EVALUATION OF FLOOR MANAGEMENT PRACTICES IN YOUNG LIME ORCHARD.

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By

Robert Michael McLean

Thesis Committee

Kent D. Kobayashi, Chairman
Henry Nakasone
Joseph DeFrank

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Horticulture.

THESIS COMMITTEE

Kent D. Kobayashi

Chairman

Joe DeFrank

Henry Nakamura

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ABSTRACT

Seven orchard floor management techniques were evaluated for weed control and tree growth in a newly planted 'Tahitian' lime (*Citrus aurantifolia* Swingle) orchard. A weeded control, mechanically mowed, polyester geotextile fabric, mulch of shredded eucalyptus (*Eucalyptus robusta* Sm.), mulch of shredded lychee (*Litchi chinensis*) leaves, hand weeding, and oxyfluorfen (2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene) herbicide were selected to determine their suitability in a newly planted lime orchard. Thirteen months of data (weed dry weight) indicated that there were no significant differences in mean weed weight among the weed control treatments; hand weeding was the worst. At the conclusion of the experiment, tree growth was greatest with the oxyfluorfen treatment.

Eucalyptus (*Eucalyptus robusta* Sm) organic mulch was tested at 4 different rates to assess its overall performance in a non-irrigated newly planted 'Tahitian' lime orchard. The four rates of eucalyptus mulch were 0, 100, 150, and 200 tonnes/ha.

Increasing mulch rates decreased mean weed dry weight. Increasing mulch rates increased trunk and limb diameters (combined), limb length, and total leaf number. Mulch rate of 150 tonnes/ha was considered optimum for satisfactory weed

suppression and enhancing tree growth. After 139 days, soil samples were collected from beneath the mulches. Ryegrass (*Lolium multiflorum*) and Leaf mustard cabbage (*Brassica juncea* L.) seeds were planted in petri dishes filled with soil. There were no significant differences in germination between the 4 rates of mulch for both species.

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CHAPTER 1

INTRODUCTION

Potential contribution of this thesis is the delimitation of herbicidal dependency in orchard floor management practices by evaluating the effectiveness of non-chemical methods of weed control in a newly planted lime orchard. Concern for groundwater contamination (Weaver et al., 1983) from continued agricultural use of herbicides has motivated the need for research that would enhance fruit tree establishment and production without deleterious consequences to the environment.

This study evaluated the potential of allelopathic inhibition of weed seed germination and seedling growth by a mulch consisting of decomposing leaf and limb litter. It has been reported that during the decomposition process of certain plant residues, phytotoxic compounds are produced (Patrick et al., 1962; Del Moral, 1979; Rice, 1984). The compounds are produced in early stages of decomposition and are more pronounced under anaerobic conditions (Patrick and Koch, 1958; Muller, 1969). Susceptibility of certain weed species to allelopathic growth inhibitors depend in part on seed size and permeability of seed coat (Williams and

Hoagland, 1982). Potential to utilize allelopathy for cropping systems in agriculture will be ascertained.

CHAPTER II

REVIEW OF LITERATURE

WEED CONTROL IN CITRUS ORCHARDS

Introduction

Successful orchard weed control is important for the establishment of healthy trees, maximum growth, and reducing nutrient, sunlight, and moisture competition (White and Holloway, 1967; Jordon and Day, 1973; Robinson and O'Kennedy, 1978; Ito and Ueki, 1979; Klingman and Ashton, 1982; Radosevich and Holt, 1984). Weeds harbor plant pathogens, and disease organisms may use weeds as secondary hosts before infecting other food crops (Klingman and Ashton, 1982).

Weed competition around the base of young citrus trees has been reported to reduce tree growth (Jones and Embleton, 1973; Jordon and Day, 1973). The size of the tree at the end of the first year is an important economic factor. First year growth can significantly influence tree size during subsequent years (White and Holloway, 1967). Since young trees are ineffective in shading out weeds, excessive competition may substantially reduce tree growth.

The most difficult weed control problems with citrus production are found in the humid tropics (Jordon and Day, 1973). Weeds have the opportunity to compete with citrus trees for nutrients, sunlight, and moisture throughout the year. Economic loss caused by weeds in citrus orchards results in less efficient land use, reduced fruit yield, and increased labor cost (Jordon and Day, 1973; Klingman and Ashton, 1982). An effective weed management program should minimize weed competition and orchard management costs (Bridges et al., 1984). Removing the undesirable effects of weed competition can be accomplished through various cultural practices: cultivation, sod culture, mulching, and herbicides (Lord and Vlach, 1973; Haynes, 1980).

In developed areas, chemical herbicides are the recognized weed management practice in orchards today (Delver, 1980; Cassamayor, Garcia and Arias, 1981; Stinchcombe and Stott, 1983), but there are associated problems. Increasing costs, the development of resistant weed species (Radosevich and Holt, 1982), long-term vegetative shifts from susceptible weed species to more tolerant weed species (Ito and Ueki, 1979; Wruckle and Arnold, 1985), phytotoxicity in orchard trees (Jordon and Day, 1973; Cary, 1978), and herbicide movement to ground water (Mayeux and Hamilton, 1983; Weaver et al., 1983) have contributed to this investigation of non-chemical means of weed control.

The use of organic mulch (allelopathic in nature) may be able to inhibit germination of weed seeds and seedling growth through the release of toxic chemicals by decomposition and leaching.

Phenolic compounds, such as caffeic acid, chlorogenic acid, coumarin, ferulic acid, fumaric acid, gallic acid, and juglone, have been shown to be inhibitory to germinating weed seeds and weed seedlings of sicklepod (*Cassia obtusifolia* L.), velvetleaf (*Abutilon theophrasti* Medic.), prickly sida (*Sida spinosa* L.), and redroot pigweed (*Amaranthus retroflexus* L.) (Williams and Hoagland, 1982). Rice (1984) reported that caffeic, ferulic, gallic, p-coumaric and p-hydroxybenzoic acids obtained from decomposed litter below eucalyptus trees inhibited seedling growth of surrounding vegetation.

Definition of terms

1. Competition: according to Radosevich and Holt (1984), competition can be either negative interactions of plants of the same species (intraspecific) or negative interactions of plants of different species (interspecific).

2. Allelopathy: defined by Molisch (1937) to describe both beneficial and inhibitory biochemical interactions between all plants and microorganisms.

Allelopathy is sometimes confused with competition. It is important although difficult to separate allelopathic effects from competition effects. Competition occurs when adjacent plants (or weeds) compete for sunlight, soil moisture, soil nutrition, and carbon dioxide (Klingman and Ashton, 1982). With allelopathy, plant compounds are added to the environment as opposed to nutrients and growth factors being removed (Putnam and Duke, 1978).

3. Cultivation: soil tillage around individual plants (or trees) for the purpose of weed control and improvement of soil structure; gradually being replaced by sod culture or chemical culture due to undesirable soil erosion consequences (Soule, 1985).

4. Sod Culture: management system used in orchards that utilizes a natural or planted ground cover (Soule, 1985). The cover is maintained by mowing. Useful for controlling tall weeds, it eventually establishes a permanent vegetative cover that protect against soil compaction and wind and rain erosion (Jones and Embleton, 1973; Ito and Ueki, 1979; Gregoriou and Rajkumar, 1984).

5. Herbicide: chemical specifically used to control weeds; used in conjunction with a weed-free strip below the orchard trees (Klingman and Ashton, 1982).
6. Mulches: organic or synthetic ground covers used to improve soil properties and suppress weed growth (White and Holloway, 1967; Gregoriou and Rajkumar, 1984) by depriving weeds of sunlight (Klingman and Ashton, 1982) and protecting the soil from wind and rain erosion.
7. Resistance: the capacity of a plant to change gradually to decrease or prevent an irreversible strain (Soule, 1985).

Cultivation

Stott (1976) reported that cultivation had been successfully used in apple orchards in England before the introduction of residual herbicides during the late 1950s. Robinson and O'Kennedy (1978) agreed that cultivation was utilized successfully in the alleys of apple tree orchards until replacement by overall (combination of preemergence and postemergence) herbicides in the 1960s. Klingman and Ashton (1982) reported that cultivation was effective in controlling small annual weeds, severing the stems before the weeds flower. Perennial weeds were more difficult to control once rhizomes and tubers developed. Cultivation can deplete carbohydrate reserves of some perennials such as quackgrass

(*Agropyron repens*) (Majek et al., 1984), thus providing a level of control.

Warnes and Anderson (1984) looked at a cultural method that combined fallowing and cultivation on land infested with wild mustard (*Brassica kaber*). After 7 growing seasons, cultivation and fallowing hastened the decline of the weed seed population to less than 3% of the original population. Majek et al. (1984) reported that in an established quackgrass sod depletion of rhizome carbohydrate reserves had been accomplished by regular fallowing and cultivation.

There are disadvantages of utilizing cultivation in orchards. White and Holloway (1967) observed that cultivation injured shallow feeder roots in apple orchards. Cary (1978) reported damage to citrus tree roots by cultivation equipment. Tucker and Muraro (1980) reported that cultivation as performed more often and used more energy than chemical herbicides. Also, they observed that cultivation altered soil structure and encouraged soil erosion with continued use in 'Valencia' orange (*Citrus sinensis* (L.) Osbeck) orchards. They also observed the development of a plow pan below the soil-cultivation layer.

Non-destructive cultivation is dependent on favorable climatic conditions (Gregoriou and Rajkumar, 1984; Heatherly and Elmore, 1983). With increasing problems of compaction and erosion, many growers have switched to herbicides and sod cultures to control weeds in citrus orchards (Tucker and Muraro, 1980).

Sod Culture

Sod management is a technique used to facilitate orchard operations and improve productivity. Shribbs et al. (1986) reported some apple (*Malus domestica*) orchards require a ground cover such as orchardgrass (*Dactylis glomerata* L.) or Kentucky bluegrass (*Poa pratensis* L.) to control erosion by reducing the impact of rain drops on the soil, allowing for increased absorption and drainage. Earlier, Jones and Embleton (1973) had considered ground covers in citrus orchards as weeds competing for nutrients, moisture, and space.

Stott (1976) proposed that apple trees grown with a complete ground cover of grass contributed to poor growth and yellow appearance of apple foliage. His work indicated that the trees were suffering from a nitrogen deficiency due to grass competition. Delver (1980) observed that orchards with grass strips had lower fertilizer requirements than orchards grown with full grass (tree to tree) covers. Stinchombe and Stott (1983) agreed that competition from a ground cover surrounding young apple trees during the first 3 years of establishment induced a nitrogen deficiency and reduced tree growth. Jordon and Russel (1981) noticed a decrease in leaf nitrogen when orange trees were grown in bermudagrass (*Cynodon dactylon* L.). Robinson and O'Kennedy (1978) stated that there was a detrimental effect on both tree growth and yield in apple orchards grown with grass ground covers. Shribbs et al. (1986) revealed that growth of apples was inhibited either moderately or severely with grass and broadleaf ground covers when compared to a straw mulch (*Secale cereale* L). Nutrient analysis of trees and ground covers indicated that lack of nitrogen was the cause of the depressed tree growth. Apple trees and ground covers both competed for nitrogen when a balanced nutrient was accessible. Although it was possible to add extra nitrogen to overcome the nitrogen deficiencies in the trees, growth inhibition was not totally reduced. Weller et al. (1985) reported that common bermudagrass inhibited growth of young peach (*Prunus persica* L. 'Norman') trees. Trees were stunted, leaves were chlorotic, and tree leaf N and K were reduced.

In other experiments with natural weed cover under young apple trees (White and Holloway, 1967), tree root permeation into soil was good, but the overall size of the root system was reduced. White and Holloway (1967) described significant competition and moisture depletion in apple trees grown with natural weed cover. Trees exhibited drought symptoms in leaves, and tree vessel size were decreased indicating moisture stress. During drier periods, considerable moisture stress was indicated by a reduction in leaf size and number and length of new shoots.

Mulches

Mulching orchard trees has been shown to increase soil moisture (White and Holloway, 1967; Gregoriou and Rajkumar, 1984), diminish daily temperature fluctuations, and increase tree growth (Gregoriou and Rajkumar, 1984) and yields (Stojanowska, 1987). However, Robinson and O'Kennedy (1978) described a reduction in yield of 2-year old apple trees when straw mulch was used. The lower yield was thought to be caused by a reduction of the soil temperature during the growing season, reduction of soil oxygen by the maintenance of excessively moist soil conditions, and increasing levels of carbon dioxide.

Gregoriou and Rajkumar (1984) obtained significant increases in trunk diameter, tree height, and canopy spread of 6-month old grafted avocado trees (*Persea americana* Mill.) when planted under 8-cm thick mulch of weathered coffee hulls. The growth increase was attributed to maintenance of uniform moisture, reduced weed competition, and improved soil structure.

Gregoriou and Rajkumar (1984) found that during the wet season, orchard soil bulk density was significantly less and surface infiltration rate significantly higher under mulched trees than under bare ground trees. Mulching improved root development and water availability in young apple trees (White and Holloway, 1967). Tree roots have been shown to exploit the shallow soil when protected by a mulch layer (Haynes, 1980).

Allelopathy

Many plant toxins have been associated with eucalyptus trees. Stunting of otherwise dominant species of *Leptospermum myrsinoides, Casuarina pusilla, Leucopogon virgatus* and *Leucopogon ericoides* was observed when these species grew in close proximity to *Eucalyptus baxteri* (Del Moral et al., 1978). Components thought to be responsible for the suppression were investigated. Competition for nutrients, sunlight, and moisture were evaluated and reported to be non-limiting, indicating allelopathic interference of growth.

Plant material in all stages of decomposition, incorporated into the soil as cover crops or residues of leaf and limb litter, is present under natural field conditions (Patrick et al., (1962). During the decomposition of the plant tissue, organic compounds are produced that may have toxic effects on neighboring plants (Lodhi, 1978).

There have been many publications reviewing the implications of allelopathy from plant crop residues. Kimber (1973) reported that aqueous extracts of several grasses and legumes inhibited growth of wheat. Patrick et al. (1962) found that decomposing plant residues of barley, rye, wheat, and vetch were toxic to the roots of lettuce and spinach seedlings. Evidence of phytotoxic substances from decomposition of plant material in field-grown lettuce and spinach was observed to be partly responsible for causing discoloration of lettuce and spinach seedling roots, death of the apical meristem, and radicle injury. The aqueous extracts from decomposing plant residue also inhibited germination of the lettuce and spinach seeds.

Allelopathy has been reported to be a significant factor in controlling understory vegetation under many tree species (Lill and McWha, 1976; Del Moral, 1979). Many studies have indicated that under certain conditions, phytotoxic substances from decomposing leaf and tree litter can suppress neighboring vegetation. Lodhi (1978) removed phenolic phytotoxins from tree litter and soil directly below hackberry, red oak, white oak, and sycamore trees. His research indicated that the accumulation of plant toxins was proportional to the mass of litter present and its decomposition rate. Turner and Rice (1975) observed that the toxicity of phenolics diminishes over time. They stated that

99% of ferulic acid from decaying hackberry leaves were lost after 300 days.

The persistence of phytotoxins in soils varies with soil conditions (Rice, 1984; Del Moral and Muller, 1969). Allelopathic effects are more pronounced during conditions of plant stress (Lodhi, 1978).

Allelopathic toxicity from decomposed plant tissue diminishes with time (Patrick et al., 1962). Lodhi (1978) reasoned that toxins leached into the soil by decaying leaf litter eventually become available to surrounding vegetation. He observed a significant reduction in seed germination and radicle growth in brome grass when exposed to phytotoxins extracted from soil samples beneath decaying litter of white oak and red oak. Tukey (1969) suggested that the nature of the soil influences the longevity of phytotoxins. Soil microorganisms may produce secondary products from metabolized leachates affecting neighboring vegetation differently than the primary substance.

Rain was responsible for leaching many plant toxins into the soil from accumulated tree litter (Del Moral and Muller, 1969). Heavy rain by fog drip from eucalyptus leaves contained significant amounts of phytotoxins inhibiting vegetative growth within the canopy area. Growth of vegetation increased in size with increasing distance from canopy drip zone (Del Moral and Muller, 1969).

Phytotoxic compounds from decomposing plant materials are common in heavy clay soils that have low soil aeration or are prone to waterlogging (Patrick, 1971). When oxygen is limiting and decomposing plant material is available, organic acids accumulate. Compounds such as methane, ethylene, acetic, lactic, butyric, formic, and other acids are produced.

Patrick and Koch (1958) noted that high soil moisture content has been shown to be a primary factor in toxins produced during decomposition of plant material. Anaerobic conditions were associated with shallow clay soils (Del Moral and Muller, 1969). This would suggest that toxins may predispose vegetative roots to invasion by root pathogens (Patrick and Koch, 1958). Del Moral and Muller (1969) reported that phenolic detoxification by microorganisms was not favorable during periods of anaerobic soil conditions. Toxins were not denatured and persisted as effective vegetative inhibitors.

Williams and Hoagland (1982) reported that naturally occurring phenolic compounds from seeds, fruits, and plant residues have been reported to be inhibitory to germinating seeds. They observed different responses for different phenolic compounds on different plant species. Juglone, coumarin, hydrocinnamic acid, and pyrocatechol inhibited germination of 5 weed species: hemp sesbania (*Sesbania* *exaltata* (Raf.) Cary), sicklepod (*Cassia obtusifolia* L.), velvetleaf (*Abutilon theophrasti* Medic.), prickly sida (*Sida spinosa* L.), and redroot pigweed (*Amaranthus retroflexus* L.). Using high purity phenolic compounds, they tested the influence of these compounds on seed germination under laboratory conditions. Each compound was prepared by dissolving it in 0.5 ml dimethyl sulfoxide (DMSO) and diluting it with distilled water for a final concentration of 10^{-5} and 10^{-3} M. Juglone inhibited germination of redroot pigweed, velvetleaf, and prickly sida. Coumarin delayed rather than inhibited germination of velvetleaf, prickly sida, and redroot pigweed. Hydrocinnamic acid and pyrocatechol also delayed germination rather than inhibited germination of velvetleaf and redroot pigweed.

Black walnut (*Juglans nigra* L.) was reported by Fisher, (1979) to produce juglone (5-OH-1, 4-napthoquinone), a phytotoxin reported to have allelopathic effects on some plants. A study of red pine (*Pinus resinosa* Ait.) and white pine (*P. strobus* L.) indicated that there was inhibition associated with walnut trees growing in adjacent stands. The relationship between the phytotoxic activity of juglone extracted from 3 soils of fine sandy loam soils were selected. A well-drained Brant (*Ochreptic hapludalf*) did not seem to be affected from any allelopathic effects of adjacent walnut trees. Pine trees growing on an imperfectly drained

Tuscola soil (*Aquic eutrochept*) showed poor growth when associated with an adjacent walnut stand. Pine trees growing on a poorly drained Colwood (*Humic haplaquept*) were all dead after 20 years when associated with adjacent walnut stands. These results suggested a strong relationship between soil conditions and allelopathic activity of walnut trees. The degree of interference increased with soil moisture.

A wide range of plant injury has been reported as being due to decomposing plant material. Seed germination has been inhibited or prevented, and seedlings have been stunted. Reduced seed germination and seedling development of lettuce, bean, broccoli, and tobacco were revealed by Patrick et al. (1962) when plant parts were exposed to decomposing plant material in the soil. Necrotic lesions on roots and root stunting were observed in lettuce when decomposed plant material was in contact with seedling roots.

Herbicides

Chemical herbicides are highly effective and versatile in orchard floor management systems (Jordon and Day, 1973; Cant, 1978; Robinson and O'Kennedy, 1978; Delver, 1980; Casamayor et al., 1981; Stinchcombe and Stott, 1983). As labor became more expensive and more effective herbicides became available, entire citrus tree rows were sprayed and kept weed free while the alleys were mowed or shallow tilled (Cary, 1978; Tucker and Muraro, 1980). Stinchcombe and Stott (1983) reported excellent weed control with a combination of pre- and postemergence (overall) herbicides in apple orchards. Robinson and O'Kennedy, (1978) also achieved excellent weed control using preemergence plus postemergence herbicides. Simazine (2-chloro-4, 6-bisethylamino-1,35-triazine) was applied after planting around young apple trees. Paraquat (1,1'-dimethyl-4,4'-bipyridylium), mecoprop (2-(4-chloro-2-methylphenoxy) propionic acid) or 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) were used as spot treatments for weeds that were resistant to simazine.

The development of herbicides for citrus orchard floor management allowed greater flexibility in selecting weed control methods. Cultivation, a destructive practice in orchard soils, was no longer necessary (Jordon and Day, 1973).

Herbicides can be selective, killing one plant and not another (Cary, 1978). Many herbicides have a broad spectrum of weed control (Klingman and Ashton, 1982). Foliar activated herbicides such as glyphosate (N-phosphonomethyl glycine) are translocated in weeds, effectively killing annuals and perennials (DeBarreda and DeBusto, 1981). Some herbicides such as simazine are residual, soil-applied chemicals that provide long lasting control (Cary, 1978; Klingman and Ashton, 1982).

When chemical herbicides are used correctly, there is less injury to tree roots and trunks, and soil structure is not altered, and water penetration into the soil is more favorable when compared with cultivated cultural practices (Cary, 1978). Tucker and Muraro (1980) observed twice as many orange tree roots at a 0 to 6-inch soil level from trees under Hyvar X (bromacil) and Karmex (diuron) when compared to trees in tillage treatment. Root loss was attributed to mechanical destruction by repeated tillage. Tucker and Muraro (1980) observed twice as many orange tree roots in the 0 to 6-inch depth under herbicide treatments than in cultivated soils.

Robinson and O'Kennedy (1978) found that simazine and paraquat allowed a 20% increase in apple yield when compared to grass (tree to tree) covercropping. Stinchombe and Stott (1983) observed apple trees grown in weed-free rows controlled with maleic hydrazide plus 2,4-D to be larger and more vigorous than trees grown in overall grass. Herbicide resistant weeds have been reported in many weed species (Stojanowaska, 1987). Ito and Ueki (1979) reported that population shifts in weeds increased as herbicide treatments progressed, but decreased when herbicide treatments were discontinued. Long-term vegetative shifts from susceptible weed species to species more tolerant of herbicides have been observed with continued herbicide use (Wrucke and Arnold

1985; Holt, 1985). Horowitz (1973) observed weed population shifts in Israel's citrus orchards when chemical herbicides were used, annual weeds being replaced by perennial weeds. Bromacil was effective against bermudagrass but orchards were later infested with other perennials such as johnsongrass (*Sorghum halapense* (L) Pers.) and nutsedge (*Cyperus rotundus* L.).

Herbicide toxicity may be a problem in citrus orchards, especially in newly established orchards (Jordon and Day, 1973; Klingman and Ashton, 1982). Improper use of herbicides has been known to affect citrus fruit quality (Cary, 1978). Stinchcombe and Scott (1983) reported that trees grown under weed-free conditions with an annual application of simazine produced significantly heavier yields but fruit quality was lowered.

Many different orchard floor management systems have been recommended from researchers. Successful establishment of newly planted trees and control of weeds for a particular orchard in one location may not be suitable under different climatic conditions. Herbicides have replaced cultivation and sod culture in many areas but there is concern with complete elimination of weed cover beneath orchard trees (Lord and Vlach, 1973). Herbicides do not damage tree roots as does cultivation equipment. Herbicides do not inhibit young tree growth as does sod culture, but bare ground associated with decreased total porosity (Haynes, 1981). Mulching protects the soil by physically absorbing the impact of raindrops, reducing surface runoff and erosion. However, mulch is expensive to haul and apply. If pruning and mulching are done in the field, these costs could be considerably lowered. Considerable research is necessary before mulching can become an acceptable orchard weed management method.

CHAPTER III

EVALUATION OF 7 WEED CONTROL METHODS IN A NEWLY PLANTED 'TAHITIAN' LIME ORCHARD

ABSTRACT

Due to the phytotoxic hazards of herbicides applied in 'Tahitian' lime (*Citrus aurantifolia* Swingle) orchards less than 1 year old, non-chemical methods of controlling weeds and enhancing tree growth were compared. An unweeded control, hand weeding, mechanically mowed, polyester geotextile fabric, eucalyptus (*Eucalyptus robusta* Sm.) mulch, lychee (*Litchi chinensis*) mulch, and oxyfluorfen (2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene) herbicide were selected to determine their effectiveness in a newly planted lime orchard. All treatments significantly reduced weed dry weight compared to the hand weeded control.

There was no significant differences in weed control between the polyester fabric mulch, lychee mulch, oxyfluorfen, and eucalyptus mulch. Hand weeding was significantly worse than the other treatments for reducing weed weight. After 139 days, there were no significant differences in seed germination between soil samples collected from underneath all rates of eucalyptus mulch.

INTRODUCTION

Orchard floor management before the early 1960s in apple, peach, and citrus consisted of continuous cultivation during the growing season (White and Holloway, 1967; Lord and Vlach, 1973). Today, annual and perennial weeds are still adequately suppressed by cultivation practices (Klingman and Ashton, 1982) though the disadvantages of cultivation are well documented. Cary (1973) observed that damage to shallow roots in citrus was caused by cultivation equipment. With increasing labor and equipment costs, cultivation has become more expensive (Tucker and Muraro, 1980). Soil structure can be adversely altered, increasing compaction and reducing water porosity (Haynes, 1980).

Haynes and Goh (1980) reported that sod culture had gradually replaced cultivation in many orchards by the 1960s. Although sod culture was successful in reducing the destructive effects of cultivation, it had some serious problems (Jordon and Day, 1973). Sod culture caused stunting and chlorosis in trees, especially in newly planted trees (Haynes, 1980). Ground covers competed for nitrogen, and soil moisture (Stott, 1976). Although some researches found this reduction in tree growth to be temporary (Haynes, 1980), most agreed that sod culture reduces growth, vigor, and yield of trees (Goode and Hyrycz, 1976; Robinson and O'Kennedy, 1978; Weller et al., 1985).

Haynes (1980) reported increased tree growth and vigor by using mulch around fruit trees. He stated that mulches increased tree roots in shallow soils and increased earthworm population. Earthworm activity was attributed to the nutrients available in the decomposed mulch.

Mulches have been successfully used to increase growth and vigor in peach trees primarily due to increased soil moisture. However, mulches are difficult to obtain and expensive to spread (Lord and Vlach, 1973). Gregoriou and Rajkumar (1984) reported excellent tree growth increases with weathered coffee mulch in mango and avocado orchards. Improved growth was attributed to the mulches ability to maintain a uniform level of soil moisture throughout the year.

The objective of this experiment was to evaluate the potential of mulches to suppress weeds and enhance tree growth in a newly planted, non-irrigated 'Tahitian' lime orchard and compare the overall performance of the mulches with more established weed control methods.

MATERIALS AND METHODS

This experiment was initiated on July 25, 1986 at Mililani, Oahu at an elevation of 340 m with an annual precipitation of 150-200 cm. The field was subsoiled to a depth of 46 cm and disked prior to tree planting. Two-year-old 'Tahitian' lime (*Citrus aurantifolia* Swingle) trees grafted on *Citrus volkameriana* rootstock were planted in non-irrigated raised beds approximately 20 cm high, with treatment plots 2 m wide by 10 m long. There were 2 trees centered in each treatment plot, spaced at 5 m within rows and 5 m between rows.

The experimental design was a randomized complete block with 8 replications. Experimental trees were planted in blocks oriented in an east to west direction. Experimental blocks were situated in the middle of the orchard with several guard rows bordering the experimental field.

Treatments consisted of the following:

a) <u>Control</u> - weeds were allowed to remain in the plots until the completion of the experiment.

b) <u>Warren's "Terrabond" Polyester Geotextile Fabric (85 mm thickness)</u> (Warren's Turf Nursery, Inc., Crystal Lake, Illinois).

c) <u>Lychee (*Litchi chinensis*) Organic Mulch</u> - applied at 200 tonnes/ha. Lychee limbs (maximum diameter 16 cm) and leaves were mechanically shredded into chips approximately 0.25 cm thick by 2 cm wide by 6 cm long.

d) Mechanically Mowed - with a weed whip at 169, 232, 302 and 372 days after planting.

e) Chemical Herbicide - oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitro-phenoxy)-4-(trifluoromethyl) benzene] at 0.9 kg active ingredient per ha at 169, 232, 302 and 372 days after planting.

f) Hand weeding - with hoes and sickles.

g) Eucalyptus (*Eucalyptus robusta* Sw) Organic Mulch applied at 200 tonnes/ha. Eucalyptus limbs (maximum diameter 16 cm) and leaves were mechanically shredded into chips.

Weeds were hand harvested with hoes and sickles from a 0.5 m^2 sample area in the middle of the treatment plot. Sample time for weed harvests were 169, 232, 302, and 372 days after the trees were planted. All above-ground weed biomass was oven-dried at 72^{o}C for 4 days and weighed.

Lime tree growth data for eucalyptus mulch was measured at 10, 113, and 354 days after planting. All but 3 main limbs, labeled "A", "B", and "C", were removed from the trees at planting. The trunk diameter of the scion 25 mm above the graft union was measured. Two measurements were recorded at the same height, rotated 90^{o} about trunk axis and averaged to compensate for irregularities in trunk diameter. Limb diameter of the 3 limbs 5 mm above the trunk/limb union to the terminal end of the limbs was taken. Lengths of the 3 limbs were measured (and combined) from the trunk/limb union to the terminal end of limbs. Total leaf count for the 3 limbs was recorded for each tree.

RESULTS

Visual observation of the treatments suggested that oxyfluorfen provided better weed control than the mulch treated plots. Many of the oxyfluorfen treated plots were totally devoid of weeds, whereas the mulch treated plots contained weeds which gave the appearance of being less effective control. However, statistically there were no differences (Table 3.1).

Hand weeded plots had significantly greater weed dry weight than all other treatments (Table 3.1). Mean weed weights for all treatments decreased from January to March (Figure 3.1). The oxyfluorfen, polyester geotextile fabric mulch, eucalyptus mulch, and lychee mulch treatments were equally effective in reducing weed dry weight (Table 3.1).

The control trees had a significantly smaller trunk and limb diameter (combined) than trees of the other treatments 113 and 354 days after planting (Table 3.2). Limb length of the control trees were significantly less than that of the other treatments 354 days after planting, but there was no difference 113 days after planting. Leaf number of control trees was significantly less than that of the other treatments 113 and 354 days after planting.

Trees in the oxyfluorfen plots had greater trunk and limb diameters (combined) compared to the mulch treated trees 113 and 354 days after planting (Table 3.2). Limb length of the oxyfluorfen treated trees was not different from that of the mulch treated trees 113 and 354 days after planting. Leaf number of the oxyfluorfen treated trees was significantly greater than that of the mulch treated trees 354 days after planting, but there was no difference 113 days after planting.

Trees in the polyester geotextile fabric mulch plots were not different in trunk and limb diameter (combined) and limb length from the lychee mulch and eucalyptus mulch treated trees 113 and 354 days after planting (Table 3.2). Leaf number of the polyester geotextile fabric mulch treated trees was significantly less than that of the lychee mulch and eucalyptus mulch treated trees 113 days after planting. There was no difference in leaf number 354 days after planting between any mulch type.

Eucalyptus mulch treated trees had significantly greater trunk and limb diameter (combined) than lychee mulch treated trees 113 days after planting, but not 354 days after planting (Table 3.2). There was no difference in limb length and leaf number between the eucalyptus and lychee mulch trees 113 and 354 days after planting.

Oxyfluorfen treated trees had significantly greater trunk and limb diameter (combined) and leaf number than all other treatments 113 and 354 days after planting (Table 3.2). There was no difference in limb length of oxyfluorfen treated trees with the mean of all other combined treatments 113 days after planting.

Eucalyptus mulch treated trees had no difference in trunk and limb diameter (combined), limb length, and leaf number when compared to other mulch treatments 113 and 354 days after planting (Table 3.2).

DISCUSSION

In the 4 categories of weed and tree data, the lychee mulch was as effective as the eucalyptus mulch and oxyfluorfen. Lychee mulch was included in this experiment to serve as a non-allelopathic organic mulch. Eucalyptus mulch was expected to control weeds better than the lychee mulch due to its presumed allelopathic properties (Del Moral and Muller, 1969; Patrick et al. 1963). Results from this experiment indicated that the eucalyptus mulch and lychee mulch were equivalent in their weed control properties. The data indicated that either both mulches were allelopathic or that the physical presence of the mulches provided the observed level of control. Whether weed control in the lychee and eucalyptus mulch treated plots were due to allelopathy or only a physical barrier or both was not determined in this experiment.

Gliessman (1978) reported that many ecologists believe allelopathy would never be an important factor in high rainfall areas because the toxins would be leached from the soil too rapidly to be effective for weed suppression. Lill et al. (1979) reported that inhibitors in *Pinus radiata* leaf litter could inhibit germination. He added that many trees are capable of inhibiting weed seed germination with decomposing litter. Lodhi (1976) observed that although most of the toxins found in decaying leaves of sycamore, huckleberry, red oak, and white oak decreased from January to August, growth reduction of neighboring vegetation was not due to physical factors. Decaying leaves, leaf leachate, and soil from beneath the trees were all found to inhibit germination and radicle growth of brome grass (*Bromus japonicus*).

The geotextile polyester fabric mulch proved to be durable and effective in inhibiting weeds from growing through it. However, it did not prevent weed seeds from germinating on its surface and penetrating to the soil below. Field observations showed that the geotextile polyester fabric mulch accumulated wind-blown soil and provided a suitable environment for weed seed germination. The geotextile polyester fabric mulch was so strong that lime trees were girdled as the trunks grew into the fabric. Increasing the diameter of the opening around the tree corrected this problem, but allowed weeds to emerge from the enlarged hole. This fabric was considered unsuitable for weed control in a commercial orchard.

The mechanically mowed treatment resulted in reduced tree growth. Jones and Embleton (1973) observed that grasses beneath young trees had a detrimental effect on citrus tree growth due to competion for various growth factors. Many of the mechanically mowed trees were chlorotic as reported by Stott (1974). The detrimental effect of grass beneath trees was not observed by Delve (1980) who reported that grass strips increased nutrient availability to the trees when the mowed grass remained as mulched. He reported little nutrient loss to the trees because the grass withdrew nutrients from the shallow, dryer portion of the soil where few tree roots were present. Weller et al. (1985) reported that young peach trees grown with common bermudagrass ground covers were stunted and chlorotic. Many of the trees grown under grass in this experiment were also stunted and had chlorotic leaves. Robinson and O'Kennedy (1978) reported that a grass ground cover resulted in a 20% yield reduction of 5-year-old apple trees when compared to weed free strips. In this experiment, limb and trunk diameter (combined), limb length, and leaf count were increased with oxyfluorfen when compared to grass ground cover. Shribbs et al. (1986) reported that a moderate to severe stunting of apple (*Malus domestica*) seedlings by grass and broadleaf ground covers.

Trees in the hand weeded plots were smaller than those in other treatments. Hand weeding was more time consuming than the other treatments and would not be recommended for weed control in orchards when other methods are available.

Based on the results of this experiment, the use of oxyfluorfen in newly planted lime orchards appears to be safe and suitable to commercial operation in Hawaii. Oxyfluorfen is not currently registered for use in bearing lime orchards. A combination of organic mulches and a postemergence herbicide such as glyphosate could be employed. The mulch would suppress many of the weeds, and the glyphosate could then be used as a spot treatment for weed control.

Mulches derived from leaves and limbs from fruit orchards other than lychee should be investigated. If heavy annual pruning is a part of management practices, chipping of limbs for mulch may prove to be cost-effective by eliminating the need to remove branches and providing a degree of weed control.

CONCLUSION

The results showed that mulches effectively controlled weeds as well as oxyflourfen. Eucalyptus and lychee mulches can be utilized to increase the growth and vigor in a non-irrigated 'Tahitian' lime orchard. When trees are pruned and chipped in the field, mulching may be a viable economic alternative to herbicides.

Table 3.1. Effects of weed control methods on weed dry weight in a lime orchard.

Treatment	Weed dry weight (g) Harvest date (days after planting) 169	354
1 Polyester fabric mulch	32	7.8
2 Lychee mulch	18	15.0
3 Oxyfluorfen	11	0.1
4 Hand weeding	108	93.0
5 Eucalyptus mulch	34	15.9
Contrasts		
4 vs. 1,2,3,5	***	***
3 vs. 1,2,5	NS	NS
1 vs. 2,5	NS	NS
2 vs. 5	NS	NS

NS, *** Nonsignificant (NS) or significant at the 0.1% level, respectively.

Table 3.2. Effects of weed control methods on tree growth in a lime orchard.

Treatment	113 Days[z]			354 Days		
	Diameter (mm)	Limb Length (mm)	Leaf number	Diameter (mm)	Limb Length (mm)	Leaf number
1 Polyester fabric mulch	102	2648	318	204	5911	2438
2 Control	96	2571	318	149	4410	851
3 Lychee mulch	119	3219	554	229	5947	3942
4 Mechanical mowing	105	2923	414	177	4668	1168
5 Oxyfluorfen	123	3186	606	246	6614	4845
6 Hand weeding	103	2708	434	201	5679	3256
7 Eucalyptus mulch	106	2912	573	218	5829	3320
Contrasts						
2 vs. 1,3,4,5,6,7	*	NS	*	***	**	***
5 vs. 1,3,4,6,7	**	NS	*	*	*	***
5 vs. 1,3,7	*	NS	NS	*	NS	**
7 vs. 1,3	NS	NS	NS	NS	NS	NS
1 vs. 3,7	NS	NS	**	NS	NS	NS
7 vs. 3	*	NS	NS	NS	NS	NS

[z]Days after planting.
[NS], *, **, ***Nonsignificant (NS) or significant at the 5%, 1%, or 0.1% level, respectively.

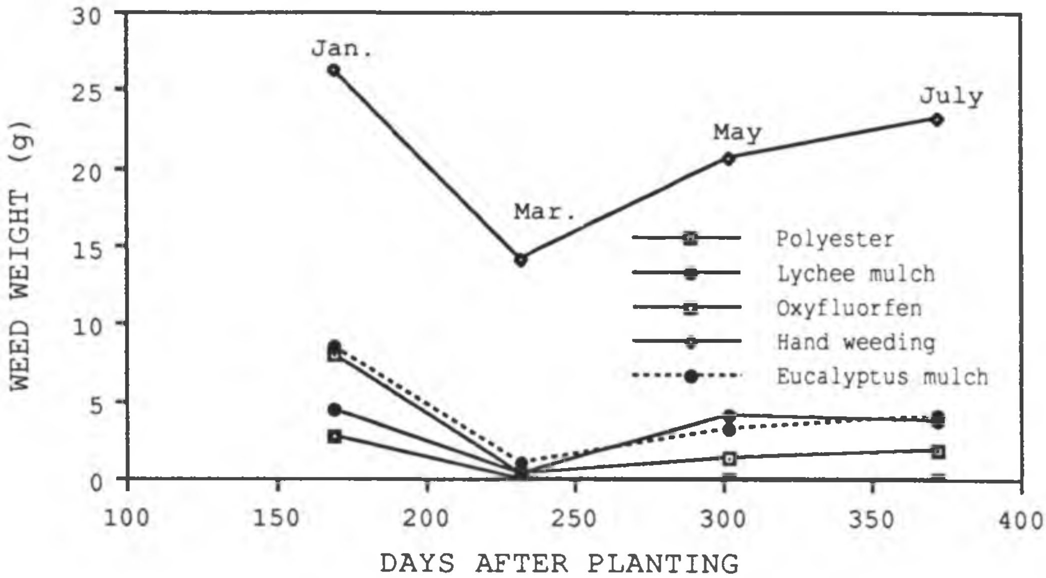

Fig. 3.1. Weed weight per plot vs. time for 5 weed control treatments.

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CHAPTER IV

EVALUATION OF 4 RATES OF EUCALYPTUS MULCH FOR WEED CONTROL IN A NEWLY PLANTED 'TAHITIAN' LIME ORCHARD

ABSTRACT

Eucalyptus (*Eucalyptus robusta* Sm) organic mulch at 4 rates was used to control weeds in a non-irrigated newly planted 'Tahitian' lime (*Citrus aurantifolia* Swingle) orchard in Mililani, Oahu. Increasing eucalyptus mulch rates resulted in a decrease in weed dry weight and an increase in tree trunk and limb diameters (combined), limb length, and total leaf count. Mulch rate of 150 tonnes/ha was determined to be optimum for satisfactory weed suppression and enhancing tree growth. After 139 days, soil samples were collected from underneath all rates of eucalyptus mulch. Ryegrass (*Lolium multiflorum*) and leaf mustard cabbage (*Brassica juncea* L.) seeds were planted in the collected soil samples. There were no significant differences in germination between the 4 rates for both species. Results of this work make it possible to examine the advantages of organic mulch material for floor management in non-irrigated, newly planted lime orchards.

INTRODUCTION

Soil water availability and adequate weed control are two important factors influencing the growth and vigor of young orchard trees (Haynes and Goh, 1980). Organic mulching conserves soil moisture by providing the soil surface with a protective cover. It has resulted in more vigorous trees by reducing weed pressure and providing a nutrient-containing material to many orchard crops such as peach (*Prunus persica* L.), avocado (*Persea americana* Mill.), and mango (*Mangifera indica* L.) (White and Holloway, 1967; Lord and Vlach, 1973; Gregoriou and Rajkumar, 1984). Although the benefits of mulching are well documented (Haynes, 1980), obtaining material and the high cost of application have limited its widespread use (Lord and Vlach, 1973).

This experiment was initiated to determine the potential of mulch from *Eucalyptus robusta* Sm to adequately suppress weed growth and enhance tree growth in a newly planted, non-irrigated 'Tahitian' lime (*Citrus aurantifolia* Swingle) orchard.

MATERIALS AND METHODS

This experiment was initiated on July 25, 1986 at Mililani, Oahu, at an elevation of 340 m with an annual precipitation of 150-200 cm. The field was subsoiled 46 cm deep, and disked prior to tree planting. Two-year-old 'Tahitian' lime (*Citrus aurantifolia* Swingle) trees grafted on *Citrus volkameriana* rootstock were planted in non-irrigated raised beds approximately 20 cm high, with treatment plots 2 m wide by 10 m long. There were 2 trees centered in each treatment plot, spaced at 5 m within rows and 5 m between rows.

The experimental design was a randomized complete block with 8 replications. Trees were planted in blocks oriented in an east to west direction. Blocks were situated in the middle of the orchard with several guard rows.

Eucalyptus limbs (maximum diameter 16 cm) and leaves were mechanically shredded into chips approximately 0.25 cm thick by 2 cm wide by 6 cm long and evenly applied to treatment plots. Eucalyptus mulch rates used were 0 (control), 100, 150, and 200 tonnes/ha.

Weeds were hand harvested with hoes and sickles from a 0.5 m^2 sample area in the middle of the treatment plot. Sampling time for weed harvests were 169, 232, 302, and 372 days after the trees were planted. All above-ground weed biomass was oven dried at 72^{O}C for 4 days and weighed.

Lime tree growth data were taken 10, 113, and 354 days after planting. All but 3 main limbs, labeled "A", "B", and "C", were removed from the trees at planting. The trunk diameter of the scion 25 mm above the graft union was measured. Two measurements were recorded at the same height, rotated 90^{O} about the trunk axis and averaged to compensate for irregularities in trunk diameter symmetry. Limb diameter of the 3 limbs, 5 mm above the trunk/limb union, was measured once. Lengths of the 3 limbs were measured (and combined) from the trunk/limb union to the terminal end of limbs. Total leaf count for the 3 limbs was recorded for each tree.

On December 2, 1986 (139 days after planting), a soil sample was randomly taken in a).25 m^2 area from each plot for each rate of eucalyptus mulch at a 1 cm depth. The 4 soil samples at each mulch rate were mixed. For each mulch rate, 40 ml of soil were placed in each of 8 petri dishes. Twenty seeds each of ryegrass (*Lolium multiflorum*) (annual), and leaf mustard cabbage (*Brassica juncea* L) were placed on the soil surface and moistened with deionized water.

The experimental design was completely randomized. The petri dishes were placed in a dark controlled environment room at 22^{O}C, and a relative humidity of 50%. Seed germination was measured every 2 days for 14 days.

Germination was counted when the radicle extended 1 mm from the seed. Germinated seeds were removed from the petri dishes. The soil was moistened every 2 days as needed.

Data was subjected to analysis of variance and trend analysis to determine weed weight and tree growth in response to increasing levels of mulch.

RESULTS

As mulch rates increased, the mean dry weight of weeds decreased (Fig.4.1). The linear equation for mulch rate on dry weed weight 169 days after application was

$$y = 50 - 0.22(x)$$

where y is mean weed dry weight (g) and x is mulch rate (tonnes/ha). The coefficient of determination (r^2) was 0.22, and the regression was significant at the 1% level. The linear equation for mulch rate on mean weed dry weight 354 days after application was

$$y = 88 - 0.38(x)$$

where y is mean weed dry weight (g) and x is mulch rate (tonnes/ha). The r^2 was 0.34, and the regression was significant at the 1% level (Fig. 4.2). The most effective mulch rate for weed control 169 and 372 days after application was 200 tonnes/ha.

There was an increase in trunk and limb (combined) mean diameter as mulch rates increased. The linear equation for mulch rate on trunk and limb diameter (combined) 133 days after application was

$$y = 93 + 0.1(x)$$

where y is mean weed dry weight (g) and x is mulch rate (tonnes/ha). The r^2 was 0.36, and the regression was significant at the 1% level. The linear equation for mulch rate on trunk and limb diameter (combined) 354 days after application was

$$y = 118 + 0.27(x)$$

where y is mean weed dry weight (g) and x is mulch rate (tonnes/ha). The r^2 was 0.37, and the regression was significant at the 1% level. The 200 tonnes/ha had the highest average growth for trunk and limb diameters (combined mean diameter).

As mulch rates increased, there was an increase in tree leaf number. The equation for mulch rate on total leaf number 133 days after application was

$$y = 246 + 1.26(x)$$

where y is mean weed dry weight (g) and x is mulch rate (tonnes/ha). The r^2 was 0.38, and the regression was significant at the 1% level. The linear equation for mulch rate on total leaf number for 354 days after application was

$$y = 1851 + 9.6(x)$$

where y is mean weed dry weight (g) and x is mulch rate (tonnes/ha). The r^2 was 0.35, and the regression was significant at the 1% level. The 150 and 200 tonnes/ha provided the highest level of total leaf number. There appeared to be no difference in total leaf number between 150 and 200 tonnes/ha.

As mulch rate increased, limb length increased. The linear equation for mulch rate on limb length for 113 days was

$$y = 2888 + 3.6(x)$$

where y is mean weed dry weight (g) and x is mulch rate (tonnes/ha). The r^2 was 0.14, and the regression was significant at the 1% level. The equation for mulch rate on limb length 354 days after application was

$$y = 5342 + 9.1(x)$$

where y is mean weed dry weight (g) and x is mulch rate (tonnes/ha). The r^2 was 0.38, and the regression was significant at the 1% level. Two hundred tonnes/ha provided the highest level of limb length increase.

DISCUSSION

This experiment showed that increasing mulch treatments decreased weed weight and increased tree growth. Tree growth responses of non-irrigated, newly planted lime trees indicated a greater response to mulch rates at the end, rather than the beginning months of the first growing season. (Fig. 4.2-4.5).

Gregoriou and Rajkumar (1984) reported that the application of weathered coffee hulls significantly increased soil moisture during dry periods. In this experiment, lime

Gregoriou and Rajkumar (1984) reported that the application of weathered coffee hulls significantly increased soil moisture during dry periods. In this experiment, lime tree roots were observed growing through the surface of the soil into the mulch at the 150 and 200 tonnes/ha rates.

Haynes (1980) observed that mulching encourages shallow rooting and increases the distribution of the root system. Earthworm populations were observed to be considerably higher in the 150 and 200 tonnes/ha rates than the 100 tonnes/ha rate and the control. This agrees with the work of Haynes (1980), indicating that the worms were feeding upon the mulch. The mulch also provided the worms with a more favorable temperature by insulating them from the desiccating effects of the sun.

The primary objective of a successful weed management program in a newly established lime orchard is to economically minimize weed competition. Although the 200 tonnes/ha rate of eucalyptus mulch gave excellent results in inhibiting weed growth, it did not dramatically increase tree growth compared to the 150 tonnes/ha rate of mulch. At the conclusion of the experiment, the trees grown with the 200 tonnes/ha rate of mulch showed a 4% increase in trunk and limb diameter, a 1% increase in leaf number, and an 8% increase limb length than the trees grown with the 150 tonnes/ha mulch rate. There was an 18% greater mean dry weight of weeds growing in plots of 150 tonnes/ha rate of mulch compared to the 200 tonnes/ha rate of mulch. This may have been due to the dampening temperature effects of the soil beneath the mulch layer.

There was no evidence of allelopathic chemicals in the soil beneath the eucalyptus mulch 139 days after application. This conclusion is based on seed germination of ryegrass and leaf mustard cabbage seeds in response to soil samples taken 139 days after application. Phytotoxic chemicals have been found in other eucalyptus species (del Moral and Muller, 1969; del Moral et al., 1978), but none have been reported for *E. robusta*.

At the beginning of this experiment, there was heavy rainfall which may have leached the toxins if any were present. Gliessman (1978) observed that there was less toxicity in oak (*Quercus* spp.) litter in the humid tropics following heavy rains. During the wet seasons, there was little build up of toxins from the leaf litter. Thus, soil analysis of samples from beneath the eucalyptus mulch treatments would have to be done before 139 days after application to detect any toxins before their possible leaching or dissipation due to microbial activity.

CONCLUSION

This study indicated that eucalyptus organic mulch could be utilized effectively to suppress weed competition and increase tree growth and vigor in a non-irrigated 'Tahitian' lime orchard. The increase in tree trunk and limb diameter (combined), limb length, and total leaf number was accomplished by reducing weed pressure The 100 tonnes/ha mulch rate did not provided adequate weed control. All other rates of mulch provided commercially acceptable weed control, while enhancing tree growth above no mulch treatment. No phytotoxic effects from soil samples beneath eucalyptus mulch were recorded from samples taken 139 days after application.

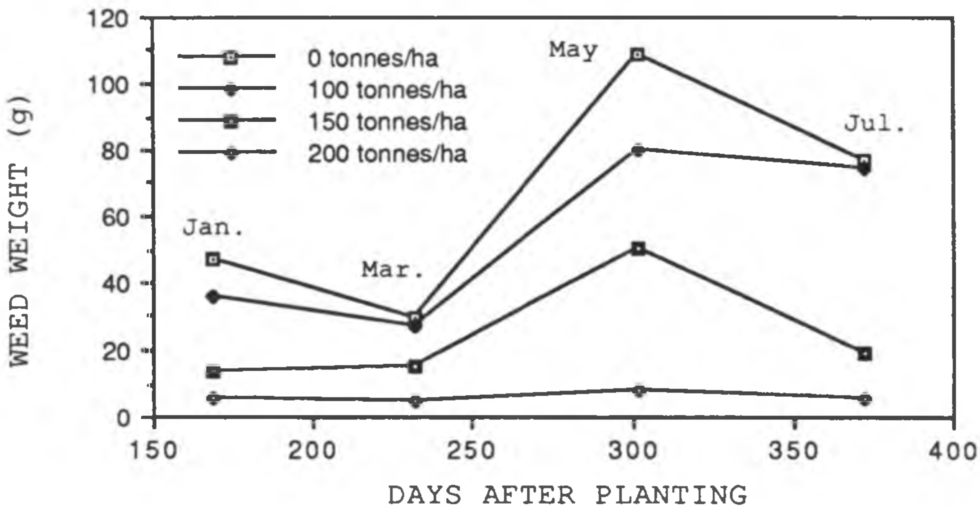

Fig. 4.1. Weed weight per plot vs. time for 3 eucalyptus mulch rates and control.

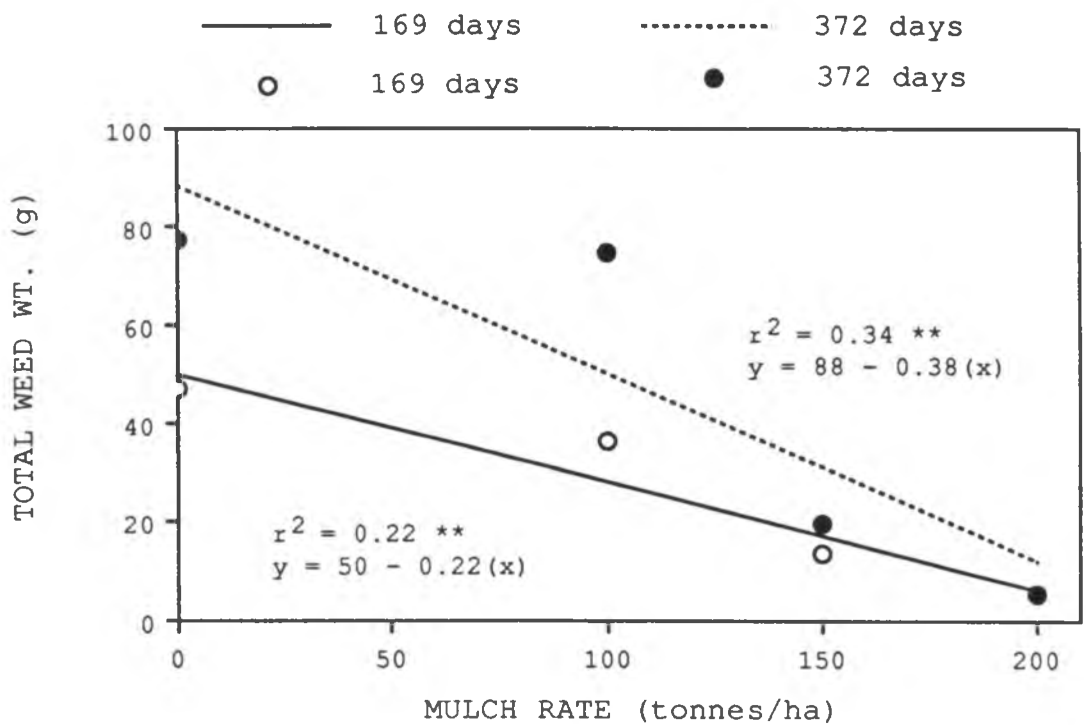

Fig. 4.2. Eucalyptus mulch rate equation effect on total weed weight per plot.

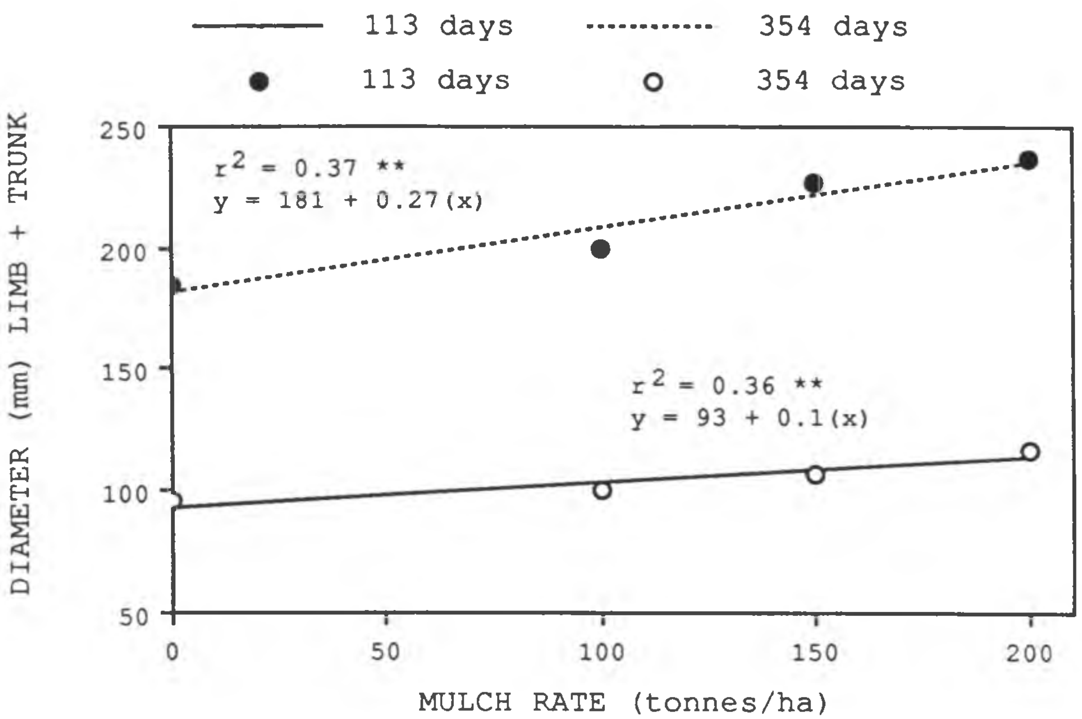

Fig. 4.3. Eucalyptus mulch rate equation effect for combined trunk and limb diameter per plot.

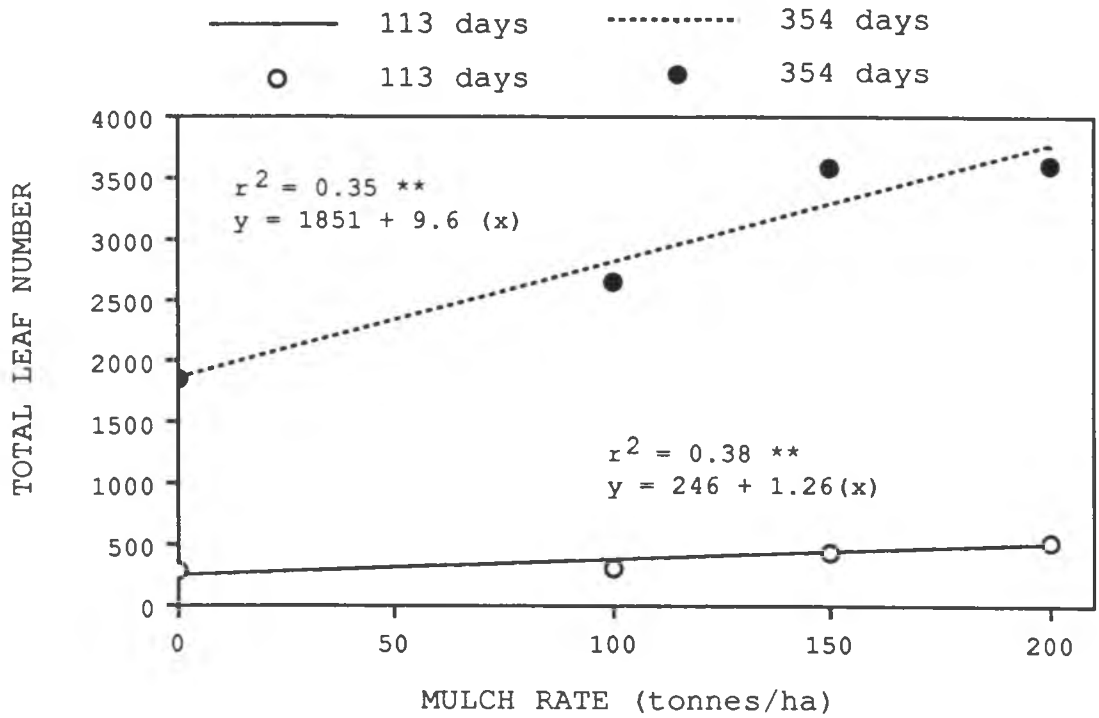

Fig. 4.4. Eucalyptus mulch rate equation effect on leaf number per plot.

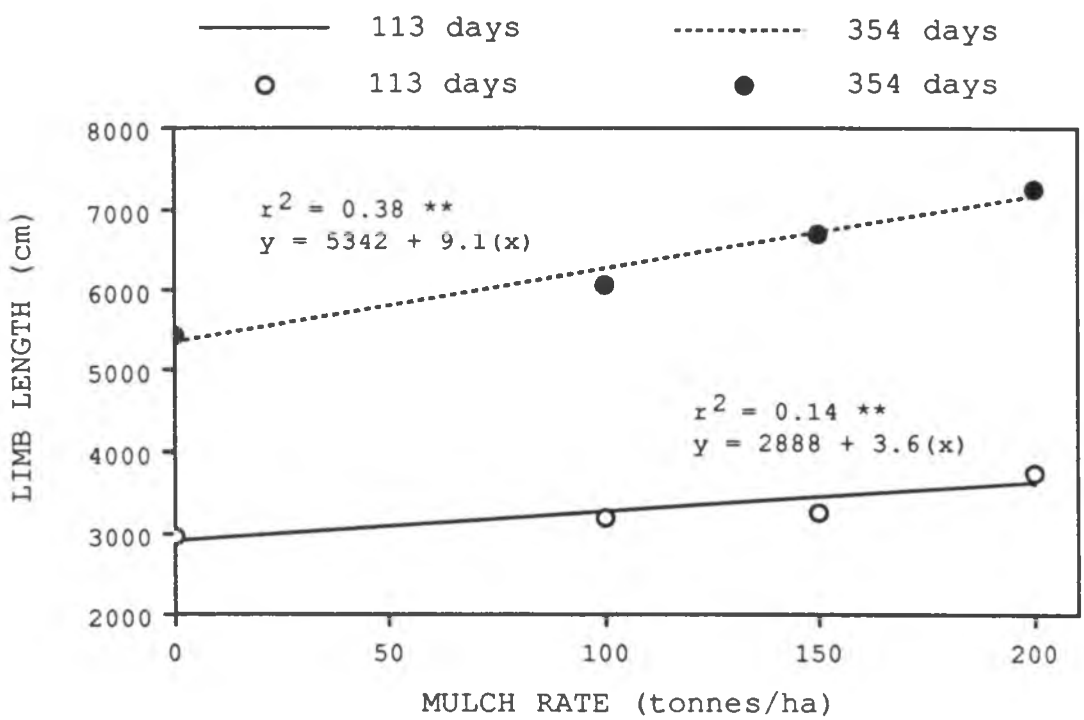

Fig. 4.5. Eucalyptus mulch rate equation effect on limb length.

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