 0-15 cm below the mulches was measured at the Pommer lemon trial. A summary of five years of data indicates that while there is a trend for mulches to increase the nitrate level in the ground water, it is not statistically significant (Table 36). Furthermore, the application of fertilizer nutrients increases soil nitrate to such an extent (see May, July and August) that effects of mulches were difficult to detect (Table 36). If mulches had a great effect on soil nitrates, the effect should be visible during winter (November-February) rains when nitrate should be leached into the ground water. Table 36 indicates nitrates leaching from mulches during winter rains are relatively low.

Weed Suppression

Weed suppression was carefully monitored at the Essick trial. Figure 2 indicates that mulches greatly suppress weeds even when applied to a depth of only 2.5 cm. Figure 3 shows that a 15 cm layer of mulch effectively reduces weeds to zero. The variety of weeds is also reduced (Figure 4). The economics of using mulch as a weed suppressant is tied to the frequency of application. Most growers would prefer to put on fewer applications. Project researchers recommend that a minimum of a 7.5-cm layer of mulch should be applied to control weeds. A 15-cm layer will function for at least three years.

Material Characteristics

Mulches varied considerably with respect to source and year. The pH values ranged between 5.30 and 8.15 (Table 37). Electrical conductivity (a measure of salinity) ranged from 0.36 to 2.70 mmhos/cm, with the higher values coming from the Coachella Valley, where high salinity is common (Table 37). Levels over 1.5 mmhos/cm may damage some crops. Ash levels varied greatly from a low of 6.2 percent to a high of 80 percent. The ash content was far greater in composted mulch than in raw yard trimmings because the composting process consumes the organic matter and concentrates the mineral portion in the compost (Table 37).

Bulk density varied from 0.15 g/cc to 0.85 g/cc, but it was consistent from year to year (Table 37). As would be expected, compost had higher bulk densities than raw yard trimmings. Total carbon, which is the food source for microorganisms, was also consistent with raw yard trimmings ranging between 30 and 44 percent and composts ranging from 10 to 19 percent (Table 37). Total nitrogen, another important nutrient for microorganisms, was also relatively constant, ranging between 0.62 and 1.42 percent (Table 37). The cation exchange capacity ranged between 30.3 and 84.6 meq/100g. Interestingly, the composts did not necessarily have higher cation exchange capacities (Table 37).

Phosphorus levels ranged from 0.06 to 0.37 percent, comparing well with concentrations in citrus and avocado soils in the area (Table 38). Potassium levels ranged from 0.40 to 1.86 percent (Table 38). This is slightly lower than that found in most California soils, which average about 1.73 percent. Zinc was quite variable ranging from 14 to 693 ppm (Table 38). Some of these values are higher than those found in California soils, which range from 88 to 236 ppm, but are still far below the maximum allowable rate for sewage sludge, which is 7,500 ppm. Copper was also variable and ranged from 7 to 215 ppm (Table 38). Many of these values are well above the concentrations found in California soils, which range from 9 to 96 ppm, but they are still well below the allowable rate for sewage sludge, which is 1,200 ppm.

Molybdenum was not found in any of the raw yard trimmings or compost (Table 38). Cadmium was found at rates between 2.1 and 4.7 ppm, which was higher than concentrations found in California soils (.05 to 1.70 ppm), but well below the allowable rate for sewage sludge, which is 85 ppm. Lead was detected in some of the materials at rates between 11 and 204 ppm (Table 38). These levels are higher than those generally found in California soils (12 to 97 ppm), but are lower than those allowed in sewage sludge, 840 ppm. Arsenic was found in only one mulch at a rate of 14 ppm. (Table 38). This is higher than the levels commonly found in most California soils (0.6 to 11.0 ppm), but less than levels allowed in sewage sludge, 75 ppm.

CONCLUSIONS

Avocado trees appear to benefit from treatments with raw or composted yard trimmings as a mulch. Two of the four avocado groves treated with mulch or compost exhibited increased growth, yield or appearance. Where mulching improved growth and yield of avocado, the mechanism was found to be a reduction in avocado root rot caused by the fungus *Phytophthora cinnamomi* and improved ability of avocado to grow in the presence of the disease. Mulching dramatically increased root length of avocado in both of the trials in which it was measured. Mulching appeared to stimulate a migration of roots up into the mulch and the mulch-soil interface.

Root infections caused by *P. cinnamomi* and *P. cinnamomi* populations were very low in the mulch and in the mulch-soil interface. Conversely hyphae of *P. cinnamomi* were frequently parasitized and dissolved in the mulch or the mulch-soil interface. Microbial activity and populations of fungi were dramatically increased in the mulch and in the soil-mulch interface.

Cellulase and laminarinase, which are produced by wood-decay microorganisms in the mulch, were found to cause the dissolution of *P. cinnamomi* hyphae. These enzymes were produced in abundance in the mulch and at the soil-mulch interface. At one site, mulching was as effective at reducing the symptoms of avocado root rot as the leading fungicide used to control the disease.

Unfortunately, neither the effects of the microorganisms nor the enzymes they produce extend deep into the soil, and the beneficial effects of the mulch on avocado root rot is restricted to the surface layers. Root rot and *P. cinnamomi* exist unabated in the soil underneath the mulch.

In addition to the unique, beneficial effects of mulch on avocado root rot, mulching was shown to benefit avocados in other ways. Mulches or composts were documented increasing nitrogen, potassium, and zinc concentrations in the leaves of avocado in at least one of the trials. Mulching is shown to prevent soil drying, and so the need for irrigation in young trees was reduced by as much as 40 percent by mulching. Mulching to a depth of 7.5 to 15 cm greatly inhibited weed growth and therefore was a good substitute for herbicides.

Citrus, on the other hand, did not benefit as much from mulching. One of the three trials exhibited improved growth and appearance due to mulching. This effect was shown to be the result of nitrogen deficiency, which was remedied by the addition of raw and composted yard trimmings. Because citrus roots generally reside deeper in the soil than avocado roots, mulching apparently had little effect on root rot or *Phytophthora* populations in citrus groves.

Citrus does benefit from improved nitrogen, phosphorus, potassium, zinc and copper nutrition, from water savings and from weed suppression provided by mulching. These benefits, however, are not unique, and growers can achieve the same results via more traditional farming methods (i.e., fertilization, irrigation and herbicide treatments). While the benefits of mulching may pay for mulch applications in citrus, there are few other compelling reasons to use mulch in citrus.

Two findings in this study, which may make mulching more attractive in citrus, were the reduction in boron levels in citrus tissue and the reduction in nematodes associated with mulching. However, these benefits were noted in one trial each, and more work should be done to thoroughly document these phenomena.

With avocados, however, there is the additional, well-documented benefit of reduced root disease, and this makes the use of mulches on young avocados planted in root rot soil a very attractive cultural practice.

Irrigation must be done carefully and cautiously when using mulches on both citrus and avocado.

Mulching can greatly reduce the amount of water used for the crop. Growers must measure soil matric potential and irrigate accordingly after mulching. Irrigating mulched trees the same amount as unmulched trees will result in mulched trees becoming overwatered. Overwatering greatly exacerbates *Phytophthora* root rot. Both citrus and avocados have suffered when this error is made. In citrus, the results can be disastrous. In avocados, the full benefit of mulches for growth and root rot suppression is not realized when trees are overwatered. Under these conditions, avocado growth may be stunted.

Finally, no damaging effects of prudent mulching of citrus and avocado with yard trimmings were detected. However, rodents such as gophers and voles seemed to prefer trees with mulch. During this project, these rodents killed a significant number of trees. Ground water contamination with nitrate from mulch was found to be minimal. Heavy metals and other toxic compounds were occasionally found in mulches, but these levels were not greatly different from those found in natural California soils and were usually far less than levels of these compounds deemed to be acceptable in sewage sludge. However, two genera of fungi which were found to be particularly prevalent in the yard trimming mulch, *Aspergillus* and *Sporothrix*, are known to be associated with human disease.

While the composted yard trimmings performed as well in these trials as the raw yard trimmings and may be superior in many ways, it is unlikely that many commercial avocado or citrus growers will use compost because of its higher cost.

RECOMMENDATIONS

When replanting avocado in soil infested with avocado root rot, growers should manage the root rot by utilizing an integrated management program. Root rot-resistant rootstocks should be planted. Trees should be treated annually with the fungicide Aliette. Trees should be mulched with 1/3 to 1 cubic yard of yard trimmings two or three times during the first eight years after planting to enhance root development and reduce populations of *Phytophthora cinnamomi*, the causal agent of avocado root rot.

Mulching prevents soil drying, especially in young orchards where substantial moisture is lost due to evaporation. Moisture concentrations in mulched soils must be monitored to prevent overwatering. Overwatering exacerbates root rot, since *Phytophthora* is favored under wet conditions. In citrus, overwatering could be disastrous when *Phytophthora* is present. In avocados, the full benefit of mulch for growth and root rot suppression is not realized when trees are overwatered. Under these conditions avocado growth can be stunted.

Mulching with yard trimmings is not recommended for citrus, except in situations like that found in the Coachella Valley of Riverside County, where the sandy soil is nearly devoid of organic matter. In sandy soil, mulches can improve soil nutrition and moisture-holding capacity. In most other situations, it does not appear that mulching benefits in citrus orchards will repay the cost of mulch applications.

The economics of using mulch as a weed suppressant is tied to the frequency of application in citrus and avocado orchards. Most growers would prefer to put on fewer applications. Project researchers recommend applying a minimum of a 7.5-cm layer to control weeds. A 15-cm layer will function for at least three years.

Two interesting observations from this study will require further research. It appears that boron uptake by citrus is greatly reduced by mulch. This element is becoming a severe problem in many citrus and avocado growing areas. Where this toxic element is a problem, mulching may provide the only known solution. In one citrus trial, mulch was shown to reduce populations of the citrus nematode. If this observation is verified, mulches could provide a valuable control method for these potentially damaging root pests. Growers using mulch should also practice sound rodent control, since these animals appear to preferentially attack mulched trees.

Application of mulches using pneumatic blowers is a viable technology, especially on hillsides where other means of spreading mulch is not feasible. Because application costs can be high, especially on the hillsides where many avocados are grown, the cost of the mulch must be kept low for it to be economically attractive to most commercial citrus and avocado growers. While composted material in this study performed as well as raw yard trimming mulch and may be a superior product in many ways, it seems unlikely that commercial citrus or avocado growers will use compost because of the higher cost.

When handling yard trimming mulch processors, truckers and growers should make an effort to reduce dust. This dust will contain spores of *Aspergillus* and *Sporothrix*, which can cause allergies and human disease, especially in those continuously subjected to these spores.

Growers, especially avocado growers, should be extremely careful when using mulch on trees not infested with avocado root rot. While the mulch itself is unlikely to contain viable *Phytophthora* propagules, there is always a possibility that contaminated soil may be picked up with the mulch. Mulch-spreading equipment should be cleaned thoroughly before it is used in a *Phytophthora*-free avocado grove. This concern is not as great for citrus growers, because citrus root rot is more widespread and much less damaging.

APPENDIX A

SCIENTIFIC TERMS

ANOVA.....................Analysis of Variance
As...............................Arsenic
B.................................Boron
Ca...............................Calcium
Cd...............................Cadmium
Cl................................Chloride ion or chlorine
Cu...............................Copper
factorial design.............A statistical design for field plots which allows for treatments to partially substitute for replication and hence increase the accuracy of the results.
Fe ....Iron
hyphae.........................Thread-like cells that make up the body of a fungus.
K ....Potassium
lysis ....Dissolution of living tissue.
matric potential............Capillary pressure in the soil expressed in units of kilopascals (kPa)
Mg..............................Magnesium
Mn..............................Manganese
Mo..............................Molybdenum
N ....Nitrogen
Na...............................Sodium
P ....Phosphorus
Pb ....Lead
pH...............................Measure of acidity
Zn ....Zinc

Appendix B

Tables

Table 1. Effect of compost and mulch on canopy volume, trunk diameter, tree rating, root length and *Phytophthora parasitica* rhizosphere populations of grapefruit trees at Debonne Ranch, Thermal, Calif., 1997 and 1998 [1]

Treatments	Canopy volume (cu m)	Trunk diameter (cm)	Tree rating (0-5; 5=dead)
1997			
Control	20.94B	11.56A	---
Compost	24.83A	11.43A	---
Mulch	24.51A	11.64A	---
1998			
Control	22.83A	11.74A	0.91A
Compost	26.38A	12.17A	0.37B
Mulch	25.72A	12.17A	0.10C
1997 and 1998			
Control	21.91B	11.65A	---
Compost	25.60A	11.80A	---
Mulch	25.13A	11.91A	---

[1] Mean values in each column not followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 2. Effect of mulch depth on canopy volume and trunk diameter of citrus trees at Pommer Ranch, Oxnard, Calif., 1997 and 1998 [1]

Treatment	Canopy volume (cu m)	Trunk diameter (cm)
1997		
No mulch	11.07 A	8.93 A
Mulch - 2.5 cm	14.50 A	7.69 AB
Mulch - 7.5 cm	6.75 A	6.78 B
Mulch - 15.0 cm	7.84 A	7.93 AB
1998		
No mulch	19.41 A	10.70 A
Mulch - 2.5 cm	18.57 A	10.66 A
Mulch - 7.5 cm	18.94 A	9.94 B
Mulch - 15.0 cm	18.31 A	10.01 AB
1997 and 1998		
No mulch	15.24 A	9.82 A
Mulch - 2.5 cm	16.31 A	9.01 B
Mulch - 7.5 cm	11.77 A	8.08 C
Mulch - 15.0 cm	12.80 A	8.92 B

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 3. Effect of mulch depth on citrus tree rating at Essick Ranch, Ojai, Calif., 1997 and 1998 [1]

Treatment	1997		1998		1997 and 1998	
	Canopy vol (cu M)	Trunk diam (cm)	Canopy vol (cu M)	Trunk diam (cm)	Canopy vol (cu M)	Trunk diam (cm)
No mulch	9.69A	7.96A	11.59A	10.25A	10.58A	9.08A
Mulch - 2.5cm	9.41A	8.90A	10.48A	10.43A	9.98A	9.41A
Mulch - 7.5cm	9.16A	8.16A	10.69A	10.25A	9.45A	9.26A
Mulch - 15cm	8.91A	8.36A	9.84A	9.95A	9.36A	9.11A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 4. Effect of compost and mulch on grapefruit yield and granulation rating at Debonne Ranch, Thermal, Calif., 1997 [1]

Treatment	Yield (kg/tree)	Granulation rating [2]
Control	45.09 A	3.59 A
Compost	45.49 A	3.55 A
Mulch	48.74 A	3.49 A

[1] Mean values followed by identical letters are not statistically different at P=0.05 according to Waller's k-ratio t test.
[2] Rating 0=no granulation; 5=total granulation

Table 5. Effect of mulch depth on citrus fruit yield at Pommer Ranch, Oxnard, Calif., 1997 and 1998 [1]

Treatment	Average fruit weight (lbs/tree)		
	1997 [2]	1998 [3]	1997 and 1998
No mulch	27.76 A	65.32 A	45.62 A
Mulch - 2.5 cm	24.36 A	73.63 A	43.69 A
Mulch - 7.5 cm	27.78 A	64.36 A	51.37 A
Mulch - 15.0 cm	25.51 A	66.66 A	47.00 A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.
[2] Data taken in February, June and August.
[3] Data taken in March and June.

Table 6. Effect of mulch depth on citrus fruit size and yield at Essick Ranch, Ojai, Calif., 1997 and 1998 [1]

Treatment	Fruit size (cm)	Average fruit weight (kg/tree)		
	1998	1997	1998	1997 and 1998
No mulch	7.189 A	58.77 A	73.19 A	65.98 A
Mulch - 2.5 cm	7.081 A	77.94 A	98.24 A	86.96 A
Mulch - 7.5 cm	7.029 A	71.01 A	90.35 A	80.68 A
Mulch - 15.0 cm	7.079 A	70.92 A	92.14 A	81.53 A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 7. Effect of compost and mulch on tree rating, canopy volume and trunk diameter of avocado trees at Vedder Ranch, Carpinteria, Calif., 1997 and 1998[1]

Treatment	Trunk diameter (cm)	Canopy volume (cu. m)	Tree rating (0-5; 5=dead)
1997			
Control	13.85 A	20.16 A	1.30 A
Compost	13.37 A	19.29 A	1.12 A
Mulch	12.39 A	14.53 A	1.12 A
1998			
Control	14.52 A	22.75 AB	0.90 A
Compost	13.65 A	27.54 A	0.24 B
Mulch	13.10 A	16.87 B	0.72 A
1997 and 1998			
Control	14.19 A	21.43 A	1.10 A
Compost	13.51 A	23.48 A	0.68 A
Mulch	12.74 A	15.70 B	0.92 A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 8. Effect of mulch, compost and rootstocks on canopy volume, trunk diameter, and tree rating of avocado trees at Powell Ranch, Escondido, Calif., 1998 [1]

Treatment	Canopy volume (cu m)	Trunk diameter (mm)	Tree rating (0-5; 5=dead)
Control	0.30 A	17.05 A	0.93 A
Spencer + 1 cu yd mulch	0.45 A	17.14 A	0.67 A
Spencer + 1/3 cu yd mulch	0.45 A	18.25 A	0.63 A
Spencer + 1/3 cu yd compost	0.42 A	18.09 A	0.83 A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 9. Effect of mulch, fosetyl-Al and rootstocks on canopy volume, trunk diameter and disease severity of avocado trees at Vanoni Ranch, Somis, CA, 1997 and 1998 [1]

Treatment	Canopy volume (cu m)		Trunk diameter (mm)		Disease severity index (DSI[2])	
	1997	1998	1997	1998	1996	1997
Mulch						
+	11.9B	25.1A	69.4A	91.8A	1.32A	1.49A
-	12.5A	25.7A	72.6A	94.7A	1.17A	1.31A
Fosetyl-Al						
+	13.4A	27.6A	73.7A	96.6A	1.19A	1.31A
-	10.9B	23.8B	68.4B	89.9B	1.31A	1.49A
Rootstock						
Thomas	11.4B	24.2B	69.8B	89.5B	1.30A	1.51A
Duke 7	9.7C	21.7C	64.4C	86.2B	1.31A	1.50A
Toro Canyon	15.5A	30.4A	78.9A	104.1A	1.13A	1.19A

[1] Mean values for each main factor in each column followed by identical letters are not statistically different according to ANOVA
at P=0.05.

[2] DSI: 1=no disease; 2=stunting evident, foliar symptoms such as slight yellowing and leaf loss (5-10%); 3=foliage symptoms obvious, wilt, up to 25% leaf loss; 4=over 50% defoliation, all leaves yellow or with necrotic edges, stags head appearance to tree, tree is in collapse; 5=dead. Data taken in 1996 and 1997; not 1998.

Table 10. Effect of mulch, fungicide and rootstocks on canopy volume, trunk diameter and tree rating on avocado trees at Sprinkling Ranch, Somis, Calif., 1996 and 1997 [1]

	Duke 7			UC 2011			Thomas		
Treatment	Can vol (cu m)	Trk diam (cm)	Tree rtg[2] (0-5)	Can vol (cu m)	Trk diam (cm)	Tree rtg[2] (0-5)	Can vol (cu m)	Trk diam (cm)	Tree rtg[2] (0-5)
1996									
Control	1.42A	4.25 B	2.08 A	2.11A	4.73 A	1.08 A	2.52A	5.79 A	0.29 A
Mulch	2.23A	5.69 A	0.65 C	2.66A	5.61 A	0.42 A	2.67A	5.96 A	0.08 A
Fungicide	2.44A	5.14 A	1.71 AB	1.99A	5.21 A	0.77 A	2.77A	5.93 A	0.27 A
Fung+mulch	2.46A	5.61 A	1.13 BC	2.35A	5.53 A	0.50 A	3.20A	6.46 A	0.00 A
1997									
Control	1.56B	4.79 B	1.58 A	2.40A	5.63 A	1.58 A	3.96A	7.32 A	0.64 A
Mulch	3.39A	6.75 A	0.23 B	3.05A	6.32 A	0.63 BC	4.91A	7.39 A	0.17 A
Fungicide	3.08AB	5.71 AB	1.39 A	2.91A	6.24 A	1.00 AB	3.98A	7.33 A	0.36 A
Fung+mulch	3.35A	6.60 A	0.33 B	3.38A	6.53 A	0.33 C	5.65A	7.36 A	0.62 A
1996 and 1997									
Control	1.49B	4.52 C	1.83 A	2.25A	5.18 B	1.33 A	3.24B	6.56 A	0.46 A
Mulch	2.81A	6.22 A	0.43 B	2.86A	5.96 A	0.52 B	3.79AB	6.65 A	0.12 A
Fungicide	2.76A	5.43 B	1.55 A	2.45A	5.72 AB	0.88 AB	3.38B	6.63 A	0.32 A
Fung+mulch	2.91A	6.11 AB	0.73 B	2.86A	6.03 A	0.42 B	4.47A	6.91 A	0.31 A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.
[2] Rating 0=healthy; 5=dead

Table 11. Effect of mulch, fosetyl-Al and rootstocks on avocado yield and fruit size at Vanoni Ranch, Somis, Calif., 1996, 1997 and 1998 [1]

Treatment	Yield (kg/tree)				Fruit size (kg)			
	1996	1997	1998	Ave	1996	1997	1998	Ave
Mulch								
+	1.44A	1.98A	0.81B	1.20B	0.269B	0.241A	0.293A	0.256A
-	1.37A	2.09A	1.33A	1.59A	0.291A	0.229A	0.281B	0.258A
Fosetyl-Al								
+	1.17B	2.38A	1.20A	1.47A	0.294A	0.235A	0.288A	0.260A
-	1.64A	1.61B	0.91A	1.31A	0.266B	0.235A	0.286A	0.254A
Rootstock								
Thomas	0.77B	1.27B	0.85B	0.94B	0.286A	0.233A	0.286A	0.258A
Duke 7	1.12B	1.45B	0.67B	1.00B	0.272A	0.239A	0.287A	0.257A
Toro Canyon	2.32A	3.26A	1.80A	2.44A	0.282A	0.233A	0.288A	0.256A

[1] Mean values for each main factor in each column followed by identical letters are not statistically different at P=0.05 according to ANOVA.

Table 12. Effect of mulch, fungicide and rootstocks on avocado fruit yield at Sprinkling Ranch, Somis, Calif., 1997 and 1998[1]

Treatment	Duke 7		UC 2011		Thomas	
	Avg fruit wt (gm)	Fruit wt/tree (kg)	Avg fruit wt (gm)	Fruit wt/tree (kg)	Avg fruit wt (gm)	Fruit wt/tree (kg)
1997						
Control	197.88A	1.11 B	224.49A	1.91 B	238.64A	2.64 A
Mulch	189.76A	2.01 AB	276.57A	1.45 B	323.95A	2.94 A
Fungicide	231.35A	2.28 AB	205.85A	2.42 AB	248.88A	3.06 A
Fung + mulch	268.14A	3.33 A	268.71A	4.10 A	319.12A	2.32 A
1998						
Control	49.07A	0.24 A	84.78A	0.80 A	139.91A	1.43 A
Mulch	142.24A	1.40 A	131.83A	1.67 A	213.55A	3.73 A
Fungicide	113.01A	0.78 A	161.53A	0.86 A	200.57A	2.68 A
Fung + mulch	124.13A	1.43 A	148.41A	1.80 A	198.89A	3.88 A
1997 and 1998						
Control	148.54A	0.77 B	172.60A	1.16 B	196.30A	2.06 A
Mulch	163.41A	1.73 AB	195.22A	1.54 B	274.11A	3.16 A
Fungicide	177.51A	1.53 AB	206.93A	1.67 B	224.80A	2.89 A
Fung + mulch	196.13A	2.35 A	209.86A	3.09 A	243.35A	3.04 A

[1]Mean values in each column not followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 13. Effect of compost and mulch on leaf nutrients at Debonne Ranch, Thermal, Calif., 1997[1]

Treatment	P (%)	Ca (%)	Mg (%)	K (%)	Na (%)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)	N (%)
Control	0.046A	4.45A	0.48A	1.74B	0.03A	7.00B	9.56A	5.00B	66.10A	2.05C
Compost	0.035A	4.04B	0.47A	2.05A	0.04A	6.68B	9.64A	6.64A	57.58A	2.32A
Mulch	0.039A	4.41A	0.46A	1.83B	0.04A	7.95A	9.55A	5.03B	64.00A	2.15 B

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 14. Effect of mulch depth on leaf nutrients of citrus trees at Pommer Ranch, Oxnard, Calif., 1996 and 1997[1]

Treatment	N (%)	P (%)	Ca (%)	Mg (%)	K (%)	Na (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)	B (ppm)
1996											
No mulch	2.828AB	0.090A	5.19A	0.311A	1.20A	0.041 A	24.16A	27.57A B	7.40A	94.16 A	280.75A
Mulch - 2.5 cm	2.721B	0.098A	5.15A	0.298A	1.25A	0.026 A	24.20A	33.38A	6.76A	93.48 A	238.79A B
Mulch - 7.5 cm	2.972A	0.088A	4.47B	0.272B	1.12A	0.022 A	23.23A	29.13A B	7.49A	86.38 A	197.31B
Mulch - 15 cm	2.859AB	0.091A	4.87A	0.282B	1.32A	0.025 A	27.37A	33.87A	10.59 A	87.89 A	215.72B
1997											
No mulch	2.735A	0.062A	3.85AB	0.284A	1.51AB	0.042 A	76.00A	48.04A	4.91A	62.28 A	235.72A

Mulch - 2.5 cm	2.755A	0.061A	4.03A	0.282A	1.34B	0.041 A	75.07A	49.91A	4.87A	59.53 A	194.53B
Mulch - 7.5 cm	2.737A	0.051A	3.97A	0.276A	1.42B	0.047 A	81.69A	53.69A	5.07A	57.46 A	187.92BC
Mulch - 15 cm	2.807A	0.059A	3.67B	0.269A	1.65A	0.043 A	66.72A	44.28A	5.29A	58.28 A	161.50C D
1996 and 1997											
No mulch	2.784A	0.077A	4.56A	0.298A	1.35A	0.042 A	48.71A	37.27A	6.22A	94.16 A	259.42A
Mulch - 2.5 cm	2.738A	0.079A	4.57A	0.290A B	1.30A	0.034 A	50.51A	41.93A	5.78A	93.48 A	215.90B
Mulch - 7.5 cm	2.854A	0.069A	4.22A	1.270A	1.27A	0.035 A	52.46A	41.41A	6.28A	86.38 A	192.62BC
Mulch - 15 cm	2.833A	0.074A	4.26A	0.274C	1.49A	0.034 A	47.61A	39.22A	7.86A	87.89 A	188.61C

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 15. Effect of mulch depth on citrus leaf nutrients at Essick Ranch, Ojai, Calif., 1996 and 1997

Treatments	P (%)	Ca (%)	Mg (%)	K (%)	Na (%)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)	N [2] (%)
1997										**1995**
No mulch	0.047A	4.500A	0.431A	1.704A	0.050A	28.67B	21.54A	6.14A	87.80A	2.701C
Mulch - 2.5 cm	0.058A	4.731A	0.411A	1.642A	0.050A	41.64AB	28.43A	6.02A	83.50A	2.838B
Mulch - 7.5 cm	0.066A	4.766A	0.411A	1.816A	0.052A	44.62A	30.00A	6.07A	90.53A	2.851A
Mulch - 15 cm	0.054A	4.540A	0.413A	1.789A	0.050A	39.79AB	28.94A	6.74A	93.80A	2.958A
1996										**1996**
No mulch	0.148B	4.196A	0.425A	0.934B	0.039A	67.75A	25.19A	7.60A	97.09A	2.870A
Mulch - 2.5 cm	0.193A	4.225A	0.356A	1.313A	0.031A	74.12A	26.96A	5.06A	87.56A	2.923A
Mulch - 7.5 cm	0.208A	3.900A	0.369A	1.247A	0.039A	80.70A	26.67A	3.57A	83.23A	2.913A
Mulch - 15 cm	0.211A	3.893A	0.370A	1.377A	0.038A	61.98A	24.76A	4.28A	105.72A	3.014A
1996 and 1997 combined										**1995-1996**
No mulch	0.104A	4.331A	0.428A	1.276A	0.044A	50.38A	23.56A	6.95A	92.96A	2.791B
Mulch - 2.5 cm	0.144A	4.424A	0.381A	1.421A	0.038A	61.23A	27.06A	5.48A	85.23A	2.847A
Mulch - 7.5 cm	0.137A	4.333A	0.390A	1.532A	0.045A	62.56A	28.34A	4.82A	86.88A	2.870A
Mulch - 15 cm	0.144A	4.170A	0.388A	1.554A	0.043A	52.47A	26.55A	5.33A	100.61A	2.935A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.
Nitrogen data for 1995 and 1996 only.

Table 16. Effect of compost and mulch on leaf nutrients of avocado trees at Vedder Ranch, Carpinteria, Calif., 1997 [1]

Treatment	N (%)	P (%)	Ca (%)	Mg (%)	K (%)	Na (%)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)
Control	2.03A	0.06A	1.65A	0.46A	0.54B	0.04A	17.12A	53.95A	4.92A	49.56A
Compost	2.33A	0.06A	1.56A	0.44B	0.82A	0.04A	19.04A	49.72A	5.34A	54.32A
Mulch	2.06A	0.05A	1.58A	0.44B	0.73A	0.04A	18.80A	49.14A	5.84A	42.10A

[1] Mean values followed by identical letters are not statistically different according to Waller's k-ratio test.

Table 17. Effect of mulch, fosetyl-Al and rootstocks on avocado leaf tissue nutrients at Vanoni Ranch, Somis, Calif., 1996 [1]

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Mn (ppm)	Fe (ppm)	Zn (ppm)	Cu (ppm)
Mulch										
+	2.43A	0.036A	1.00A	1.19A	0.411A	0.044A	39.8A	60.4A	17.0A	4.72A
-	2.37B	0.036A	0.98A	1.19A	0.406A	0.044A	40.2A	61.2A	16.3B	4.67A
Fosetyl-Al										
+	2.40A	0.037A	0.98A	1.21A	0.411A	0.044A	40.0A	64.5A	16.6A	4.80A
-	2.40A	0.035A	1.00A	1.19A	0.405A	0.044A	40.0A	57.1B	16.7A	4.59A
Rootstock										
Thomas	2.43A	0.035A	1.23A	1.02B	0.326C	0.039B	37.6B	58.9A	17.3A	4.37B
Duke 7	2.42A	0.038A	1.00B	1.27A	0.430B	0.050A	45.5A	62.2A	17.1A	5.37A
Toro Cyn	2.34B	0.035A	0.88C	1.30A	0.469A	0.043B	36.9B	61.2A	15.6B	4.35B

[1] Mean values for each main factor in each column followed by identical letters are not statistically different according to ANOVA at P=0.05.

Table 18. Effect of mulch, gypsum, fosetyl-Al and rootstocks on avocado leaf tissue nutrients at Vanoni Ranch, Somis, Calif., 1997 [1]

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Mn (ppm)	Fe (ppm)	Zn (ppm)	Cu (ppm)
Mulch										
+	2.54A	0.049A	1.15A	1.43A	0.379A	0.040A	35.5A	58.5A	20.0A	6.30A
-	2.50B	0.047A	1.12A	1.45A	0.384A	0.040A	36.7A	61.3A	19.3B	6.35A
Fosetyl-Al										
+	2.52A	0.048A	1.13A	1.43A	0.382A	0.040A	35.6A	61.9A	19.9A	6.24A
-	2.51A	0.048A	1.12A	1.44A	0.381A	0.041A	36.6A	57.9B	19.3A	6.41A
Rootstock										
Thomas	2.57A	0.049A	1.22A	1.32B	0.331C	0.040AB	35.3B	63.6A	21.2A	6.40A
Duke 7	2.49B	0.048A	1.13B	1.49A	0.385B	0.041A	39.1A	57.8B	19.3B	6.33A
Toro Cyn	2.49B	0.047A	1.05C	1.50A	0.428A	0.039B	33.9B	58.3B	18.4C	6.24A

[1] Mean values for each main factor in each column followed by identical letters are not statistically different according to Fisher's least significant difference (LSD).

Table 19. Effect of fungicide and mulch on leaf nutrients of avocado trees at Sprinkling Ranch, Somis, Calif., in 1996 and 1997 [1]

Treatments	P (%)	Ca (%)	Mg (%)	K (%)	Na (%)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)
1996									
Control	0.04A	1.12A	0.49A	0.62BC	0.036A	25.62A	122.0A	5.00A	64.77A
Mulch	0.05A	1.19A	0.45A	0.72A	0.034A	23.73A	106.8A	4.80A	61.15A
Fungicide	0.04A	1.21A	0.51A	0.58C	0.031B	23.88A	150.1A	5.43A	75.10A
Mulch+Fung	0.04A	1.22A	0.44A	0.68AB	0.033AB	23.74A	126.1A	6.01A	77.80A
1997									
Control	0.05A	1.24A	0.46A	0.71B	0.041A	26.53A	90.2AB	5.77A	75.89A
Mulch	0.05A	1.26A	0.43BC	0.95A	0.041A	25.53A	96.8A	5.63A	69.46A
Fungicide	0.06A	1.18A	0.44B	0.74B	0.041A	25.86A	83.4 B	5.55A	62.67A
Mulch+Fung	0.05A	1.32A	0.41C	0.97A	0.040A	26.78A	39.6AB	5.73A	60.33A
1996 and 1997									
Control	0.04A	1.17A	0.47A	0.67B	0.038A	26.05A	106.7A	5.36A	70.63A
Mulch	0.05A	1.23A	0.44B	0.84A	0.038A	24.67A	101.6A	5.23A	65.59A
Fungicide	0.05A	1.19A	0.47A	0.66B	0.036A	24.91A	115.3A	5.49A	60.00A
Mulch+Fung	0.04A	1.28A	0.43B	0.84A	0.037A	25.36A	106.6A	5.86A	68.48A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 20. Effect of mulch, fungicide and rootstocks on nitrogen from avocado leaves at Sprinkling Ranch, Somis, Calif., 1996 and 1997 [1]

Treatment	Duke 7	UC 2011	Thomas
1996		nitrogen (%)	
Control	2.446 A	2.327 A	2.415 A
Mulch	2.356 A	2.348 A	2.328 A
Fungicide	2.364 A	2.330 A	2.379 A
Mulch + fungicide	2.351 A	2.309 A	2.324 A
1997			
Control	2.558 A	2.544 A	2.495 A
Mulch	2.467 A	2.468 A	2.463 A
Fungicide	2.421 A	2.476 A	2.420 A
Mulch + fungicide	2.459 A	2.422 A	2.379 A
1997 and 1998			
Control	2.497 A	2.427 A	2.495 A
Mulch	2.414 A	2.413 A	2.463 A
Fungicide	2.393 A	2.409 A	2.420 A
Mulch + fungicide	2.413 A	2.370 A	2.379 A

[1] Mean values followed by identical letters are not statistically different according to Waller's k-ratio test.

Table 21. Effect of compost and mulch on root length in citrus and avocado trials [1]

Treatment	Citrus trials			Avocado trials	
	Debonne	Pommer	Essick	Vanoni	Sprinkling
	Root length (cm/100 cc soil)				
Control	43.3 A	7.1 A	14.6 A	13.3 B	5.1 B
Compost	46.4 A	------	------	------	------
Mulch	47.2 A	6.1 A	8.7 A	19.0 A	14.5 A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 22. Effect of mulch and *Phytophthora cinnamomi* on avocado root length and root infection from samples taken at various depths in Vanoni Ranch, Somis, Calif. in January and March 1966 [1]

Sample location	Root length[2] (cm)		Root infection[2] (*P. cinnamomi*)	
	January	March	January	March
Mulched tree				
Mulch surface	0.00 B	0.00C	0.0B	0.0B
Mid-mulch	8.34 B	0.16C	0.0B	0.0B
Interface	22.71AB	10.24A	0.4B	0.0B
Soil 7.5 cm	16.70AB	3.78BC	1.2A	0.2AB
Soil 15 cm	8.80AB	3.14BC	0.8AB	0.6A
Unmulched tree				
Soil surface	0.00B	0.47C	0.0B	0.0B
Soil 7.5 cm	37.34A	6.11AB	0.4B	0.4AB
Soil 15 cm	6.95B	3.70BC	1.0A	0.0B

[1] Mean values in each column followed by identical letters are not statistically different according to ANOVA and LSD, P=0.05. Data were transformed (tangent) before analysis.
[2] Root length is length of roots (cm) recovered from 100g soil.

[3] Root infections are the number of *P. cinnamomi* infections occurring on ten 1-cm root pieces harvested from each sample.

Table 23. Evaluation of Topa Topa avocado seedlings planted in mulch and soil recovered from Duke 7 trees at Sprinkling Ranch, Somis, Calif., March 1998 [1]

Treatment	Healthy roots	Root length	Root dry weight	Shoot dry weight	*Phytophthora cinnamomi*
	(%)	(cm)	(gm)	(gm)	(% infection) [2]
Control	3.3 B	104.70 B	1.85 A	8.53 A	20.0 A
Mulch	22.7 A	206.90 A	2.79 A	9.13 A	37.5 A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.
[2] *P. cinnamomi* percent recovery on 10 Eucalyptus leaf disks per 2 samples of 1-gm dry weight avocado soil each.

Table 24. Effect of mulch on *Phytophthora parasitica* populations in citrus groves and on *P. cinnamomi* populations in avocado groves [1]

	Citrus trials			Avocado trials	
Treatment	Debonne (1997-98)	Pommer (1995)	Essick (1997)	Vanoni (1997-98)	Sprinkling [2] (1998)
	propagule/gm rhizosphere soil	propagule/gm rhizosphere soil	propagule/gm rhizosphere soil	average leaf isolation/ 20 roots	propagule/gm rhizosphere soil
Control	10.9 A	0.00 A	0.55 A	0.52 A	5.3 A
Mulch	8.5 A	0.29 A	0.75 A	0.55 A	3.0 A
Compost	15.6 A	--------	--------	--------	--------

[1] Values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.
[2] Determined by the most probable number method using Eucalyptus leaf disk baits.

Table 25. *Phytophthora* populations associated with mulched and unmulched soils from avocado trees at Vanoni Ranch, Somis, Calif., January and March 1996 [1]

Sampling location	Total *Phytophthora*		*Phytophthora cinnamomi*	
	January	March	January	March
Mulched tree				
Mulch surface	0.0 B	0.0 C	0.0 B	0.0 B
Mid-mulch	0.0 B	0.0 C	0.0 B	0.0 B
Interface	1.2 B	1.8 C	0.0 B	0.2 AB
Soil 7.5 cm	4.8 A	6.0 B	1.2 A	0.0 AB
Soil 15 cm	5.8 A	8.3 AB	0.6 AB	0.3 A
Unmulched tree				
Soil surface	0.0 B	1.7 C	0.0 B	0.0 B
Soil 7.5 cm	7.8 A	8.2 AB	1.0 A	0.0 AB
Soil 15 cm	5.2 A	10.0 A	0.4 AB	0.4 AB

[1] Mean values in each column followed by the same letter are not significantly different according to two-way ANOVA and LSD (P<0.05) using 5 replications of mulched and unmulched tree pairs.

Table 26. Fecundity of *Phytophthora cinnamomi* mycelium buried in mulch and soil profiles under avocado trees at Vanoni Ranch, Somis, Calif., 1996

Sampling location	Zoospores [1] (mg)	Lysis rating [2] (0-5)	Parasitism [3] (%)
Mulched tree			
Mulch surface	603 C	1.4 BC	0 A
Mid-mulch	3090 AB	2.8 ABC	50 A
Interface	2065 B	4.5 A	65 A
Soil 7.5 cm	11426 A	3.6 AB	50 A
Soil 15 cm	6493 AB	3.1 ABC	30 A
Unmulched tree			
Soil 1 cm	121 C	0.8 C	0 A
Soil 7.5 cm	3640 AB	0.9 BC	20 A
Soil 15 cm	2269 B	1.0 BC	35 A

[1] Zoospores released per mg mycelium of *P. cinnamomi* recovered from each transect level after 3 days. Column means followed by same letter are not significantly different according to LSD P<0.05.
[2] Visual rating of the integrity of recovered mycelia of *P. cinnamomi*: 0 = no lysis healthy mycelium; 5 = mycelium completely dissolved.
[3] Percent of mycelia with parasitized hyphae, 4 samples per treatment.

Table 27. Effect of mulch depth on nematode larvae recovered from citrus tree soil at Pommer Ranch, Oxnard, and Essick Ranch, Ojai, Calif., September 1998 [1]

Treatment	Pommer Ranch	Essick Ranch
	nematode larvae (50 cc soil)	
No mulch	4607.75 A	232.81 A
Mulch - 2.5 cm	3500.20 A	69.32 B
Mulch - 7.5 cm	3825 35 A	58.78 B
Mulch - 15.0 cm	3474.94 A	106.00 A

[1] Mean values followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 28. Effect of mulch depth on citrus soil nutrients at Pommer Ranch, Camarillo, CA, 1998 [1]

Treatment	N (ppm)	P (ppm)	K (ppm)	Na (Meq/L)	B (ppm)	Cl (meq/L)	pH	Ece (mmhos/cm)
No mulch	62.4A	59.0B	382D	1.28A	0.40C	1.60A	7.10A	2.04A
Mulch – 2.5 cm	82.0A	93.0A	610C	0.68A	0.51C	0.66B	6.96A	1.47A
Mulch – 7.5 cm	70.9A	81.4AB	756B	1.00A	0.69B	0.98AB	6.98A	1.47A
Mulch – 15 cm	55.4A	92.0A	932A	0.90A	0.99A	0.36B	6.92A	1.56A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 29. Effect of mulch depth on citrus soil nutrients at Essick Ranch, Ojai, CA, 1998 [1]

Treatment	N (ppm)	P (ppm)	K (ppm)	Na (meq/L)	B (ppm)	Cl (meq/L)	pH	Ece (mmhos/cm)

No mulch	17.25A	13.50C	150.0A	2.85A	0.23C	0.90A	7.20A	1.20A
Mulch-2.5cm	31.40A	32.80B	164.0A	2.92A	0.30BC	0.82A	6.88B	1.54A
Mulch-7.5cm	45.20A	62.40A	236.0A	2.90A	0.37AB	1.26A	6.72C	1.78A
Mulch-15 cm	52.00A	74.60A	232.0A	2.80A	0.44A	1.02A	6.74C	1.62A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 30. Effect of mulch and compost on avocado soil nutrients at Vedder Ranch, Carpinteria, Calif., 1988 [1]

Treatment	N (ppm)	P (ppm)	K (ppm)	Na (meq/L)	Boron (ppm)	Cl (ppm)	pH	Ece (mmhos/cm)
Control	14.68A	27.40B	326.0A	3.98A	0.14B	3.22A	7.16A	1.48A
Mulch	18.42A	45.20AB	626.0A	3.22A	0.21B	3.52A	7.26A	1.74A
Compost	18.22A	72.20A	834.0A	4.56A	0.72A	3.56A	7.40A	1.69A

[1] Mean values in each column followed by identical letters are not statistically different according to Waller's k-ratio t test.

Table 31. Effect of mulch on avocado soil nutrients at Vanoni Ranch, Somis, Calif., 1997

Treatment	Nutrient/element [1]										
	pH	Ece (mmhos /cm)	N_{tot} (%)	TKN (%)	P_{Olsen} (ppm)	K (ppm)	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	OM (%)	C_{tot} (%)
Mulch	7.19B	3.04A	0.166 A	0.123 A	25.8A	347.1 A	26.68 A	9.92A	7.48A	2.97A	2.20A
No mulch	7.26A	2.90A	0.121B	0.091B	15.3B	260.7B	26.76 A	8.12B	6.79B	1.93B	1.36B

[1] Mean values in each column followed by identical letters are not statistically different according to ANOVA at P=0.05.

Table 32. Effect of mulch on avocado soil nutrients at Vanoni Ranch, Somis, Calif., 1998

Treatment	Nutrient/element/chemical quality [1]							
	N_{tot} (%)	TKN (%)	P_{olsen} (ppm)	K (ppm)	OM (%)	C_{tot} (%)	Zn (ppm)	Mn (ppm)
Mulch	0.159A	0.149A	17.64A	284.6A	2.90A	2.17A	7.32A	30.7A
No mulch	0.122B	0.112B	12.21B	218.3B	1.87A	1.40B	6.67B	23.7B

[1] Mean values in each column followed by identical letters are not statistically different according to ANOVA at P=0.05.

Table 33. Fungal populations associated with mulched and unmulched avocado soils at Vanoni Ranch, Somis, Calif., 1996

Sampling location	Total fungal colonies [1] ($x\ 10^6$ /gm^{-1} soil)	
	January	March
Mulched tree		
Mulch surface	35.0 AB	93.2 A

Mid-mulch	45.0 A	58.5 B
Interface	26.6 BC	43.3 BC
Soil depth 7.5 cm	10.1 CD	31.8 CD
Soil depth 15 cm	6.4 D	17.5 DE
Unmulched tree		
Soil surface	4.1 D	11.3 E
Soil depth 7.5 cm	2.9 D	14.0 DE
Soil depth 15 cm	3.4 D	13.2 E

[1] Mean values in each column followed by identical letters are not statistically different according to LSD at P=0.05.

Table 34. Effect of mulch on microbial activity of samples taken from various depths under avocado trees at Vanoni Ranch, Somis, Calif., January and March 1996[1]

Sampling location	Microbial activity[2]	
	January	March
Mulched tree		
Mulch surface	1.17 A	1.37 A
Mid-mulch	1.30 A	1.58 A
Interface	0.63 A	1.49 B
Soil depth 7.5 cm	0.04 B	0.63 C
Soil depth 15 cm	0.00 B	0.28 C
Unmulched tree		
Soil surface	0.01 B	0.10 C
Soil depth 7.5 cm	0.00 B	0.05 C
Soil depth 15 cm	0.00 B	0.04 C

[1]Mean values from each column followed by same letter are not significantly different according to LSD at P=0.05.
[2]Microbial activity is expressed as μg fluorescein diacetate hydrolized/gm^{-1} sample/hr^{-1}.

Table 35. Effect of mulch on enzyme activities of samples taken from various depths under avocado trees at Vanoni Ranch, Somis, Calif., January and March, 1996 [1]

Sampling location	Enzyme activity [2]					
	CMCase[3]		Laminarinase		"P. cinnase"[4]	
	Jan	Mar	Jan	Mar	Jan	Mar
Mulched tree						
Mulch surface	4.29A	4.22A	45.58A	11.83A	5.33A	2.63A
Mid-mulch	3.41AB	3.28A	8.45B	9.63A	3.60AB	1.53A
Interface	1.57BC	1.44B	3.36B	3.33B	0.91AB	0.38B
Soil 7.5 cm	0.14C	0.30C	2.03B	0.02B	0.13AB	0.13B
Soil 15 cm	0.11C	0.15C	2.78B	0.00B	0.27B	0.00B
Unmulched tree						
Surface	0.29C	0.02C	0.02B	0.04B	0.00B	0.00B
Soil 7.5 cm	0.49C	0.02C	1.67B	0.00B	0.00B	0.13B
Soil 15 cm	0.00C	0.00C	0.18B	0.08B	0.00B	0.00B

[1] Values are means of samples from 5 tree pairs; mean values in each column followed by the same letter are not significantly different according to LSD at P=0.05.
[2] Enzyme activity is expressed as μg reducing sugars/gm^{-1}/hr.$^{-}$
[3] CMCase is carboxymethyl cellulose.
[4] "P. cinnase" is the activity detected against cell walls of *P. cinnamomi.*

Table 36. Effect of mulch depth on nitrogen in soil water[1] under lemon trees at Pommer Ranch, Oxnard, Calif., 1994 – 1999

Treatment	Average monthly soil nitrogen (NO_3) 1994 - 1999												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave [2]
Control	9.8	12.0	9.1	5.9	16.1	8.4	26.3	45.7	9.9	10.9	11.3	9.2	14.6 A
Mulch 2.5cm	18.8	12.2	14.1	7.4	27.8	10.2	60.9	22.3	11.3	6.6	7.2	7.9	17.2 A
Mulch 7.5 cm	14.4	15.1	11.4	9.5	28.3	12.0	24.9	19.3	10.1	5.9	7.7	7.2	13.8 A
Mulch 15 cm	11.7	15.5	17.7	10.8	29.0	8.1	72.3	44.3	11.4	10.9	8.2	7.9	20.7 A

[1] Soil water was sampled 0-15 cm below the mulches.

[2] Mean values followed by identical letters are not statistically different according to Waller's k-ratio t test. There were no statistical differences between treatments in the monthly data.

Table 37. Analysis of critical characteristics of mulches and composts used in this study in 1997 and 1998

Location	Mulch type	pH		Ece (mmhos/cm)		Ash (%)		Bulk density (g/cm^3)		Total carbon (%)		Total nitrogen (%)		CEC (meq/100g)	
		97	**98**	**97**	**98**	**97**	**98**	**97**	**98**	**97**	**98**	**97**	**98**	**97**	**98**
Debonne	Mulch	6.20 8.05		2.70	1.57	6.2 43.4		0.15	0.22	44.4	29.9	0.72	1.30	31.4	34.1
Debonne	Compost	7.90 7.69		2.33	1.29	80.0 73.4		0.85	0.62	10.4	15.1	0.94	1.35	30.3	35.9
Pommer	Mulch	7.40	----	0.69	----	15.6	----	0.35	----	41.2	----	1.34	----	84.6	----
Essick	Mulch	7.40	----	0.69	----	15.6	----	0.35	----	41.2	----	1.34	----	84.6	----
Vedder	Mulch	6.00 7.28		1.13	0.66	15.6 18.6		0.31	0.26	42.4	45.2	0.40	1.03	47.4	50.7
Vedder	Compost	8.15 7.84		0.73	0.36	60.1 67.8		0.63	0.77	18.5	18.6	1.42	1.33	61.4	67.7
Powell	Mulch	7.10 6.41		0.38	1.53	22.9 13.1		0.40	0.21	40.4	42.4	0.93	0.80	50.9	38.5
Powell	Compost	7.10	----	0.64	----	65.7	----	0.62	----	18.9	----	1.26	----	76.6	----
Vanoni	Mulch	5.30	----	1.25	----	6.8	----	0.19	----	46.1	----	0.68	----	36.6	----
Sprinkling	Mulch	5.85	----	1.78	----	15.2	----	0.25	----	42.0	----	0.62	----	41.8	----

Table 38. Analysis of nutrients and heavy metals in mulches and composts used in this study in 1997 and 1998

Location	Mulch type	P (%)		K (%)		Zn (ppm)		Cu (ppm)		Mo (ppm)		Cd (ppm)		Pb (ppm)		AS (ppm)	
		97	**98**	**97**	**98**	**97**	**98**	**97**	**98**	**97**	**98**	**97**	**98**	**97 98**		**97**	**98**
Debonne	Mulch	0.09 0.24		1.21 1.86		23	87	7	81	0	0	0	0	0 47		0 14.6	
Debonne	Compost	0.25 0.35		1.28 1.75		115	161	37	69	0	0	2.5	0	0 25		0	0
Pommer	Mulch	0.18	----	0.31	----	306	----	36	----	0	---	4.7	---	97 -	---	0	0
Essick	Mulch	0.18	----	0.31	----	306	----	36	----	0	---	4.7	---	97 -	---	0	0
Vedder	Mulch	0.07 0.14		0.43 0.57		71	56	19	19	0	0	0	0	41 70		0	0
Vedder	Compost	0.35		0.85		393	637	138	215	0	0	4.0	1.5	204		0	0

Powell	Mulch	0.37 0.09		0.69 0.14		693	46	12	17	0	0	0	0	107 0		0	----
Powell	Compost	0.15 0.18	----	1.00 0.30	-----	238	----	25	----	0	---	2.1	----	11 57 -	---	0	----
Vanoni	Mulch	0.06	----	0.40	-----	14	----	6	----	0	---	0	----	0 -	---	0	----
Sprinkling	Mulch	0.07	----	0.58	----	91	----	12	----	0	---	0	----	0 -	---	0	----

APPENDIX C

FIGURES

Figure 1. Soil Moisture Tension Under Mulched and Unmulched Trees

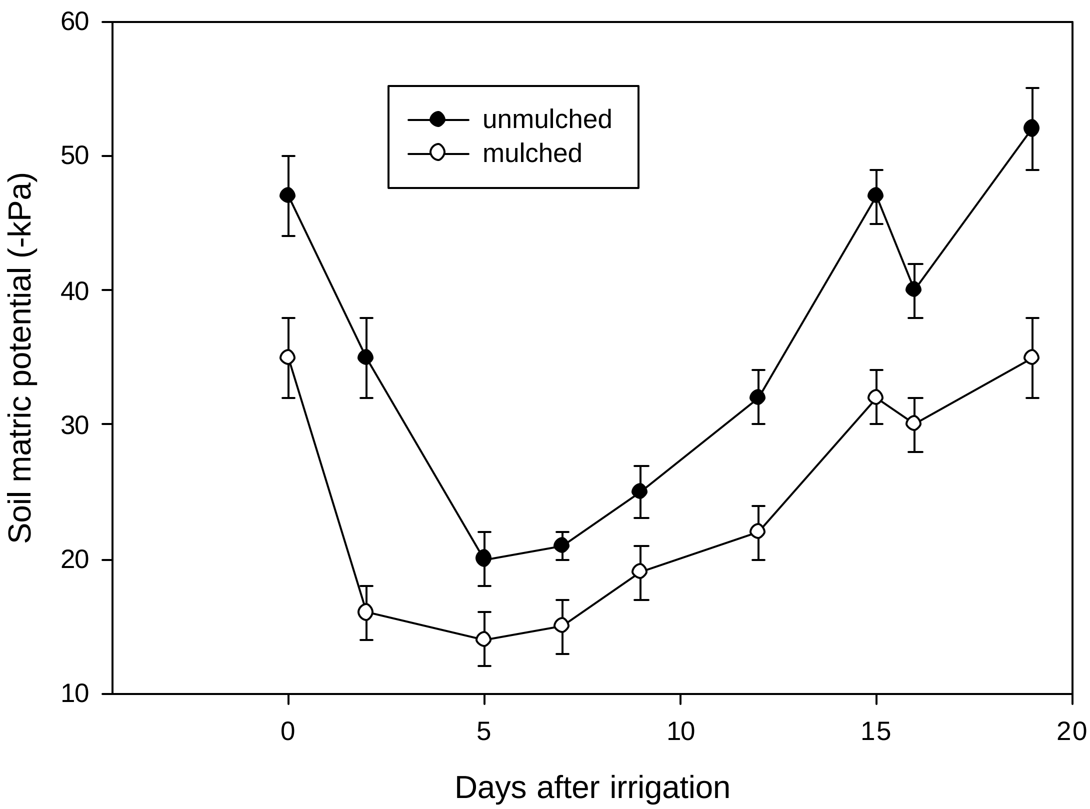

Figure 2. Total Weed Counts for Grasses and Broadleaf Weeds at Various Mulch Depths

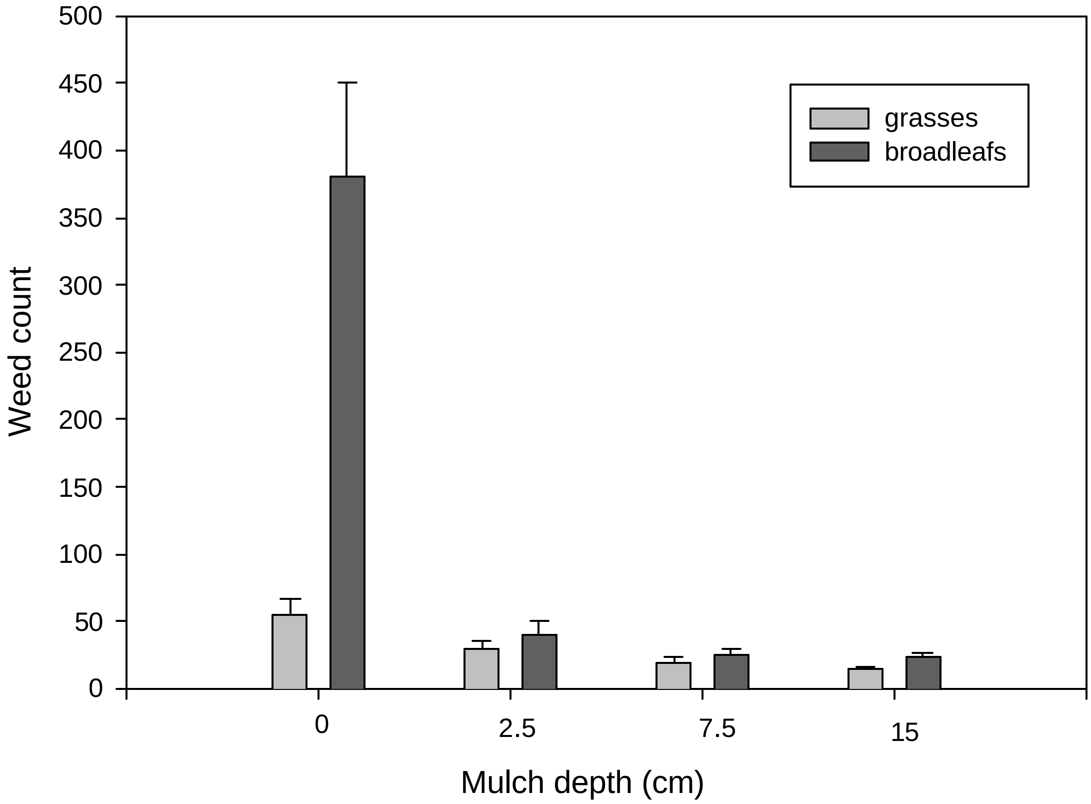

Figure 3. Percentage Weed Cover of Plots Treated With Different Depths of Mulch From April 1994 to April 1996

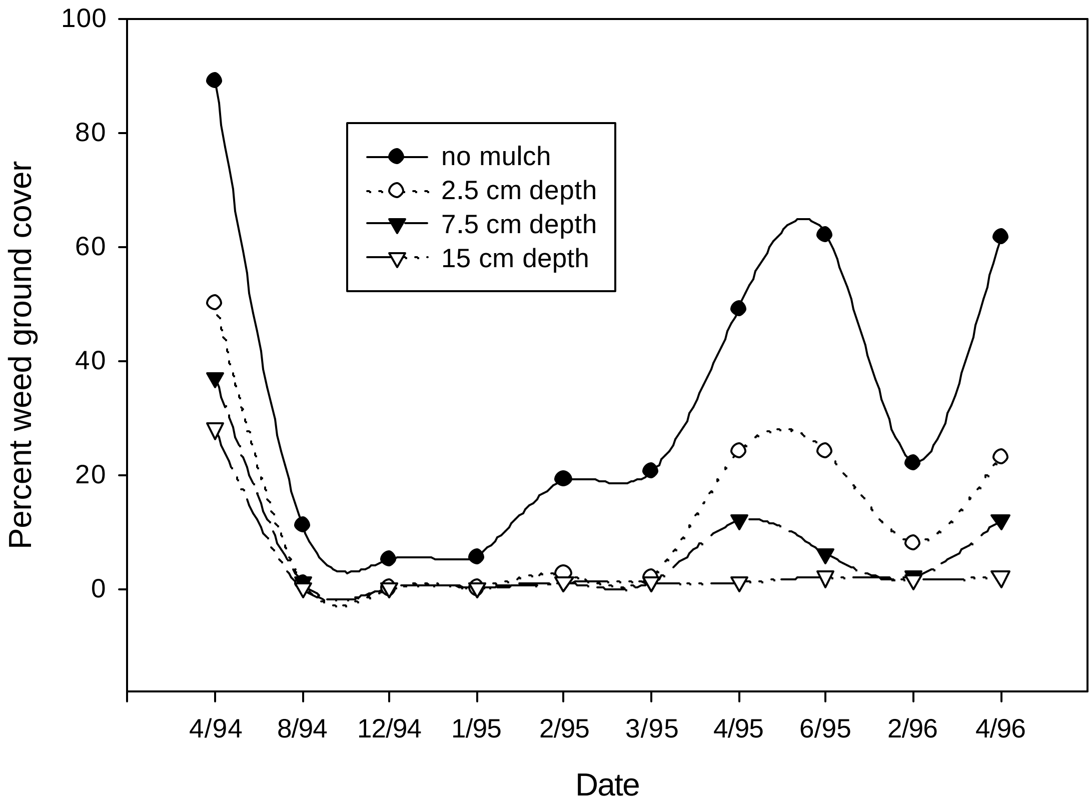

Figure 4. Variety of Weeds in Mulches